MAINTENANCE GUIDEBOOK FOR ROAD PAVEMENT

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Chapter 1: Introduction

1-1 The significance and necessity of maintenance and repair

Roads are one of the most basic types of social infrastructure. Including the length of unpaved roads, they extend a total of approximately 1.2 million kilometers. Paving roads ensures safe, smooth, and comfortable flows of traffic while maintaining roadside environments. Pavement is affected by vehicle traffic, rainwater, ultraviolet rays, and other factors as soon as service starts; pavement suffers from rutting, cracking, and other types of degradation that gradually decrease its performance. Pavement (road surface) conditions directly affects roads' structural durability as well as safety, comfort, and other factors for road users and roadside residents. Accordingly, road performance must be recovered efficiently using appropriate methods in a timely manner.

Activities to maintain and repair pavement (road surfaces) required for road administration are broadly classified into those for "maintenance" and "repair." This guidebook adopts the following definitions.

Maintenance: Maintenance refers to mending regularly performed according to a plan or minor mending performed as needed. Maintenance recovers road performance mainly by patching or surface treatment.

Repair: Repairs restore the surface to the level of performance achieved during the construction stage in cases in which maintenance is either not economical or is not expected to lead to sufficient recovery. Repairs are performed mainly by reprocessing or mill and overlay.

This classification has been defined from a technical perspective. Note that road administrators may adopt a different classification for budgets and other aspects of their work.

Pavement must be constructed based on the premise performance will degrade. Necessary administrative actions must be performed appropriately depending on pavement conditions. According to changes in pavement stock and expenses as shown in **Figure-1.1.1**, recently there has been an increase in stock while repair costs have decreased due to financial constraints and other factors. This fact suggests that in-service pavement has been used despite the fact that performance is degrading. From a long-term perspective, however, pavement's degrading performance must be recovered. A new method must be established for more rational, efficient pavement administration even with financial constraints. In addition, against the backdrop of the shift toward adopting performance specifications (e.g., those providing functions required for pavement), taking action based on this shift is essential in maintenance and repair work.

Thus, appropriate maintenance and repair of pavement is important to ensure the safety and comfort of road users and roadside residents as well as to carry out efficient pavement administration within limited budgets.

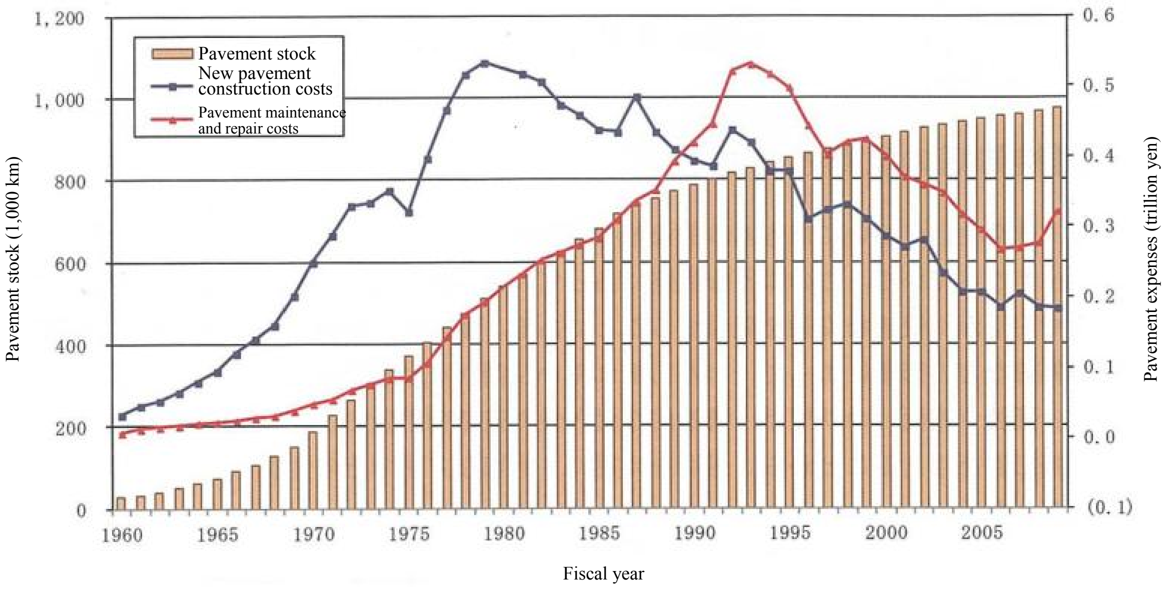


Figure-1.1.1: Changes in pavement stock and expenses[1)]

1-2 Considerations on the use of this guidebook

1-2-1 Scope and use of this guidebook

This guidebook outlines how to perform pavement administration by describing maintenance and repair concepts, selection of maintenance and repair methods based on surveys and evaluation, design and construction, performance checks and inspections, and accumulation of construction records according to the content of relevant documents published by the Japan Road Association. The guidebook contains as many examples, photographs, and other types of actual construction work data as possible so that readers can develop concrete images of pavement maintenance and repair. We hope it will serve those engaged in work on-site as a reference for developing technical understanding and judgment.

1-2-2 Content of this guidebook

Figure-1.2.1 illustrates this guidebook's content. "Chapter 2: Concepts of Maintenance and Repair" describes the new administration methods and concepts that future road administrators must know, illustrating the ideal pavement administration and the flow of pavement administration as a PDCA (Plan-Do-Check-Act) cycle. The chapter also outlines target administrative values, life cycle costs, and other issues. A method for defining target administrative values is concretely described in Appendix 1. Chapter 2 describes a method for implementing administration of trunk road pavement and daily service roads, with concrete examples shown in Appendices 2 and 3.

Chapter 3 and the following chapters introduce concrete examples of implementation maintenance and repair of sections selected in the process of pavement administration. "Chapter 3: Implementation Plans for Maintenance and Repair" describes the process from surveys for evaluating actual pavement conditions to selection of a maintenance and repair method as an "implementation plan" for a selected section. Appendices 4 and 5 concretely describe damage to asphalt and concrete pavement as well as the causes thereof, together with photographs and other information, allowing those engaged in work on-site to take appropriate action to address pavement damage based on this information. "Chapter 4: Implementing Maintenance and Repair" describes concrete maintenance and repair methods, listing application conditions, appropriate materials, construction methods, considerations, and other matters. The chapter also describes the needs of pavement as well as maintenance and repair implementation based on variable traffic flow volumes and other factors as "maintenance and repair based on the addition of functions and other factors." "Chapter 5: Performance Checks and Inspections" describes methods for checking and inspecting performance achieved by maintenance and repair. "Chapter 6: Accumulating Construction Records" describes the purpose and methods for collecting construction records as well as how to use such collected records.

Since this guidebook has been prepared as a reference for maintenance and repair of roadways, the methods and concepts described in this guidebook must be applied appropriately by referring to Chapters 2 through 4 when applying them to sidewalks, bicycle tracks, and other types of roads. The content of this guidebook must not be applied verbatim; the intention behind the text must be understood in order to implement optimal maintenance and repair based on road administrators' actual situations and site conditions.

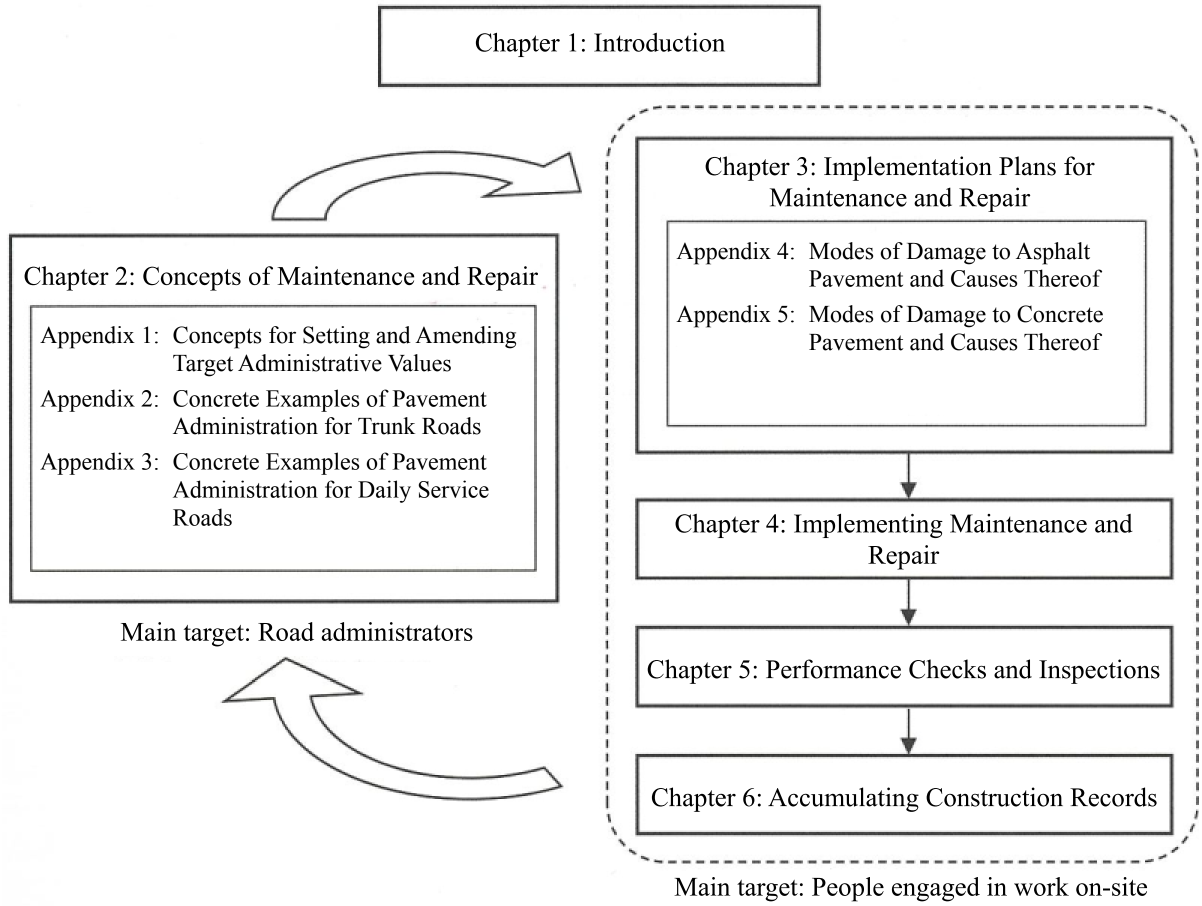


Figure-1.2.1: Content of this guidebook

1-2-3 Relevant documents

Needless to say, we must comply with related laws when selecting and handling materials and performing construction work. **Table-1.2.1** lists technical documents relevant to this guidebook. We need to refer to these documents appropriately.

The rutting level has been described as "the amount of rutting" in relevant documents. This guidebook, however, refers to the rutting level as "the rut depth." This term is used to express the rutting level more clearly. It should be noted that the rut depth, determined by the same conventional measuring method, has the same meaning.

Table-1.2.1: Relevant documents

Category	Document name	Date published
Road structure	Explanation and Applications of the Government Order on Road Design Standards	Feb. 2004
Pavement	Technical Standards for Pavement Structures and Their Descriptions	Sep. 2001
	Guidelines for Pavement Design and Construction (2006 edition)	Feb. 2006
	Pavement Design Handbook	Feb. 2006
	Pavement Construction Handbook (2006 edition)	Feb. 2006
	Pavement Recycling Handbook (2010 edition)	Nov. 2010
	Asphalt Mixing Installation Handbook (1996 edition)	Oct. 1996
	Guidelines for Road Maintenance and Repair	Jul. 1978
	Explanations of Common Specifications for Asphalt Pavement Construction	Dec. 1992
	Pavement Performance Evaluation Methods —Methods for Evaluating Essential and Principal Performance Indices— (2013 edition)	Apr. 2013
	Pavement Performance Evaluation Methods: Separate Volume —Methods for Evaluating Performance Indices Defined as Needed—	Mar. 2008
	Handbook of Pavement Survey and Test Methods (four volumes)	Jun. 2007
Earthworks	Road Earthwork Guidelines	Jun. 2009
Bridges	Specifications and Explanations of Highway Bridges	Mar. 2012
	Painting and Corrosion Prevention Handbook for Steel Highway Bridges	Dec. 2005
	Waterproof Handbook for Highway Bridge Decks	Mar. 2007

[Reference]

1) Road Bureau; Ministry of Land, Infrastructure, Transport and Tourism: 2011 Annual Report on Highway Statistics

Chapter 2: Concepts of Maintenance and Repair
—Approach to Administration—

2-1 The ideal form of administration

Full-scale construction of most road facilities in Japan began after World War II, with a large number of bridges and tunnels constructed during the period of high economic growth. Consequently, a considerable amount of stocks were accumulated as property. Pavement differs from other types of road facilities in that damage and degradation is caused by cumulative fatigue from direct and repeated traveling traffic loads during service use, ultraviolet rays, and other factors. Repair and maintenance, including reconstruction, are thus required administrative actions to ensure performance and to achieve target administrative values. In other words, pavement must be constructed based on the premise of performance degradation, and necessary administrative actions must be appropriately implemented on constructed pavement to ensure pavement conditions are checked properly. Various methods are available to determine target administrative values. Such values must be determined appropriately in consideration of road characteristics, traffic conditions (e.g., volume and speed), the state of local roads, and other factors so that each road administrator can properly implement pavement administration. **Figure-2.2.1** illustrates the concept of setting target administrative values described in the *Guidelines for Pavement Design and Construction* (2006 edition).

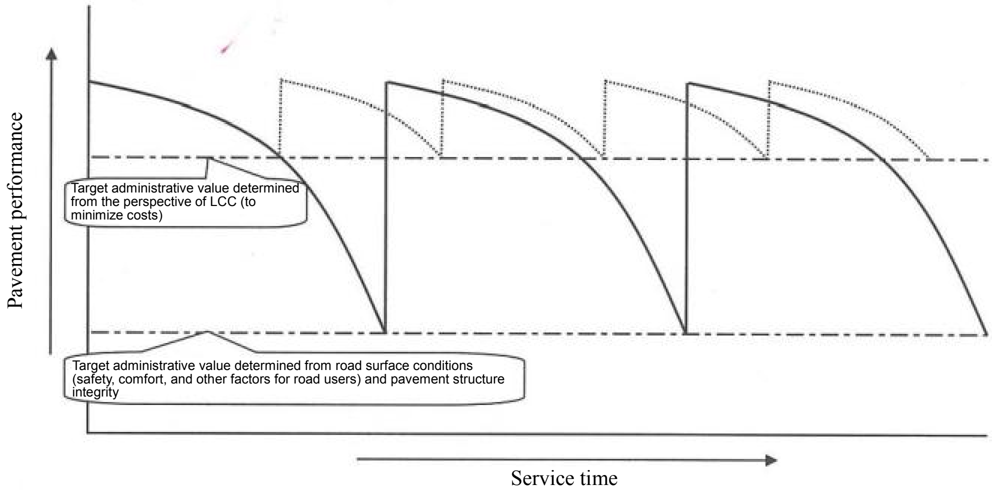


Figure-2.1.1: Concept of setting target administrative values[1)]

Against the backdrop of a society with an aging population due to a low birth rate, local economic strength decreases in accordance with the total and working populations, while costs in the areas of social security expenses (e.g., pensions, medical expenses, and welfare costs) increase. These factors act as financial constraints, placing a more severe strain on road facility administration finances.

Pavement administration must be implemented over the long term, and effectiveness of pavement administration projects must be verified by evaluating performance and effects. Accountability for projects' adequacy and property value must be ensured through appropriate communications with road users (including actual road users and area residents) as well as taxpayers. Pavement management therefore cannot be completed by simply streamlining and reducing the costs of pavement administration projects. Strategic pavement administration refers to implementing projects from the perspective of improvement and reconstruction of pavement administration work processes to maintain long-term, sustainable service standards while acquiring credibility with road users and taxpayers under various constraints.

The ideal form of pavement administration is intended "to achieve administration that is easy-to-understand and transparent to road users and taxpayers" and "to achieve efficient administration that yields optimal effects at minimal costs."[2)] Such administration regards pavement to be an important property of citizens, aiming to increase satisfaction in a customer-, achievement-oriented manner. It is carried out efficiently within a limited budget according to plans and serves to maintain and enhance functions while iterating through a cycle of extracting and solving issues that occur during administration in order to realize improvements. Thus, the ideal form of administration is necessary to provide citizens with optimal effects. To fulfill this requirement, pavement management must be established by adopting management approaches for pavement administrative activities. The goal of pavement management is to establish a management system for rational decision-making for administrative actions on pavement property as well as to acquire credibility with society regarding administrative actions in order to contribute to safe, smooth flows of traffic through long-term, sustainable operation and improvement of the system.

Specifically, the ideal form of pavement administration is as follows.

(1) To achieve administration that is easy-to-understand and transparent to road users and taxpayers

The ideal form of pavement administration expresses the outcomes of pavement administration in terms of easy-to-understand indices and makes efforts to build consensus regarding such indices (i.e., target administrative values) with road users and taxpayers by analyzing needs through communication with these parties. Information about various actions implemented by road administrators to achieve the target administrative values is voluntarily disclosed, thereby increasing the interest of road users and taxpayers in order to have them understand pavement administration. In the ideal form of pavement administration, communication with road users and taxpayers is enhanced through such activities and a PDCA cycle is established, including appropriate adjustment of target administrative values according to actual pavement administration and other factors, thus realizing transparent pavement administration.

Roads and pavement are essential social infrastructures for people’s lives. Maintaining pavement conditions not only straightforwardly contributes to comfortable traffic flows for roads users but also plays important roles in physical distribution, emergency medical services, and other activities supporting citizens’ lives, and so pavement administration must be implemented from these perspectives as well.

(2) To achieve efficient administration that yields optimal effects at minimal costs

Various choices can be made regarding combinations of costs and effects depending on the service level to be provided and the mode of pavement administration. An appropriate combination is selected according to road users’ requirements, road administrators’ policies, financial constraints, site conditions, and other factors. It is essential to provide the service with the best cost-performance by selecting an appropriate maintenance and repair method having appropriate timing in consideration of lifecycle costs (LCC; see 3-4-2 (1) 5)). Once the short-term and long-term budget scales have been estimated with respect to LCC, a consensus as described in (1) can be achieved regarding the relationship between the estimated budget scales and service levels. To estimate such budget scales, we must forecast pavement performance and carry out activities[3)] to examine maintenance and repair methods through follow-up surveys and other types of inspections.

Some road administrators have already implemented pavement management activities. However, “to achieve administration that is easy-to-understand and transparent to road users and taxpayers” as well as “to achieve efficient administration that yields optimal effects at minimal costs,” more sophisticated activities are necessary. In addition, technical knowledge (e.g., how to forecast pavement performance and the relationship between surface characteristics and road user satisfaction[4)]) must be accumulated. Since individual road administrators find themselves in different situations depending on the needs of road users, finances, site conditions, available materials and human resources, and other factors, they are required to address possibilities in pavement management by giving consideration to such factors. Such road administrators must share information[5)] about how they carry out pavement management in order to contribute to the synergistic evolution of pavement management, which will allow the ideal form of pavement management to gradually be established.

The following is an example from overseas. In the United Kingdom, after the privatization program introduced in the 1980s, the need for asset management standardization increased as private companies were required to implement appropriate maintenance and administration of social infrastructures. In 2004, the British Standards Institution formulated process standards for asset management in PAS 55 (PAS: Publicly Available Specification). In 2009, the ISO (International Organization for Standardization) started to take actions for international standardization of asset management (e.g., formulation of the ISO 55000 series) based on PAS 55. The ISO has defined management as "controlled activities for leading and managing an organization" and management systems as "systems that determine policies and goals as well as achieving such goals." Management systems must have a mechanism for continuously improving management integrated into the organization that is functioning appropriately.[6)] The ISO requires organizations to implement such continuous improvement, and so this concept must be adapted to pavement administration.

2-2 Management

2-2-1 Overview

Pavement management refers to activities to implement the PDCA cycle as illustrated in the diagram in **Figure-2.2.1**. A pavement management system is a system for implementing this PDCA cycle. Through the system, pavement management is generally carried out in accordance with the following procedure: 1) determine target administrative values; 2) perform a present condition of pavement; 3) evaluate integrity and forecast changes in integrity; 4) accumulate and update data; 5) formulate a maintenance and repair plan and adjust the target administrative values; 6) carry out maintenance and repair; and 7) feedback evaluation and results. This procedure forms a PDCA cycle that can be simultaneously characterized as a policy-making cycle (e.g., analysis of needs through communication with road users and taxpayers as well as adjustment of target administrative values based on the actual conditions of pavement administration, including implementation of maintenance and repair) as well as characterized as an engineering cycle for improving work processes at a level close to that of on-site work practices (e.g., validation of selected construction methods through analysis of accumulated data on serviceability realized through maintenance and repair as well as implementation of cause investigations and improvement measures for routes and sections that degrade quickly).

Pavement management systems are classified into two categories: network-level systems and project-level systems.[7)] Network-level pavement management systems treat roads as networks. In these systems, all sections of the network are analyzed to determine when each section satisfies its target administrative values, and the minimum cost is estimated for the entire network based on the setting level of target administrative values in consideration of LCC. In project-level pavement management systems, each section requiring network-level maintenance and repair is separately analyzed[8)] in order to determine target sections, evaluate existing pavement, and perform technical evaluations on design, methods to adopt, and other matters. Thus, an implementation plan for maintenance and repair is formulated and implemented so as to minimize LCC of the sections concerned. Needless to say, the results of maintenance and repair are stored in a database and reflected in the network-level pavement management system.

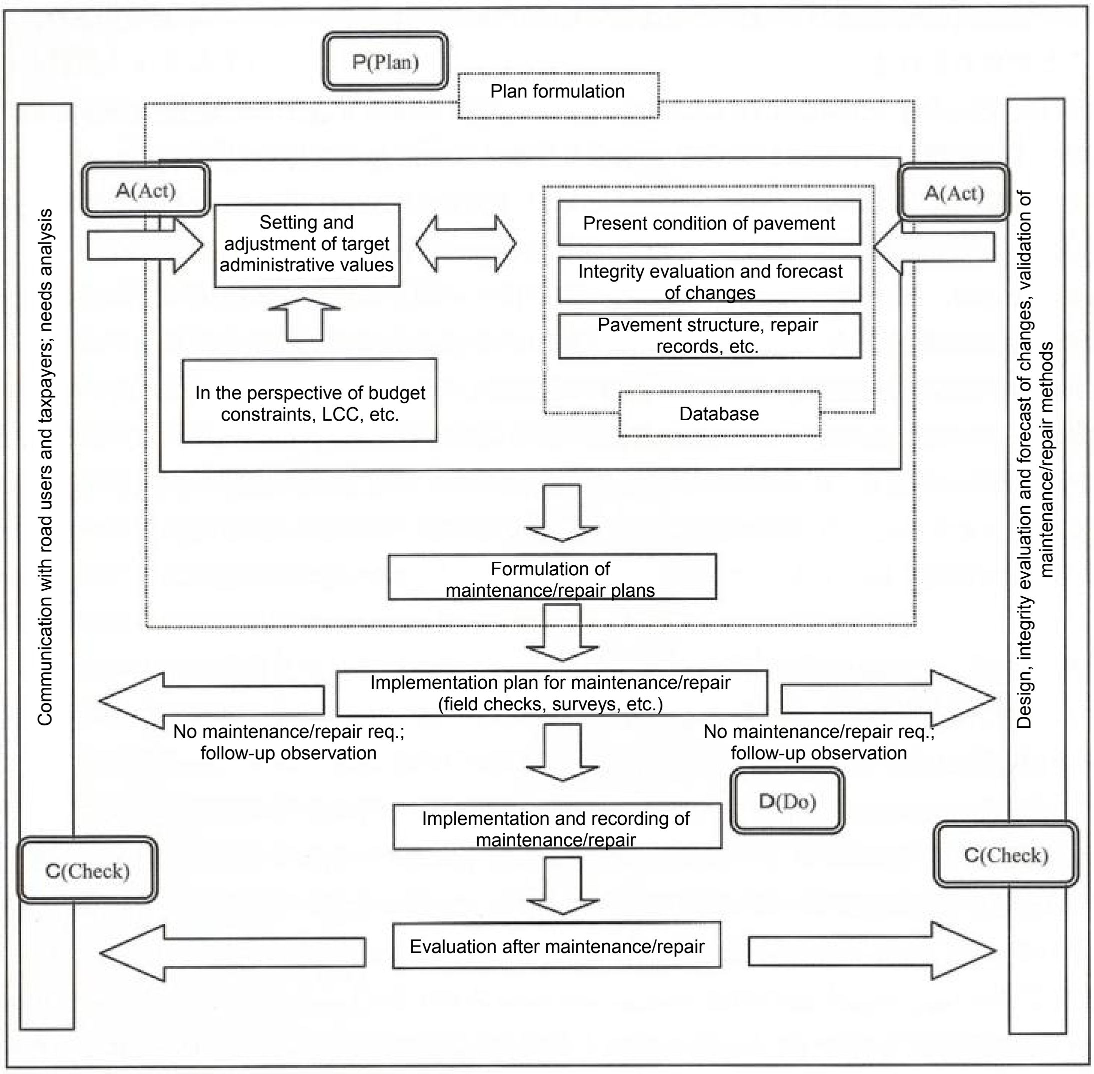


Figure-2.2.1: Pavement management system workflow

2-2-2 Procedures

Pavement management is implemented in accordance with the following procedures.

(1) Setting target administrative values

Target administrative values express or rank the significance of pavement functions. Indices used for target administrative values are classified into two categories: service indices, which reflect the needs of road users and taxpayers and describe pavement conditions in an easy-to-understand manner, and administrative indices, which are used to allow road administrators to comprehend and evaluate road conditions in a technical manner.

The most significant service index is satisfaction with ride quality. Satisfaction is affected by pavement functions (e.g., safety, roughness, comfort, and the environment). Since service indices that require no expertise such as satisfaction in ride quality and a sense of security are also easy for the general public to understand, they are used[2] to communicate with road users in order to explain the effectiveness of maintenance and repair of pavement to the general public as well as on other occasions.

Typical administrative indices include the pavement crack ratio and deflection[9] measured with FWD (falling weight deflectometer). These indices do not often draw the attention of road users but are essential for road administrators in implementing appropriate pavement administration (e.g., grasping the structural integrity of pavement). In other words, they are indices to meet the needs of road administrators.[10)]

In pavement administration, target administrative values are determined by giving balanced consideration to both types of indices (refer to **Figure-2.2.2**). In some cases, a single index formulated by combining service and administrative indices in a well-balanced manner is used to determine target administrative values, but in other cases multiple indices may be used. Since present condition (monitoring) of pavement is performed using the index employed to determine the target administrative value, that value must be determined with reference to historical administration records, future administrative systems, and other factors.

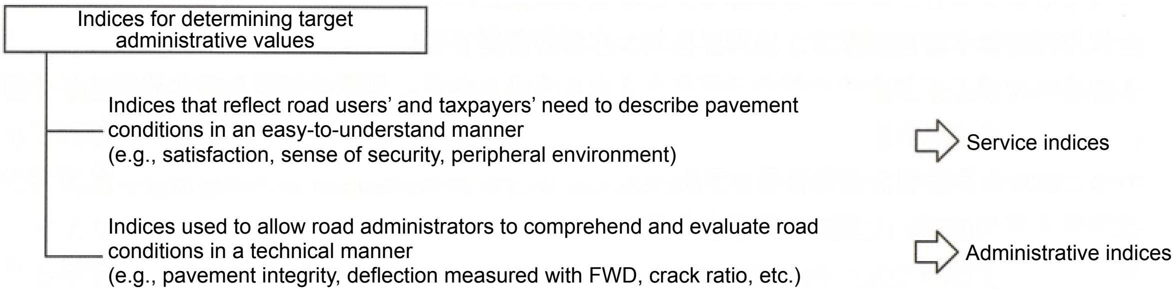


Figure-2.2.2: Service and administrative indices[formulated with reference to 2)]

Based on management levels, target administrative values exert a different influence on the level of services for road users and budgets required for pavement administration. Thus, it is necessary to obtain road users' and taxpayers' understanding of prescribed target administrative values, which requires us to provide easy-to-understand explanations from the perspectives of services provided for road users, burdens on taxpayers in exchange for services (or budgets required), and other matters.

Target administrative values are determined in consideration of matters such as "the relationship between surface conditions and service levels," "classifications by road, local, and other conditions," and "budgets for maintaining the target values." These may be determined separately depending on road characteristics. It is also essential to consider the values from the perspective of medium- to long-term use as well as short-term use and to examine pavement administration costs so as to minimize LCC.

For the concepts behind setting and adjusting target administrative values, refer to the examples in Appendix 1 as necessary.

(2) Performing present conditions of pavement

To objectively evaluate the conditions of all roads under administration, pavement conditions must be grasped across all roads so as to obtain information on the indices corresponding to the prescribed target administrative values. Present condition should be performed in a quantitative manner. However, different assessment levels are selected separately for each case depending on the characteristics of each road, local circumstances, and the details of previously carried out pavement administration. Once road conditions have been grasped, actions to satisfy the individual needs of road users can be implemented appropriately, improving the transparency of pavement administration.

(3) Evaluating integrity and forecasting changes in integrity

Integrity is determined through quantitative and qualitative evaluations of the pavement conditions of each section by checking those conditions against their target administrative values. Road administrators use the integrity obtained from such evaluations as a fundamental piece of data for forecasting changes to determine the timing of road maintenance and repair as well as to estimate costs appropriately.

Forecasting changes in integrity plays an essential role in LCC estimation, formulation of maintenance and repair plans, and other activities. However, pavement degrades at different rates depending on various factors (e.g., pavement structures and materials, maintenance and repair history, traffic characteristics, and climate). These factors affect pavement degradation to various extents. To forecast changes in integrity, such uncertainties in the degradation process must be considered.

In addition, various levels of accuracy are required to forecast changes in integrity from the perspective of pavement management. Take the example[1] of a section that degrades slowly due to low traffic volume, for which a model that determines only the interval of the maintenance and repair cycle was created, and road administrates thus estimated LCC from cost alone. In such cases, the maintenance and repair cycle interval and details of maintenance and repair may be determined exclusively from historical records and the situations of nearby sections. For roads having fast-degrading pavement due to high traffic volumes, changes in integrity may be forecast using a solid volume regression equation; historical data on surface characteristics and other physical properties are statistically processed per index (e.g., crack ratio and rut depth), and the solid volume regression equation is formulated depending on the classification of traffic volume (e.g., large vehicles), the classification of regions (e.g., snowy and cold-prone areas versus general areas), the classification of maintenance and repair methods used in previous work, and other classifications. The pavement condition degradation process is always subject to uncertainties. To reduce the effects of such uncertainties, some new activities have adopted the concept of risk management. In these activities, patterns in the degradation process of pavement in each section are detected on the basis of accumulated data on surface characteristics and other physical properties; a probabilistic degradation forecasting model[11] is then used to estimate the required amount of investment for the future.

Regardless of approach, a degradation forecasting model created from information available at one point in time may be optimal at that point but is not always optimal in the future. The degree of serviceability varies based on technical progress in administrative actions for pavement. It is thus necessary to examine the effectiveness of degradation forecasting models at appropriate intervals.

When a degradation forecasting model updated using newly-obtained inspection data estimates the service life of pavement to be longer than that estimated by the prior version of the model, the administrative actions carried out up until that point can be considered to be effective in decelerating the average degradation speed. If some measures have been taken during this period to extend the pavement's service life, the shift appearing in the degradation forecasting model can be used to evaluate the effectiveness of such measures. Pavement degradation forecasting models not only play essential roles in planning (Plan) but also more significant roles in after-the-fact assessment (Check and Act).

(4) Accumulating and updating data

Databases are a key element in pavement management.[8] Databases must be designed not only to store data on road conditions (e.g., surface characteristics) but also to serve as pavement databanks to store information on road types, pavement structures, pavement materials, maintenance and repair records, and other basic types of data. Such data provides valuable information[12] that will be used in various stages (e.g., everyday maintenance and administration, examination of maintenance and repair methods for actual work, and implementation of actions to satisfy the needs of road users). Thus, a centralized database should be constructed to prevent obtained data from being lost. In addition, information on road administration (e.g., maintenance and repair records) must be accumulated appropriately in the created database to ensure effective use by road administration in actual work. Establishing a management sytem[2] that allows road administrators to search for necessary information and to modify, update, and accumulate data precisely and promptly is essential.

(5) Formulating maintenance and repair plans as well as adjusting target administrative values

The most efficient maintenance and repair plan for all roads under administration is formulated giving consideration to LCC by treating the roads as a network and extracting those routes and sections that do not satisfy the target administrative values (which have been determined in terms of pavement performance and service levels depending on road characteristics on the basis of the results of the present condition of pavement and change forecasts). Subsequently, a long-term plan for the network is formulated, demand for maintenance and repair investment is forecast, and the effects of investment are evaluated.[13] In the process of calculating LCC, a maintenance and repair pattern is selected[14] from among the various patterns available (combinations of pavement replacement, mill and overlay, surface treatment operations, and other operations—note that it is necessary to set a pavement degradation forecasting model and unit prices for each pattern) so as to minimize LCC while satisfying the prescribed target administrative values.

Specifically, planning is implemented in accordance with the following procedure: forecast changes in pavement performance; detect the timing of when sections will not satisfy the prescribed target administrative values and estimate the number of such sections; determine a maintenance and repair pattern to minimize each section's LCC; and estimate the amount and expenses of future maintenance and repair projects based on LCC. This is how pavement maintenance and repair plans are formulated. Such plans are the optimal output expected from pavement management and can be regarded to be a "long-term investment plan for pavement."

Thus, long-term overall investment plans can be formulated at the network level. Such plans may be modified by reexamining target administrative values whenever necessary in consideration of budget constraints and based on the plans' details and feasibility. Since revisions of target administrative values affect the required budget, it is necessary to estimate the required budget scale corresponding to the prescribed target administrative values from historical records and current knowledge to examine whether the estimated budget scale is realistic. It is also necessary to examine the estimated budget scale in consideration of the needs grasped through communication with road users and taxpayers (refer to Appendix 1).

In Japan, there is no standard method for calculating LCC. However, LCC is generally estimated by roughly classifying expense types into the following three categories: expenses for road administrators, expenses for road users, and expenses for local communities in areas along the roads. **Table-2.2.1** lists typical expense types for each category.

Table-2.2.1: Examples of LCC expense types[from 2)]

Classification	Expense type	Detailed expense type examples
Expenses for road administrators	Surveys and planning	Survey and design costs
	Construction	Construction costs and field expenses
	Maintenance for administration	Maintenance, snow removal, inspection, and repair costs
	Reconstruction	Reconstruction and disposal costs, field expenses
	Personnel expenses for administrators	Personnel and overhead expenses, etc.
	Related public administration	Public relations costs
Expenses for road users	Vehicle traveling	Fuel and increased wear on vehicle costs
	Time loss	Expenses due to time lost due to lane restrictions for construction and detours
	Other	Costs of accidents and psychological burdens (e.g., ride discomfort and discomfort due to traffic congestion)
	Safety recovery	Costs to recover safety through maintenance and repair work
	Ensuring punctuality	Cost of ensuring punctual travel by relieving traffic congestion due to construction work
	Availability during abnormal events	Costs of benefits produced by reinforcement construction to alleviate disaster-related traffic restrictions and closed roads
Expenses for local communities in areas along roads	Environment-related	Effects of noise, vibrations, etc. on areas along roads
	Other	Psychological burdens on residents and economic losses of business owners in areas along roads due to construction

It is not always necessary to consider all of these expense types when estimating LCC. LCC should be estimated for appropriately selected expense types based on the purpose, required accuracy, construction conditions, traffic conditions, the conditions of areas along roads as well as local conditions, and other factors. For example, in LCC estimation for a local area with low traffic volume and that is affected only slightly by traffic congestion and other traffic regulation-related phenomena, expenses for road administrators accounted for an overwhelmingly large proportion of LCC.[15)] In such cases, LCC can be estimated using only the expenses for administrators. In another example, LCC was estimated for an urban area using expenses for road users (e.g., for vehicle traveling, for time lost due to traffic congestion, and other costs) and the psychological burdens on residents in the areas along the roads due to repair work.[16)] In some cases, expenses for road users are difficult to estimate. However, a study was conducted on integrating the benefits of pavement providing various functions (e.g., porous asphalt) into expenses for road users,[17)] and a model has been developed to estimate pavement degradation, the effects of improvement brought about by investment in road administration (e.g., maintenance and repair), road users' traveling expenses, and expenses for losses due to traffic congestion.[18)]

(6) Implementing maintenance and repair

When implementing field maintenance and repair work at the project level on portions that have been extracted as candidates for maintenance and repair at the network level, target sections must be determined, existing pavement evaluated, and technical evaluation carried out on the design, methods to adopt, and other matters separately for each portion.[8)] Further, an implementation plan for maintenance and repair must be formulated. These matters are described in Chapter 3 and the following chapters. For example, when a section has been extracted as a target for maintenance and repair, it is necessary to determine the ranges that can be addressed by individual maintenance and repair operations as well as other factors by considering whether the section has suffered overall or localized damage, the level of damage to adjacent sections and the records of maintenance and repair thereof, the roadside usage situation, and the impacts of construction restrictions on traffic. In addition, an appropriate maintenance and repair method must be selected in consideration of pavement structure, damage causes, maintenance and repair records, and other on-site conditions.

Whenever damage, degradation, or other problems that may adversely affect safety are found, implementation of emergency measures to ensure safety must be given the highest priority regardless of budget constraints.

(7) After-the-fact assessment and feeding back of results

After completing maintenance and repair, work data must be stored in a database. It is also necessary to perform after-the-fact assessment of maintenance and repair work as well as to feed back results into the pavement management system's maintenance and repair plan.

Specifically, it is essential to adopt a cycle of action (e.g., adjustment of target administrative values in consideration of needs grasped through communication with road users and taxpayers). Pavement administration transparency is improved through such activities.

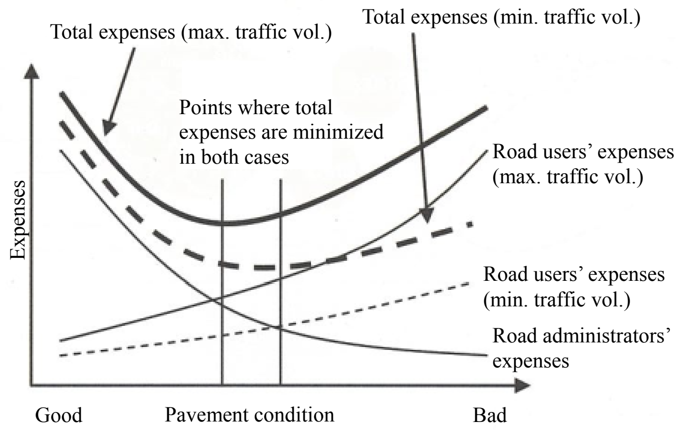
In addition to management feedback for policy-making, engineering feedback is also required to improve the accuracy of the degradation forecasting model as well as to validate that model based on the present condition of pavement, integrity evaluation and forecast of changes in integrity, and analysis of accumulated data on maintenance and repair, new construction methods, and other matters. In recent years, "preventive maintenance" has been attracting increased attention. This type of maintenance is repeatedly implemented before pavement develops significant structural performance abnormalities. Once the effectiveness of a preventive maintenance method has been verified by after-the-fact assessment of the relationship between expenses and durability, the method will be adopted in more administration work. If its effectiveness is unable to be verified, adoption of an alternative preventive maintenance method will be considered. Such actions fall under the category of engineering feedback.

The PDCA cycle thus functions appropriately through feeding back of after-the-fact assessment into work for setting and adjustment of target administrative values, selection of maintenance and repair methods, and other factors.

Above, we examined the workflow for pavement management. However, different road administrators must handle different sections and lengths of roads, different traffic volumes, and other different road characteristics in different road administration systems. They also may have different situations in terms of grasping surface characteristics and other factors. At this point in time, administrative activities may be performed at various pavement management levels. Still, it is essential to implement the applicable activities based on the actual administrative situation in order to establish the aforementioned workflow.

Column: The relationship between pavement target administrative values and everyday life and socioeconomic activities

Degradation of pavement conditions due to rutting and decreased surface evenness causes “slow traveling,” “adverse impacts on freight,” “fast progression of damage to vehicles,” “increased noise and vibration,” and other problems, leading to increased expenses for road users. For example, some pavement conditions may affect the supply of fresh garden produce to urban areas and thereby increase expenses, while function addition (e.g., replacing dense-graded asphalt pavement with porous asphalt pavement as well as replacing existing pavement with that for maintaining good landscapes) may increase benefits for road users. The target administrative values for pavement, which are related to service indices, are thus closely associated with everyday life and socioeconomic activities, and giving consideration to expenses for road users is fundamental when estimating LCC. However, only a small amount of knowledge has been accumulated thus far regarding the rationality of pavement maintenance and repair and the economic benefits brought about by function addition. In particular, there is significant room for discussion on matters such as to what extent benefits should be considered, and further research is still required. Since as we have seen, the total of expenses for road administrators and expenses for road users must be considered in LCC estimation, it is necessary to determine the target administrative values for pavement in consideration of the characteristics and roles of roads, modes of road use, and other factors (refer to the figure on the right).



Example: Comparison of total expenses from the perspective of traffic volume

2-2-3 Hierarchical structure

Pavement management systems require those who engage in road administration to consider their own roles and to take action to fulfill their roles in the management workflow. Final decisions regarding work improvements and other matters are made by those with authority over budget allocations, and each person in charge of road administration must follow those decisions to cooperatively achieve improvement targets. In other words, pavement management systems are structured so as to consist of multiple levels with different time perspectives and different organizational hierarchies for decision making.

The PDCA cycle closest to fieldwork is the cycle for everyday administration work. In this cycle, a maintenance and repair plan (P) is formulated for the fiscal year under the annual budget, maintenance and repair projects are done (D), and their achievements are checked (C & A). In intermediate cycles, a medium-term maintenance and repair plan (P) is formulated on the basis of the results of present condition of pavement, the priorities of pavement maintenance and repair as well as the annual budget are determined (D), and progress toward achieving the medium-term plan is checked (C & A). In the cycle closest to the policy-making side, the target administrative values to be achieved using limited resources and the long-term budget necessary for satisfying the values are determined from long-term perspectives, and issues to be considered going forward as well as policies on measures to address such issues are determined[19] as essential matters. It is important to consciously perform pavement management at each decision-making level as well as the everyday administration work level.

There is a pavement management system model for realizing such hierarchical activities and continuous work improvement using a logic model, which is a tool for modeling all maintenance and administration work as well as improving work performance by monitoring (**Figure-2.2.3**).

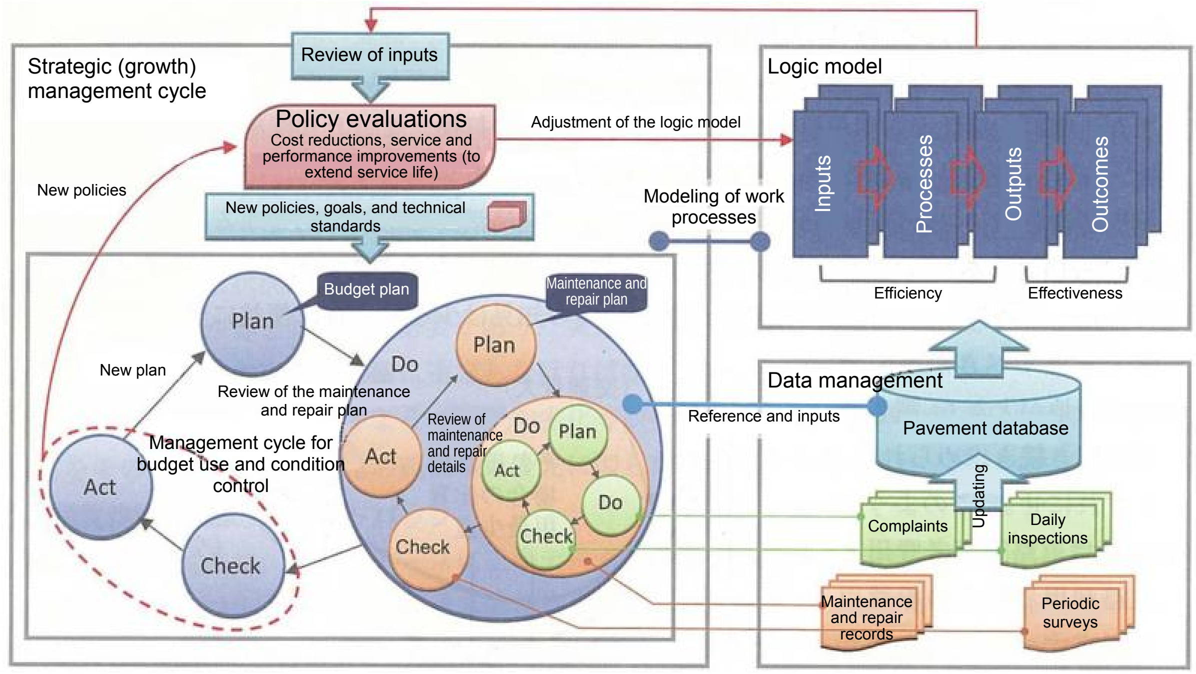
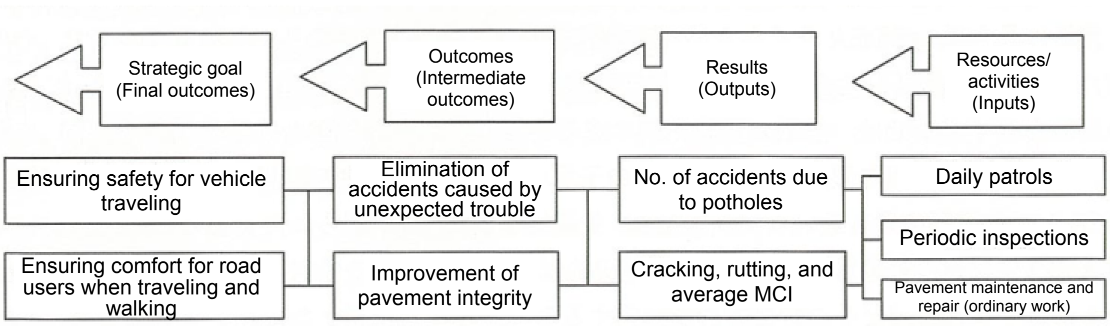


Figure-2.2.3: Example of a pavement management system model [created based on 20)]

Column: Logic models

Logic models express the goals of maintenance and repair work as outcomes from the perspective of services, logically link work performed to achieve goals through outcomes, and thereby express all work systematically. Work implemented in accordance with logic models is quantitatively evaluated with the output and outcome indices. The contribution of daily work and individual projects to the overall project is analyzed based on this evaluation. Targets for input improvement are selected by extracting work (activities) producing only small contributions. If a goal is not achieved according to the plan, its cause is analyzed using a logic model. Then, in a subsequent review of the plan, the combination of means (inputs) for achieving the goal will be reexamined.



(Example of a logic model)

2-3 Methods for implementing management

This section describes examples of concrete methods for implementing pavement management separately on trunk roads and daily service roads. For descriptions of actual pavement management cases, refer to Appendices 2 and 3 as necessary.

"Trunk roads" and "daily service roads" as mentioned above cannot be unambiguously defined only according to road classification. Rather, they are classified according to their activity level regarded as rational from the perspective of pavement management. "Trunk roads" are relatively heavily traveled roads, and their pavement degrades quickly. As a result, maintenance and repair expenses increase relative to their length. They require pavement management based on the quantitative present condition of pavement through periodic surveys of the surface characteristics. A PDCA cycle performed through such data accumulation leads to timely maintenance and repair by a comparatively appropriate method to minimize LCC, contributing to effective pavement administration. In contrast, "daily service roads" are relatively lightly traveled roads, and their pavement degrades slowly. Their long length makes full-scale surveys of surface characteristics very expensive, and may not reduce maintenance and repair expenses. Therefore, they require simplified methods for present condition of pavement and other pavement management measures. "Trunk roads" and "daily service roads" are roughly characterized as follows.

Trunk roads: These roads have relatively high traffic volume (particularly in terms of large vehicle traffic), their pavement degrades quickly, and high-speed and efficient periodic present condition using a surface characteristics survey vehicle is effective for their administration.

Daily service roads: These roads have a relatively long length and have relatively low traffic volumes; present condition by visual inspection, notification, and other approaches as well as data management are important for their administration.

2-3-1 Methods of trunk road management

(1) Setting target administrative values

Appropriate indices for target administrative values must be selected in consideration of the results of previous surface characteristics surveys and future surveying plans, administrative records of principal damage modes, and maintenance and repair methods as well as other information.

As described in 2-2-2 (1), indices for target administrative values are classified into service and administrative indices. Since not only pavement conditions but also various other factors (road standards, linearity, traffic volume, and weather), affect road user satisfaction, the relationship between satisfaction and pavement conditions is difficult to understand quantitatively when determining service indices. This relationship may be estimated from the results of monitor evaluation test[4] hearing surveys as well as other research performed on vehicular behavior and other objects dependent on surface conditions. Indices can be modified based on such estimates. For the time being, indices for surface characteristics can also be used for target administrative values indices without any adjustment.

When indices for surface characteristics have been selected for target administrative values, a single index (such as the international roughness index (IRI), surface roughness, crack ratio, or rut depth) may be used independently, or a composite index formulated by combining multiple types of surface characteristics data may be used (as with the pavement maintenance control index (MCI) or other indices). Single indices cannot be used to make direct comparisons between the pavement conditions of multiple degraded locations for each damage mode (e.g., crack-dominant and rut-dominant degradation). Values obtained from evaluation using single indices clearly reflect the relationship between pavement conditions and pavement performance, degradation, and damage modes. Composite indices can be used as unifiers to evaluate multiple locations whose pavement conditions have degraded in different damage modes. Accordingly, they are useful in evaluating the order of priority of maintenance and repair work and ascertaining macroscopic pavement conditions.

The following formula for computing MCI[21] is an example of a composite index.

MCI is set to the minimum of the following values.

$$MCI = 10 - 1.48C^{0.3} - 0.29D^{0.7} - 0.47\sigma^{0.2}$$
$$MCI_0 = 10 - 1.51C^{0.3} - 0.30D^{0.7}$$
$$MCI_1 = 10 - 2.23C^{0.3}$$
$$MCI_2 = 10 - 0.54D^{0.7}$$

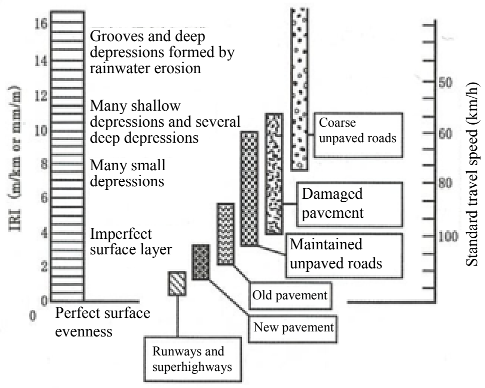
C: Crack ratio (%);
D: Rut depth (mm);
σ: Surface roughness (mm).

Regardless of the above example, indices for target administrative values must be selected independently in consideration of the characteristics and situations of each road, local circumstances, actual pavement administration, types of accumulated data, and other conditions.

After selection, appropriate target administrative values shall be determined based on actual pavement administration, road characteristics, and other factors.

Column: International roughness index (IRI)

IRI is the surface roughness index proposed by the World Bank in 1989. Its definition is "a virtual vehicle model formed by extracting one wheel from a biaxial four-wheel vehicle is called a quarter car, and the ratio (m/km or mm/m) of its accumulated longitudinal motion displacement to its travel distance when it travels on a road surface at a constant speed is the roughness of the road surface." IRI can be used as a single measure to evaluate the longitudinal irregularity of road surfaces, ranging from unpaved roads that have undergone no maintenance work to runways for which high evenness is required (refer to the figure). Four different classes of methods are used for IRI measurement, including a leveling method, bodily sensation checking, and visual inspection by inspectors in a patrol car. These measurement methods, which allow for relative comparisons between the surface conditions of various roads to be performed relatively cheaply, have drawn attention in recent years.



(Relationship between surface characteristics and IRI)

(2) Performing a present condition of pavement

Trunk roads generally have high traffic volume, with large vehicles accounting for a large portion. They play principal roles in human transport and physical distribution as infrastructures supporting socioeconomic activities, and their pavement consequently degrades quickly. For such roads, a present condition of pavement must be performed, mainly by road administrators. Since the present condition generally needs to assess the pavement's condition without disturbing traffic, typical surface characteristics (IRI, surface roughness, cracking, and rutting) are measured by surveying with a surface characteristics survey vehicle (**Photograph-2.3.1**), by patrolling inspections, and other approaches. Pavement management is implemented based on the data obtained, and the data influences how degradation forecasting models are set. Thus, it is necessary to ensure a measurement accuracy appropriate to each survey and inspection method. Each surface characteristics survey vehicle used should be equipped with automatic surface characteristics survey equipment that has undergone a performance validation test[22] for periodic verification of each measurement item's accuracy, or should provide accuracy equal to or better than the verified accuracy.

Photograph-2.3.1: Surface characteristics survey vehicles

The frequency of present condition must be determined in consideration of the provided service level, accuracy of the performance forecast, and systematic and budget constraints on road administrators. To maintain a high service level under the limits of administration, surface characteristics surveys may be implemented yearly. However, they are generally performed with a surface characteristics survey vehicle every three to five years, with the results combined with short-term forecasts of performance in present condition. The frequency of present condition may be altered considering the speed of change in surface characteristics and the validation results of degradation forecasting models.

Present condition of pavement is required to be performed on all target roads, but surface characteristics need not be measured on all lanes. As is the case with present condition frequency, measurement may be performed to various extents. Each section's pavement conditions are generally represented by the surface characteristics measured for a representative lane.

(3) Evaluating integrity and forecasting changes in integrity

Integrity is evaluated by quantitatively and qualitatively checking each section's pavement conditions against target administrative values. When the crack ratio or other indices expressing surface characteristics are used as indices for target administrative values, integrity must be quantitatively evaluated using the crack ratio and other values obtained by surface characteristics surveys.

Forecasting of changes in integrity is generally performed using a degradation forecasting model constructed for each surface characteristics index, such as the crack ratio or rut depth, or directly for target administrative value indices based on accumulated surface characteristics data. Needless to say, high-accuracy degradation forecasting models are desirable; however, since there are uncertainties about the pavement's degradation process, and since surface characteristic data is periodically obtained, the accuracy of degradation forecasting models is not always important at the beginning of pavement management activities. As the first step, degradation forecasting models may be constructed by referring to a degradation forecasting model used by administrators of nearby roads. In this case, survey expenses may be reduced by using accumulated data and reviewing the frequency of obtaining surface characteristics data (based on validation of the degradation forecasting models). It is also important to appropriately implement a PDCA cycle at the validation level of degradation forecasting models. The after-the-fact assessment by engineering approaches described in 2-2-2 (7) is also important. Such engineering approaches focus on the adequacy of degradation forecasting models constructed for individual maintenance and repair patterns influencing LCC estimation, as well as on appropriate correspondence of maintenance and repair methods to damage and degradation conditions.

Road administrators use various surface characteristics degradation forecasting models. In one example,[5] the model is set by applying a linear regression equation to historical records. In another example,[23] a surface characteristics degradation forecasting model is constructed by a probabilistic approach in consideration of the uncertainty of the speed of degradation development in different routes and portions, and risk management is implemented in consideration of the uncertainty of the degradation process.

(4) Accumulating and updating data

Maintenance and repair methods for pavement must be examined by considering not only pavement degradation, pavement damage, and investigation of causes but also the conditions for pavement design, structure, materials, paving time, maintenance and repair records, and other factors related to the target sections. Information management in a centralized database prevents data from being overlooked and contributes to the provision of highly useful information necessary for selecting effective maintenance and repair methods. **Table-2.3.1** lists some examples of the types of data to be stored.

Table-2.3.1: Examples of pavement-related data to be stored[created from 24)]

Data classification	Examples of data to be stored
Location	Route No., distance marking or coordinate system, lane No., and place name
Road structure	Lane structure, road width, bridges and similar structures, and intersections
Situation of roadside area	DID, classification of snowy and cold regions, and use of roadside areas
Traffic situation	Results of traffic volume surveys (including large vehicle classification) and travel speed
Actual pavement situation	Designed daily volume for pavement (design class), design CBR, state of performance specifications, T_A, pavement structure, materials, year and month of paving, contractor name, and plant name
Pavement design	Designed daily volume for pavement (design class), design CBR, state of performance specifications, T_A, residual T_A, pavement structure, materials, reason for maintenance and repair, and survey results (e.g., deflection measurement with FWD)
Pavement construction	Construction project name, contractor name, plant name, ordering system, whether new paving or maintenance and repair, reason for maintenance and repair, construction method, construction period, pavement structure, materials, and results of performance checking
Surface characteristics	Crack ratio, rut depth, surface roughness, and other factors (skid resistance, etc.)
Other surveys	Deflection measurement with FWD and environmental noise
Reference surveys	Notified data, complaint data, etc.

To operate a database, it is essential to construct a management system that allows searches of necessary information as well as adjustment, updating, and accumulation of data to be performed precisely and promptly. In addition, the database must be capable of reflecting information about small-scale emergency maintenance and repair work and other information appropriately.

Databases are the core elements of pavement management systems. However, it is important to start with available data to construct a feasible database and to increase the amount of data gradually every time it is updated, rather than to spend time constructing a complete initial database.

After-the-fact assessment is performed using accumulated data, whether through an engineering approach (e.g., improvement of accurate surface characteristics degradation forecasting models) or policy-making approach (e.g., consideration of the relationship between surface characteristics and road users' satisfaction). Database management should be realized by updating accumulated data while accumulating new data. Stored data types may increase in response to new survey methods, technical development, new needs of road users and local residents, and other conditions.

It is also necessary to take measures to ensure the database's capabilities can be expanded. To enhance databases' practical convenience, it is useful to link database information with map information. For example, the rated ranks of pavement integrity may be illustrated in different colors on a route network (**Figure-2.3.1**). Such an approach allows database information to be easily and promptly grasped, contributing to effective use.

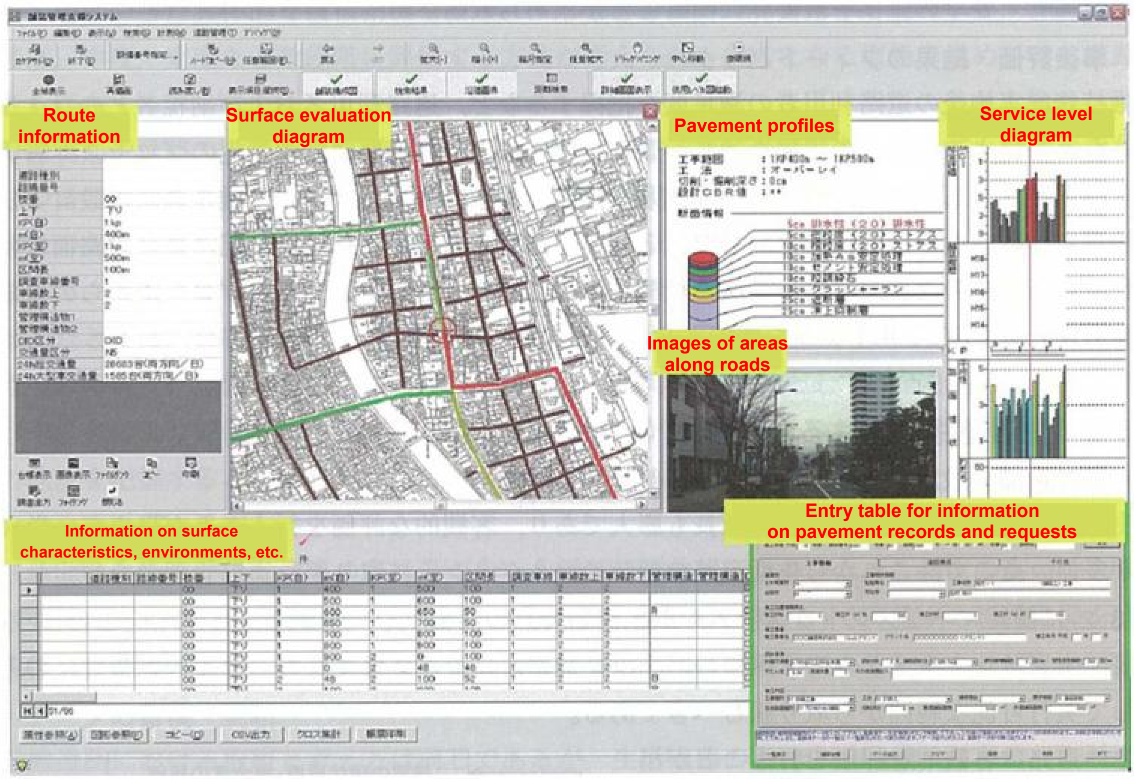


Figure-2.3.1: Example of linkage of pavement integrity, etc. with map information

(5) Formulating maintenance and repair plans and adjusting target administrative values

In the workflow previously described, the overall pavement conditions are assessed at the network level, candidate portions required for medium- and long-term maintenance and repair are extracted on the basis of the prescribed target administrative values, a pattern for minimizing expenses for road administrators and other expenses in the road lifecycle is extracted from among multiple maintenance and repair patterns, and a maintenance and repair plan specific to the combination of the timing, target section, and maintenance and repair method is formulated.

Maintenance and repair plans must be formulated in consideration of LCC that at least includes expenses for road administrators. Planning is carried out by comparing multiple alternatives under the prescribed constraints of target administrative values and budget so that the plans will produce maximum effects at minimal cost. This process requires the degradation forecasting models constructed for individual maintenance and repair plans previously described. In practice, pavement replacement, mill and overlay, and surface treatment operations are basically combined.

Long-term overall investment plans are thus formulated at the network level. Target administrative values may be appropriately reexamined to adjust plans given budget constraints depending on the plans' details and feasibility.

In the future, maintenance and repair plans should be formulated by estimating LCC with consideration given not only to expenses for road administrators but also to expenses for road users and local roadside communities.

(6) Implementation of maintenance and repair

For actual maintenance and repair, an implementation plan is formulated and implemented on the basis of independent technical judgments on pavement damage and degradation at each site, as described in Chapter 3 and the following chapters. Consequently, methods or other actual work-related matters may be different from those of the maintenance and repair plan formulated in the pavement management system. It is therefore essential to reflect actually used methods and other matters accurately in the database.

Emergency actions must be taken to ensure safety is the highest priority whenever damage, degradation, or other problems are detected that may adversely affect safety, regardless of budget constraints.

(7) After-the-fact assessment and feedback of results

It is necessary to assess needs, satisfaction, and other matters by communicating with road users and taxpayers after implementing maintenance and repair as well as to feed back the process of adjusting target administrative values and formulating maintenance and repair plans without fail to complete the PDCA cycle. It is also necessary to validate the selection of design and construction methods used for maintenance and repair and, whenever necessary, to perform follow-up surveys using the results of such after-the-fact assessment to iterate PDCA cycles appropriately by engineering approaches (e.g., improvement of surface characteristics degradation forecasting models for individual maintenance and repair methods, adoption of additional effective methods, and standardization of their use).

2-3-2 Methods used for activities for daily service roads

(1) Setting target administrative values, performing present condition of pavement, and evaluating integrity

Daily service roads consist of a large number of routes, and their total length is enormous. No objective evaluation has been completed on many of these routes. **Figure-2.3.2** illustrates a simplified workflow for daily service roads under a pavement management system at the beginning of pavement management by road administrators. As seen in this workflow, it is not necessary to prepare all required elements for a pavement management system at the beginning. Feasible pavement management should be started only with consideration given to future expandability.

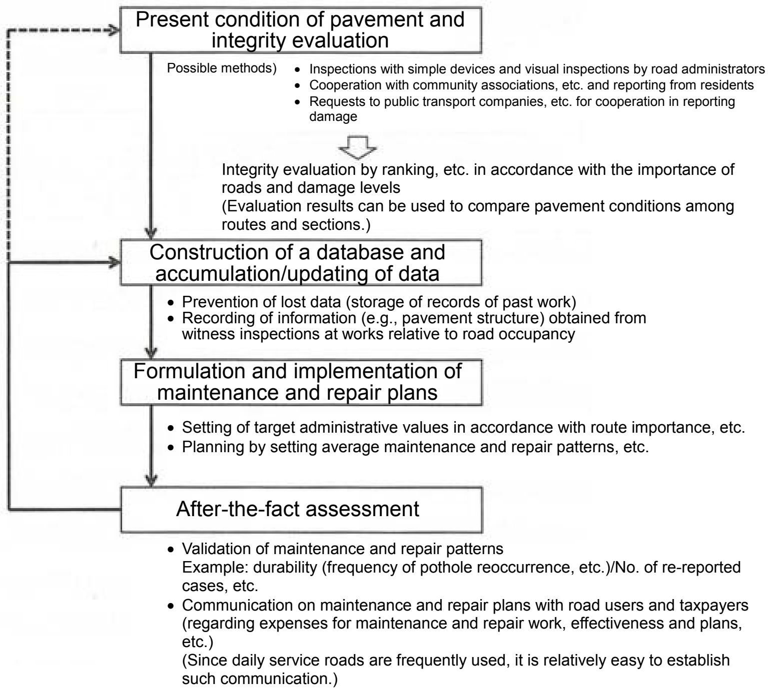


Figure-2.3.2: Simplified workflow for a pavement management system for daily service roads (example)

No objective evaluation has been completed on many of the routes. The target administrative values for daily service roads must be determined in consideration of future present condition performed on the pavement.

The total length of daily service roads is enormous, but their pavement degrades slowly because the traffic volume of large vehicles is usually small. Thus, it is impractical for road administrators to initiate the performance of a present condition of their pavement using a surface characteristics survey vehicle (as is used on trunk roads). Traffic on daily service roads is mainly regional traffic, and many of their users are roadside residents. Practical methods for present condition of daily service roads' pavement include inspection with simple devices and visual inspection by road administrators, approaches in residential cooperation (e.g., reporting from residents), and combinations of these methods. Approaches in residential cooperation are implemented by making requests to organizations other than those of road administrators, cooperating with organizations such as public transport companies and community associations, establishing a system in which conditions are reported to road administrators, and accumulating the details of the reported information. It is more effective to store photographs and images together with such information. Approaches in residential cooperation also facilitate communication to satisfy road users.

An example of an inspection with simple devices is where a small vehicle or a motorized bicycle is used to continuously acquire data on pavement conditions by capturing images or other means. In visual inspections, pavement damage is classified into several levels such as light, medium, or severe damage compared to reference photographs or other criteria for concrete damage indices (e.g., cracking, faulting, patching, and traces of road occupation recovery). Some road administrators have started activities that can serve as references.[25)]

It is desirable to perform present condition of pavement appropriately in consideration of actual administration, road characteristics, and constraints on road administrators due to the system and budget, and other factors. Present condition will contribute to the implementation of objective, transparent pavement administration.

As the next step, the integrity of target daily service roads must be evaluated at the network level. In visual inspection, for example, integrity is classified[25)] into the three levels of light, medium, or severe damage by comparing pavement with photographs indicating damage levels. In evaluations based on reported information, the content and number of reports may be used. However, since objectivity cannot be ensured by such an approach, it is necessary to access site situations through photographs and other means.

(2) Forecasting changes in integrity

The traffic volume of large vehicles on daily service roads is generally low, and thus such roads' pavement degrades slowly. For these roads, pavement management does not require high-accuracy forecasting of changes in integrity. Accumulated data on implemented maintenance and repair are used together with information obtained from the present condition implemented in (1) to estimate the amount of projects required for future maintenance and repair.

(3) Accumulating and updating data

Data is accumulated and updated in a similar manner to that of trunk road activities. However, much of the data on existing pavement structure as well as maintenance and repair records may be lost for daily service roads consisting of large numbers of routes. Existing data should be organized first to form a database, and the database should be enriched gradually (e.g., by checking pavement structures in witness inspections at works relative to road occupancy). Since daily service roads consist of a large number of routes and often undergo modification or abolition, information linkage with maps (e.g., color-coding of actual pavement conditions in each map area block) is more effective than for trunk roads.

(4) Formulating and implementing maintenance and repair plans

Maintenance and repair plans must be formulated by extracting candidate portions for maintenance and repair after present condition of pavement and integrity evaluation while comprehensively considering budget constraints, leveling of the amount of projects, and other factors. Present condition makes it possible to objectively extract candidate portions for maintenance and repair and to cope with regional disparities in pavement conditions. As described in Chapter 3 and following chapters, it is necessary to select appropriate maintenance and repair methods on the basis of field surveys before implementing daily service road maintenance and repair. Data obtained in this process must be reflected in the database.

(5) After-the-fact assessment and feeding back of results

"To achieve administration that is easy-to-understand and transparent to road users and taxpayers" and "to achieve efficient administration that yields optimal effects at minimal costs," after-the-fact assessment is important for pavement management for both daily service and trunk roads. Since residential cooperation approaches are used as methods for present condition of pavement of daily service roads and since these roads are frequently used by local residents, it is relatively easy to establish communication with road users and taxpayers. The PDCA cycle illustrated in **Figure-2.2.1** is expected to contribute to active projects to realize highly transparent pavement management.

2-4 Approaches to management

The ideal form of pavement management was described in 2-1 and 2-2. Even road administrators who practice advanced pavement management, however, take on a workflow similar to that illustrated in **Figure-2.4.1** at present. This workflow lacks the viewpoint of assessing needs through substantial communication with road users and taxpayers, compared to the workflow illustrated in **Figure-2.2.1**. The details of maintenance and repair plans as well as expenses for the plans vary significantly depending on the target administrative values. It is therefore necessary not only to implement efficient pavement management under limited maintenance and repair budgets but also to accumulate knowledge about the influence of the levels of pavement surface characteristics on the satisfaction of road users, socioeconomic factors, and other issues. This can also be used to determine desirable levels of target administrative values based on the needs of road users and taxpayers as well as medium- and long-term expenses for maintenance and repair required to reach such levels, and to implement activities for pavement management so as to reach agreement with road users and taxpayers.

Pavement management begins with present condition. However, no present condition has been implemented on some roads, and it has been implemented only partially on other roads under administration. In both cases, it is desirable to begin with currently feasible activities depending on the actual situations of road administrators and actual administration as well as to gradually improve the workflow into the ideal form of pavement management (shown in **Figure-2.2.1**) by enhancing understanding of the concepts and workflow of pavement administration through information exchange[5)] with other road administrators and the subsequent transmission of information to residents.

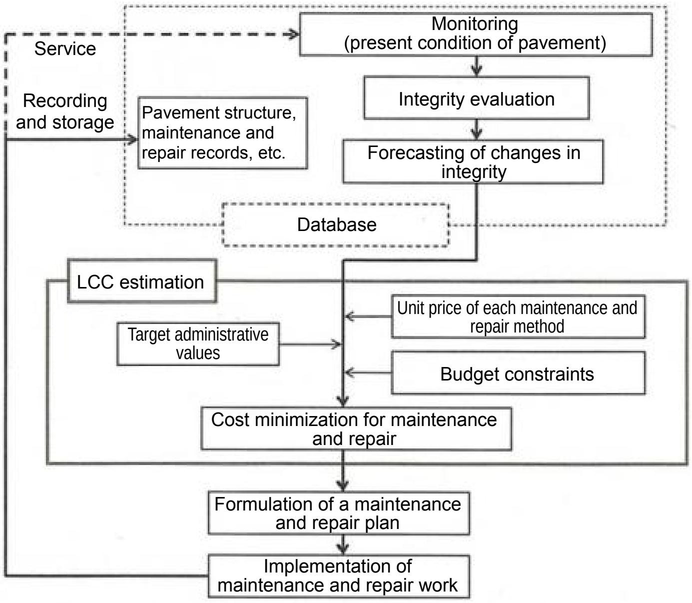


Figure-2.4.1: Workflow of pavement management at present

[References]

1) Japan Road Association: Guidelines for Pavement Design and Construction (2006 edition), p. 19, p. 28, pp. 185–192, February 2006
2) Committee on Road Maintenance and Repair, Japan Road Association: Handbook on Road Asset Management, July 2008
3) For example, Kaneko, Tadaka, and Maruyama: Field Survey on a Preventive Repair Method for Pavement (No. 2), Monthly Report of the Civil Engineering Research Institute for Cold Region, No. 667, pp. 27–33, December 2008
4) For example, Watanabe and Ishida: A Discussion on Target Administrative Values for Pavement, Collection of Technical Reports of the 11th Hokuriku Road Pavement Conference, D-11, August 2009
5) Japan Road Association website: http://www.road.or.jp/technique/090210.html
6) Sawai: International Standardization of Asset Management Systems (Movements Related to ISO 5500X), Asset Management Summer School —For International Standardization of ISO 5500X—,

pp. 15–23, August 2011
7) Kasahara: Pavement Management Systems, Journal of JSCE, No. 478/V-21, pp. 1–12, November 1993
8) Watanabe: A Discussion on Activities for Pavement Management, Civil Engineering, Vol. 65, No. 1, pp. 36–42, January 2010
9) Japan Road Association: Handbook on Pavement Survey and Test Methods, pp. [1] 234–240, June 2007
10) Pavement Research Laboratory of the Public Works Research Institute, National Highway Division of the Ministry of Construction's Road Bureau: Research and Study on Planned Pavement Administration Methods, Reports from the 52nd Technical Research Meeting of the Ministry of Construction, pp. 22-4–22-7, November 1998
11) Bench-marking Evaluation for Long-life Pavement Based on Logic Model, Journal of Practical Research by Civil Engineers, Vol. 1, pp. 40–52, March 2010
12) R. Haas, W. R. Hudson, and J. Zaniewski: The Latest Pavement Management, Pavement Research Committee of the Hokkaido Civil Engineering Association, pp. 57–64, pp. 157–162, June 2000
13) Public Works Research Institute, National Highway First Division of the Ministry of Construction's Road Bureau: Comprehensive Research on Pavement Administration Levels and Maintenance and Repair Methods, Collection of Reports on Specified Subjects in the Road Category at the 41st Technical Research Meeting of the Ministry of Construction, pp. 323–362, October 1987
14) Ito: Asset Management for Road Pavement, *Doro* (Roads), Vol. 764, pp. 34–38, October 2004
15) Yabu and Ito: Construction of a Pavement Management System, Civil Engineering Journal, Vol. 46, No. 12, December 2004
16) Sekiguchi: An Example of a Model for Evaluating Economic Efficiency of Loop Road No. 7, *Hoso* (Pavement), Vol. 32, No. 5, pp. 9–18, May 1997
17) Tsunokawa, Kiryu, and Ozawa: Cost-benefit Analysis of Applicable Conditions of Drainage Pavement and the Optimal Administration Level, Vol. 44, No. 3, pp. 13–19, March 2009
18) Sakai, Arakawa, Inoue, and Kobayashi: The Development of the Hanshin Expressway Bridge Management System, Journal of Applications of Civil Engineering Information, Vol. 17, pp. 63–70, November 2008
19) Kobayashi: Importance of Administration Based on Preventive Maintenance, JSCE Magazine, "Civil Engineering," Vol. 95, No. 12, pp. 14–17, December 2010
20) Aoki: Strategy to Establish a De Facto Standard for Pavement Overseas (Kyoto Model), Asset Management Summer School —For International Standardization of ISO 5500X—, pp. 91–102, August 2011
21) Public Works Research Institute, National Highway First Division of the Ministry of Construction's Road Bureau: Research and Study on Planning for Pavement Maintenance and Repair, Collection of Reports on Specified Subjects in the Road Category at the 34th Technical Research Meeting of the Ministry of Construction, pp. 247–254, November 1980
22) Public Works Research Center website: http://www.pwrc.or.jp/kaihatsu02.html
23) Road Maintenance Section of the Nagasaki Prefectural Government's Civil Engineering Department: Guidelines for Pavement Maintenance and Administration, March 2009
24) Japan Road Association: Pavement Design Handbook, p. 254, February 2006
25) Uesugi, Seki, Suehiro, Nagase, and Endo: The Method of Evaluating Community Roads for Asset Management System in Yokohama City, Journal of Pavement Engineering, Vol. 13, pp. 31–38, December 2008

Chapter 3: Implementation Plans for Maintenance and Repair

3-1 Overview

Maintenance and repair processes include extraction of sections (routes) requiring maintenance and repair, present condition and sectional pavement damage evaluation, and selection of maintenance and repair methods appropriate for damage levels, causes, and other factors. This chapter describes procedures for these activities and their concepts based on maintenance and repair as described in Chapter 2.

Specifically, the following activities are to be performed on extracted sections requiring maintenance and repair. This chapter describes these activities as an implementation plan for maintenance and repair in the order illustrated in **Figure-3.1.1**.

1. Present condition of damage by field surveys
2. Evaluation of damage levels
3. Identification of damage causes (inferences)
4. Selection of applicable maintenance and repair methods based on evaluation results
5. Performance examination and conditions necessary for design
6. Road surface design and structural design

Though this chapter describes matters related to roadway pavement, these activities for survey, evaluation, and design also apply similarly to sidewalk, bicycle track, and other types of road pavement.

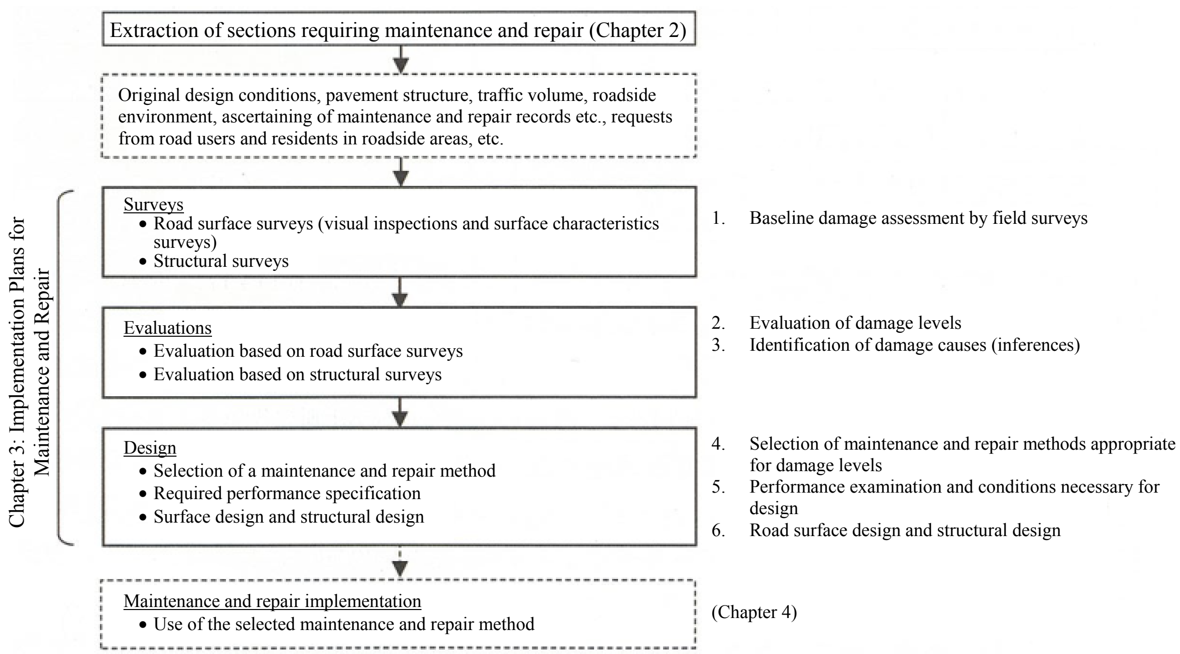


Figure-3.1.1: Content of Chapter 3

For major modes of pavement damage and their causes, refer to "Appendix 4: Modes of Damage to Asphalt Pavement and Causes Thereof" and "Appendix 5: Modes of Damage to Concrete Pavement and Causes Thereof."

3-2 Surveys

Effective, economic pavement maintenance and repair are based on precisely ascertaining actual damage and its causes, selection of appropriate maintenance and repair methods, and proper maintenance and repair design. In this process, it is essential to survey pavement damage to evaluate actual conditions, thereby producing data important for extracting sections subject to maintenance and repair, selection of maintenance and repair methods, or maintenance and repair design.

As illustrated in **Figure-3.2.1**, pavement damage surveys are classified into “road surface surveys” and “structural surveys.” Road surface surveys include visual inspections performed mainly by observation and surface characteristics surveys using surveying and testing devices, tools, or other instruments used for measurement and evaluation. Structural surveys examine the interior conditions of pavement and subgrade. This section describes survey methods used to formulate implementation plans for pavement maintenance and repair.

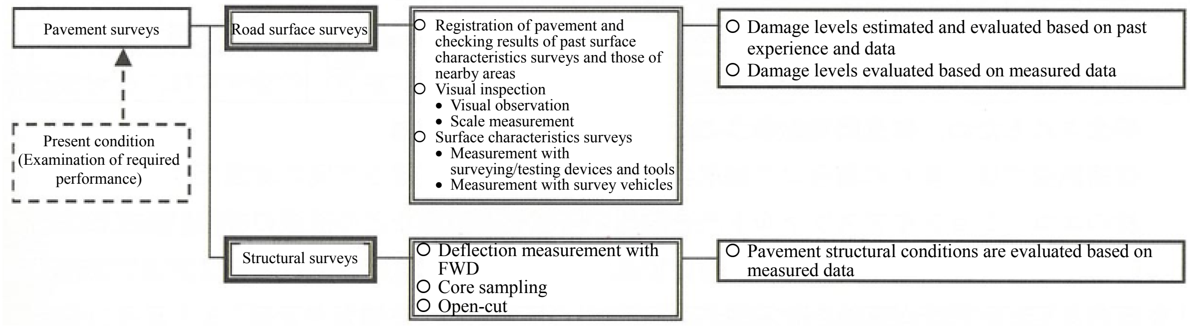
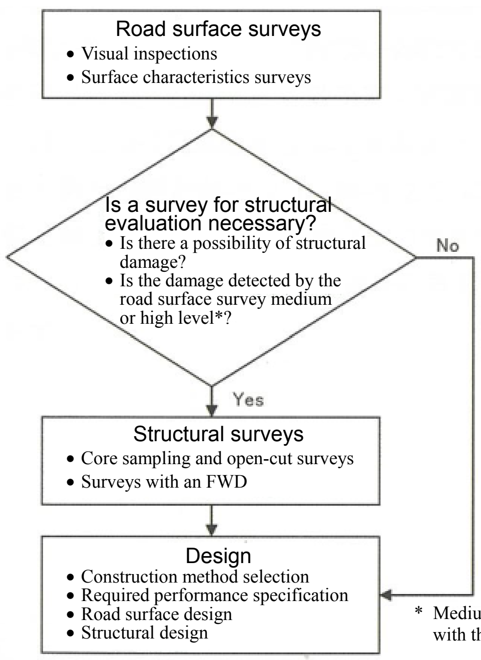


Figure-3.2.1: Pavement maintenance and repair surveys

3-2-1 Survey workflows

Figure-3.2.2 illustrates a survey workflow. Performing a structural survey is desirable if the road surface survey results suggests structural damage is due to a cause in the binder or layers underneath, or under the concrete slab, or if there is significant damage.



* Medium- or high-level damage refers to damage categorized as M or H in accordance with the classification for selecting construction methods defined in “3-3 Evaluation.”

Figure-3.2.2: Workflow for pavement surveys

Surveys must be carried out in accordance with the following concepts.

- Surveys are implemented to ascertain the types, levels, and causes of damage as well as to design maintenance and repair based on the survey results.
- To design maintenance and repair, it is essential to identify whether damage has been caused by the surface, road, binder or layers underneath, or under the concrete slab.
- Pavement damage is classified as either road surface damage or structural damage. Road surface damage is caused by conditions present in the surface or only affecting the road surface portions. Structural damage develops in the binder or layers underneath, or under the concrete slab, and affects the surface or binder, or it develops from road surface damage, directly disturbing the pavement's structure and function and thus affecting durability.
- To accurately evaluate possible structural damage, it is essential to identify the damage mode and level to estimate the affected portion.
- For example, structural surveys must be carried out when it is difficult to estimate the affected damaged portion in the depth direction from surface characteristics alone, or when the pavement's bearing capacity has presumably degraded due to cracking, rutting, or other phenomena that are accompanied by sinking.
- When damage is categorized as M or H according to the classification for selecting maintenance and repair methods (refer to "3-3 Evaluation"), structural damage may have occurred, and it is thus desirable to carry out a structural survey.
- In most structural surveys, damage levels (not only the affected damaged portion in the depth direction but also its modes, such as base course materials erosion or asphalt mixture layers granulation) are directly examined by core sampling. For trunk roads and other roads, surveys with FWD (non-destructive surveys examining the conditions of layers as deep as the subgrade and base course) may also be performed.
- Structural surveys may be omitted when records of similar damage cases and actions are available or when the category and causes of damage can be determined by road surface surveys alone.

Figure-3.2.3 illustrates four patterns of surveying and examining existing pavement. Pattern 1 consists of a visual inspection, surface characteristics survey, and structural survey. Pattern 2 consists of a visual inspection and surface characteristics survey. Pattern 3 consists of a visual inspection and structural survey. Pattern 4 consists of only a visual inspection.

In other cases, a surveying and examining pattern consisting of a surface characteristics survey and structural survey may be implemented without a visual inspection: for example, when an examination or follow-up survey is scheduled to evaluate the details of sections subject to maintenance and repair. When past data and that on nearby sections can be used as design input values, implementing a structural survey is sufficient, or the data may be examined by itself instead. This is because surveys are carried out in order to obtain information and data necessary for technical design.

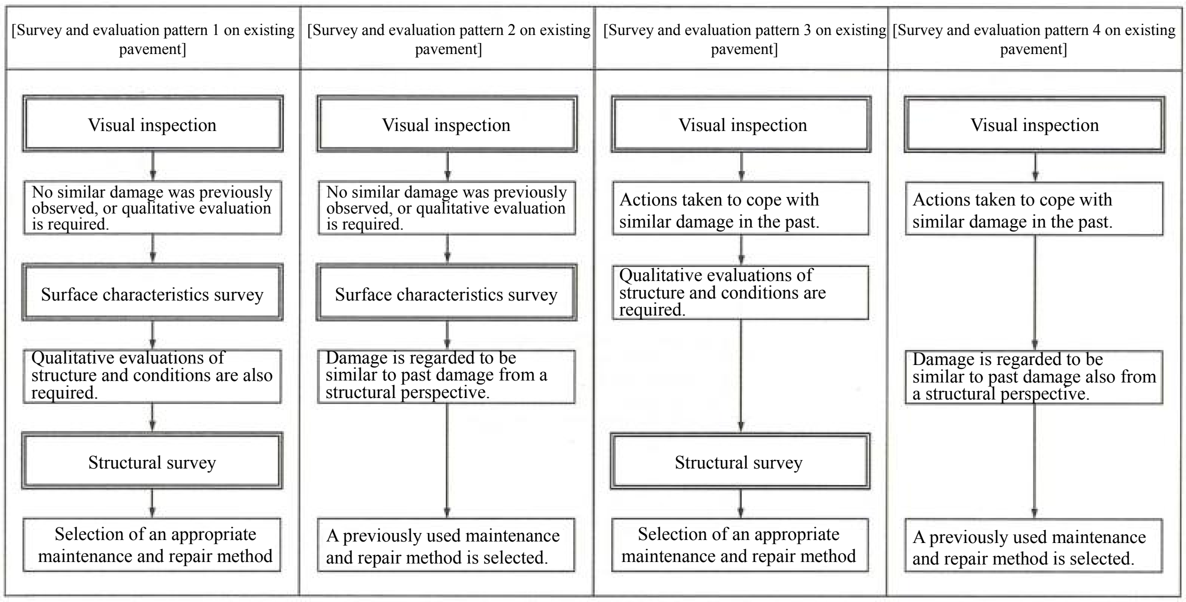


Figure-3.2.3: Examples of survey and examination patterns

3-2-2 Road surface surveys

Pavement road surface surveys are implemented to ascertain road surface conditions through visual inspection mainly by visual observation and surface characteristics surveys using surveying and testing devices, tools, and other instruments to perform quantitative evaluation. The following describes methods are used for visual inspections and surface characteristics surveys.

(1) Visual inspections

Visual inspections evaluate damage by visual observation or by using simple tools (e.g., a scale) and infers (identifies) damage causes based on available data and other information (e.g., traffic volumes and climate conditions). The results of visual inspections are used as data for damage evaluations and judgments regarding the need for structural surveys (with consideration given to engineers' experience and other factors). Visual inspections, such as observing and recording detailed road surface conditions, are principally performed by walking along the road. If a walking inspection is difficult, a vehicle should be used to observe road surface conditions.

The results of visual inspections should be compiled in a survey table, with observation charts and photographs attached when necessary. In-service conditions (e.g., traffic volumes, climate conditions, roadside environments, and maintenance and repair records) should also be entered into the table. Visual inspection plays one of the main roles in daily service road surveys.

Tables-3.2.1 and **3.2.2** list visual inspection items and details. For the details of survey methods refer to see "S001 Simple survey methods for damage conditions" in the *Handbook of Pavement Survey and Test Methods* (Vol. 1).

Table-3.2.3 lists example results of asphalt pavement visual inspections, while **Table-3.2.4** lists example results of concrete pavement visual inspections.

Table-3.2.1: Overview of visual inspections (asphalt pavement)

Survey item	Details
Cracking	○ Visual observation • Conditions of cracks • Cracking level • Crack widths • Checking for materials separated from the bottom
Rutting	○ Visual observation or scale measurement • Rutting level • Accumulated water level and water splashing level
Faulting and surface roughness (Corrugation, depressions, bumps, and blistering)	○ Visual observation or scale measurement • Height difference from the surrounding area • Checking for materials separated from the bottom ○ Sensory evaluation • Noise and vibration during vehicular travel
Potholes	○ Visual observation or scale measurement • Areas and depths of potholes • Surrounding conditions (oil leakage, filler ooze, etc.)
Polishing, flushing, and bleeding (Degradation of skid resistance)	○ Visual observation or scale measurement • Polishing areas • Accumulated water level and water splashing level ○ Sensory evaluation • Noise, vibration, and skidding during vehicular travel
Scattering of porous asphalt pavement aggregates	○ Visual observation or scale measurement • Areas and depths of aggregate scattering • Accumulated water level and water splashing level ○ Sensory evaluation • Noise and vibration during vehicular travel
Void choking and clogging in porous asphalt pavement	○ Visual observation • Choking levels • Accumulated water level and water splashing level ○ Sensory evaluation • Permeation of sprinkled water
Partial occurrence of bumps in porous asphalt pavement (Lateral flow)	○ Visual observation or scale measurement • Rutting level • Accumulated water level and water splashing level
Stripping	○ Visual observation or scale measurement • Oozing of filler components onto the pavement surface • Areas and depths of partial sinking
Ascertaining of service conditions	○ Traffic volumes, climate conditions, roadside environments, maintenance and repair records, etc.

Table-3.2.2: Overview of visual inspections (concrete pavement)

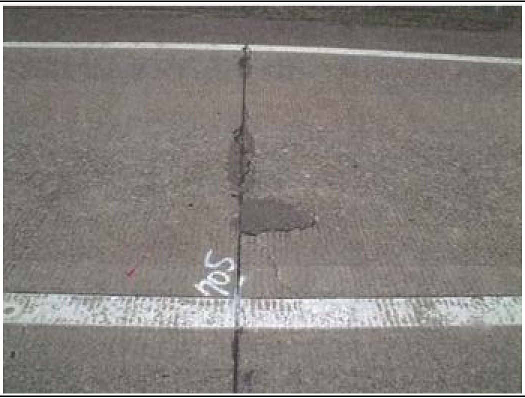
Survey item	Details
Cracking	○ Visual observation • Condition of cracks (modes, edge defects, etc.) • Crack widths • Separation of sandy components
Joint damage	○ Visual observation or scale measurement • Levels of protrusion and scattering around joints • Joint widths and levels of edge defects
Faulting	○ Visual observation or scale measurement • Height difference from the surroundings area • Checking for materials separated from the bottom ○ Sensory evaluation • Noise and vibration during vehicular travel
Rutting	○ Visual observation or scale measurement • Rutting level • Accumulated water level and water splashing level
Potholes	○ Visual observation or scale measurement • Areas and depths of potholes • Surrounding conditions
Scaling and raveling	○ Visual observation or scale measurement • Stripping levels (areas and depths) • Accumulated water level and water splashing level • Deformation in the longitudinal direction (irregularities) ○ Sensory evaluation • Noise and vibration during vehicular travel
Polishing (Degradation of skid resistance)	○ Visual observation or scale measurement • Polishing areas • Accumulated water level and water splashing level ○ Sensory evaluation • Noise, vibration, and skidding during vehicular travel
Ascertaining of service conditions	○ Traffic volumes, climate conditions, roadside environments, maintenance and repair records, etc.

Table-3.2.3: Examples of visual inspection results for asphalt pavement

Route No.	xx Road No. xx	Reference No.	5	Location	xx Town in xx City
Survey item			Surveyor	❑❑ ❑❑	
Photograph location	Photograph			Comment	
Down lane at xx Kilometer Post (hereafter, KP)				Road surface damaged mainly by cracking Alligator cracks in the rutting portion on the left. No cracks but approx. 15-mm depressions in the rutting portion on the right. No materials separated from the bottom. It is inferred that only the surface course has been damaged. Checking by core sampling or other approaches is necessary.	
Down lane near xx KP				Road surface damaged mainly by cracking Road surface with appearance similar to that observed at the above measuring point. The rutting portion on the right has basically not suffered any deformation.	
Down lane near xx KP				Road surface damaged mainly by cracking Alligator cracks accompanied by sinking have developed in the rutting portion on the left. Since there is a utility hole near that portion, sinking caused by buried objects may be a cause of the cracking.	
Down lane at xx KP				Almost no damage is observed.	

Table-3.2.4: Examples of visual inspection results for concrete pavement

<table>
<tr><td>Route No.</td><td>xx Road
No. xx</td><td>Reference No.</td><td>7</td><td>Location</td><td>xx Town in xx City</td></tr>
<tr><td>Survey item</td><td colspan="2"></td><td>Surveyor</td><td colspan="2">❑❑ ❑❑</td></tr>
<tr><td>Photograph location</td><td colspan="3">Photograph</td><td colspan="2">Comment</td></tr>
<tr><td>Down lane at xx Kilometer Post (hereafter, KP)</td><td colspan="3"></td><td colspan="2">Decrease in surface roughness

Wavy lines.
The concrete slab exhibits partial sinking.
The concrete slab retains its soundness.
The subgrade’s bearing capacity may degrade due to water springing from the cut slope’s face.</td></tr>
<tr><td>Down lane near xx KP</td><td colspan="3"></td><td colspan="2">Joint damage

Corner cracks have developed.
Edge defects occurred in joints repaired with asphalt mixture.
Grooving in tire traveling portions has disappeared due to abrasion.</td></tr>
<tr><td>Down lane near xx KP</td><td colspan="3"></td><td colspan="2">Joint damage: Tunnel entrance

The pavement has been used for 26 years with only a small number of edge defects occurring.
Located in a snowy region, the road surfaces in the tire traveling portions suffer from polishing; accordingly, skid resistance may be degraded.</td></tr>
<tr><td>Down lane at xx KP</td><td colspan="3"></td><td colspan="2">Partial defects

Partial defects are observed in traveling portions.
Inclusion of foreign objects or other events during construction may have caused the defects.</td></tr>
</table>

(2) Surface characteristics surveys

Surface characteristics surveys use surveying and testing devices, tools, or other instruments to convey the pavement’s surface condition (damage level) as a numeric value, including crack ratio measurement, rut depth measurement, and surface roughness measurement on paved surfaces. The results of surface characteristics surveys are used to infer (identify) the causes of damage and to qualitatively evaluate the local or complex damage to sections subject to maintenance and repair as well as the surface characteristics thereof. The results thus serve as reference data for the selection and design of maintenance and repair methods or for the evaluation of the necessity of carrying out a structural survey. For details of such evaluation, refer to “3-3-2 Damage evaluation.”

Tables-3.2.5 and **3.2.6** list road surface damage examples for asphalt and concrete pavement as well as items and methods for surface damage surveys. These examples list the survey items required for each type of damage. Appropriate survey items should be selected depending on damage conditions. For details of the survey method corresponding to each survey item, refer to the *Handbook of Pavement Survey and Test Methods*.

Surface characteristics surveys should also be performed on daily service roads whenever necessary to provide reference data for the selection and design of maintenance and repair methods.

Table-3.2.5: Types of road surface damage, survey items, and survey methods (asphalt pavement)

Survey item	Survey method[Note 1)]	Damage type[Note 2)]						
		Cracking		Rutting	Surface roughness	Other types of damage		
		Linear cracks	Alligator cracks			Faulting	Potholes	Stripping
Crack measurements on paved road surfaces	S029	⊙	⊙	○	△	△	⊙	⊙
Rut depth measurements on paved road surfaces	S030	△	○	⊙	⊙	△	△	○
Surface roughness measurements on paved road surfaces	S028	△	△	○	⊙	△	△	○
International Roughness Index (IRI) surveys	S032T	△	△	○	⊙	△	△	○
Faulting measurements on paved road surfaces	S031	△	△	△	△	⊙	△	○
Pothole measurements	S033T	-	-	-	-	-	⊙	○
Skid resistance measurements on paved road surfaces	S021	△	△	△	△	△	△	△
On-site permeable water volume measurements	S025	-	-	-	-	-	-	-

Survey item	Survey method[Note 1)]	Damage type[Note 2)]				Damage unique to porous asphalt mixtures[Note 2)]		
		Other types of damage						
		Polishing	Corrugation	Bumps	Depressions	Aggregate scattering	Void choking and clogging	Partial bumps
Crack measurements on paved road surfaces	S029	△	△	△	△	△	△	○
Rut depth measurements on paved road surfaces	S030	△	△	⊙	⊙	△	△	⊙
Surface roughness measurements on paved road surfaces	S028	△	⊙	△	△	△	-	-
International Roughness Index (IRI) surveys	S032T	△	⊙	△	△	△	-	-
Faulting measurements on paved road surfaces	S031	△	△	△	△	△	-	△
Pothole measurements	S033T	-	-	-	-	△	-	-
Skid resistance measurements on paved road surfaces	S021	⊙	△	△	△	△	△	△
On-site permeable water volume measurements	S025	-	-	-	-	○	⊙	△

Note 1) The codes listed in the survey methods column are those used in the *Handbook of Pavement Survey and Test Methods*.
Note 2) ⊙ indicates a required survey item, ○ indicates a desirable survey item, and △ indicates a survey item performed whenever necessary.

Table-3.2.6: Types of road surface damage, survey items, and survey methods (concrete pavement)

Survey item	Survey method[Note 1)]	Damage type[Note 2)]						
		Cracking	Joint damage	Faulting	Rutting	Potholes	Scaling	Polishing
Crack measurements on paved road surfaces	S029	⊙	-	-	-	-	-	-
Surface roughness measurements on paved road surfaces	S028	△	⊙	⊙	△	△	○	○
International Roughness Index (IRI) surveys	S032T	△	⊙	⊙	△	△	○	○
Rut depth measurements on paved road surfaces	S030	-	△	○	⊙	-	△	△
Faulting measurements on paved road surfaces	S031	-	⊙	⊙	-	-	-	-
Pothole measurements	S033T	-	-	-	-	⊙	△	-
Skid resistance measurements on paved road surfaces	S021	-	-	-	-	-	-	⊙
Coarseness measurements on paved road surfaces	S022	-	-	-	⊙	-	⊙	⊙
Tire noise measurements on road surfaces	S027	△	△	△	-	-	△	△

Note 1) The codes listed in the survey methods column are those used in the *Handbook of Pavement Survey and Test Methods*.
Note 2) ⊙ indicates a required survey item, ○ indicates a desirable survey item, and △ indicates a survey item performed whenever necessary.

3-2-3 Structural surveys

(1) Structural surveys of asphalt pavement

Structural surveys are performed to ascertain the pavement's interior and pavement structure detailed by deflection measurement with FWD (falling weight deflectometer), cutting core sampling, open-cut surveys, and other approaches.

Results of deflection measurement with FWD can be used to judge whether pavement has a sufficient bearing capacity. Analysis of measured deflection can be used to detect damaged layers.

The characteristics of cracking portions, such as cracks' widths and depths, can be directly measured by cutting core sampling. Cores sampled from the edge and outside of cracking portions, as illustrated in **Figure-3.2.4**, as well as the cracking portions often reveal whether cracks have originated from the surface or bottom of the asphalt mixture layer.

The characteristics of rutting portions, such as whether deformation has developed only at the surface course or has reached the binder course, can be revealed by measuring the thickness of each layer's cut core.

Sampled cores can be used to perform tests to determine the mixture's grading distribution, the recovered asphalt's properties, and the mixture's properties. Sampled cores are generally 10 cm in diameter; however the use of cores 15 cm in diameter allows more samples to be obtained from each core. Samples should be collected from both damaged and undamaged portions.

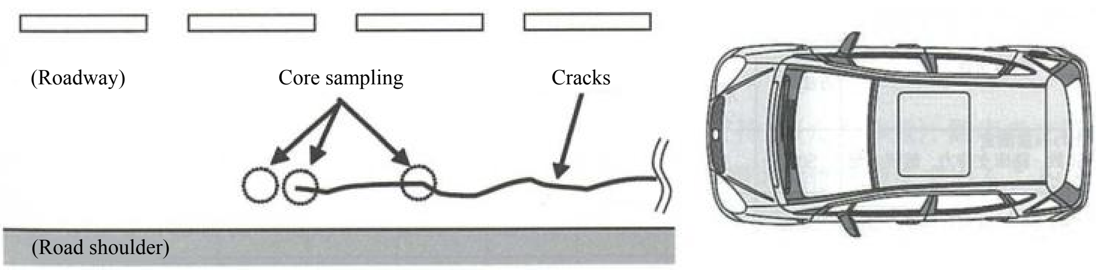


Figure-3.2.4: Example of core sampling from a cracking portion

Open-cut surveys involve cutting of road surfaces, making them significantly extensive surveys. However, damage causes can often be identified by measuring each layer's thickness and performing CBR tests and material tests on collected samples. In addition, open-cut surveys directly observe the subgrade, base, and asphalt mixture's bottom layer over a relatively wide area, with the observed results used to select reliable maintenance and repair methods.

The results of structural surveys, which can identify whether damage is road surface or structural damage, can be used as reference data for the selection and design of repair methods.

Table-3.2.7 lists the types of structural damage as well as items and methods for structural damage surveys, indicating the survey items required for each damage type as needed. For the details of the survey method corresponding to each survey item, refer to the *Handbook of Pavement Survey and Test Methods*.

Structural surveys should also be performed on daily service roads whenever necessary to provide reference data for the selection and design of maintenance and repair methods.

Table-3.2.7: Types of structural damage, survey items, and survey methods (asphalt pavement)

Survey item	Survey method (Note 1)	Damage type (Note 2)								
		Cracking								
		Linear cracks						Alligator cracks		
		Fatigue cracking	Rutting	Cracking at construction joints	Reflection cracking	Cracking due to thermal stress	Cracking due to frost heaving	Cracking due to reduced subgrade or base course bearing capacity	Cracking due to subgrade or base course settlement	Cracking due to asphalt mixture degradation and aging
Deflection measurement with FWD (Elastic modulus, subgrade bearing capacity, pavement soundness, etc.)	S047	○	○	△	△	△	⊙	⊙	⊙	⊙
Core sampling (Simple measurement of each layer for width, crack depth, density, etc.)	S002	○	⊙	○	○	○	○	△	⊙	○
Core sampling (Extraction tests, strength tests, etc.)	S002	○	○	△	△	△	○	△	○	○
Open-cut surveys (Each layer's width, subgrade/base course material properties, subgrade bearing capacity, etc.)	S002	△	△	△	△	△	○	○	○	△

Survey item	Survey method (Note 1)	Damage type (Note 2)								
		Cracking		Rutting			Surface roughness	Other types of damage		
		Alligator cracks								
		Cracking around structures	Cracking due to binder course stripping	Settlement of subgrade or base course due to consolidation	Flow	Abrasion	Longitudinal direction irregularities	Faulting	Potholes	Stripping
Deflection measurement with FWD (Elastic modulus, subgrade bearing capacity, pavement soundness, etc.)	S047	⊙	△	○	△	△	⊙	⊙	⊙	⊙
Core sampling (Simple measurement of each layer for width, crack depth, density, etc.)	S002	△	⊙	⊙	⊙	○	○	○	○	⊙
Core sampling (Extraction tests, strength tests, etc.)	S002	△	⊙	○	○	△	○	○	○	○
Open-cut surveys (Each layer's width, subgrade/base course material properties, subgrade bearing capacity, etc.)	S002	△	○	△	△	△	△	△	△	○

Survey item	Survey method (Note 1)	Damage type (Note 2)						
		Other types of damage				Damage unique to porous asphalt mixtures		
		Polishing	Corrugation	Bumps	Depressions	Aggregate scattering	Void choking and clogging	Partial bumps
Deflection measurement with FWD (Elastic modulus, subgrade bearing capacity, pavement soundness, etc.)	S047	-	△	△	⊙	-	-	△
Core sampling (Simple measurement of each layer for width, crack depth, density, etc.)	S002	△	○	○	○	△	△	○
Core sampling (Extraction tests, strength tests, etc.)	S002	△	△	△	△	△	△	△
Open-cut surveys (Each layer's width, subgrade/base course material properties, subgrade bearing capacity, etc.)	S002	-	△	△	△	-	-	△

Note 1) The codes listed in the survey methods column are those used in the *Handbook of Pavement Survey and Test Methods*.
Note 2) ⊙ indicates a required survey item, ○ indicates a desirable survey item, and △ indicates a survey item performed whenever necessary.

(2) Structural surveys of concrete pavement

Structural surveys are performed to ascertain the pavement's interior and pavement structure detailed by deflection measurement with FWD, cutting core sampling, open-cut surveys, and other approaches. Results of deflection measurement with FWD can be used to estimate load transfer rates at cracking portions and joints as well as subgrade and base course bearing capacities. Crack depths, the condition of reinforcements (steel), and other properties can be ascertained by observing sampled cutting cores. Structural surveys thus allow for detailed structural evaluations.

Open-cut surveys are significant extensive surveys. They are implemented when it is absolutely necessary to identify the cause of damage or when the bearing capacity and other characteristics of underlying concrete pavement slabs are to be evaluated in detail. The results of structural surveys, used to determine whether the damage is road surface damage or structural damage, can be used as reference data for the selection and design of repair methods.

Table-3.2.8 lists the types of structural damage and the items and methods of structural damage surveys, showing survey items required for each damage type as needed. For the details of the survey method corresponding to each survey item, refer to the *Handbook of Pavement Survey and Test Methods*.

Table-3.2.8: Types of structural damage, survey items, and survey methods (concrete pavement)

Survey item	Survey method[Note 1)]	Damage type[Note 2)]						
		Cracking	Joint damage	Faulting	Rutting	Potholes	Scaling	Polishing
Deflection measurement with FWD (Subgrade and base course bearing capacities, load transfer rate, pavement soundness, etc.)	S046	○	○	○	-	-	-	-
Cutting core sampling (Crack depth measurement, locations of reinforcements, density, etc.)	S002	○	△	○	-	-	-	-
Open-cut surveys (Subgrade and base course bearing capacities, lateral shapes of each layer, conditions of concrete pavement slabs, strength, etc.)	S002	△	△	△	-	-	-	-

Note 1) The codes listed in the survey methods column are those used in the *Handbook of Pavement Survey and Test Methods*.
Note 2) ⊙ indicates a required survey item, ○ indicates a desirable survey item, and △ indicates a survey item performed whenever necessary.

(3) Guidelines for deciding whether to implement structural surveys

Structural surveys should be implemented when the affected portion's damage in the depth direction or whether structural damage has occurred is difficult to determine based only on results of surface characteristics surveys.

The following indicate that a structural survey should be performed.

- The affected portion's damage in the depth direction is difficult to identify only from the results of the surface characteristics survey.
- Cracking or rutting accompanied by sinking has occurred, and the damage characteristics suggest the possibility of insufficient bearing capacity.
- Damage is categorized as M or H in accordance with the classification for selecting maintenance and repair methods (refer to "3-3 Evaluation").

(4) Example of a structural survey with FWD

As an example of a structural survey, **Figure-3.2.5** shows the survey results of measurement with FWD, **Photograph-3.2.1** shows measurement of an asphalt pavement surface with FWD, and **Photograph-3.2.2** shows measurement of a concrete pavement surface with FWD.

Measurement with FWD can determine the bearing capacities (as deflection) of asphalt and concrete layers, subgrade bearing capacity, equivalent remaining thickness, and the elastic moduli of asphalt and concrete layers. **Figure-3.2.5**, however, shows deflection D_0 occurring immediately below the FWD's loading point; such deflection is used as an index for evaluating the pavement's structural bearing capacity.

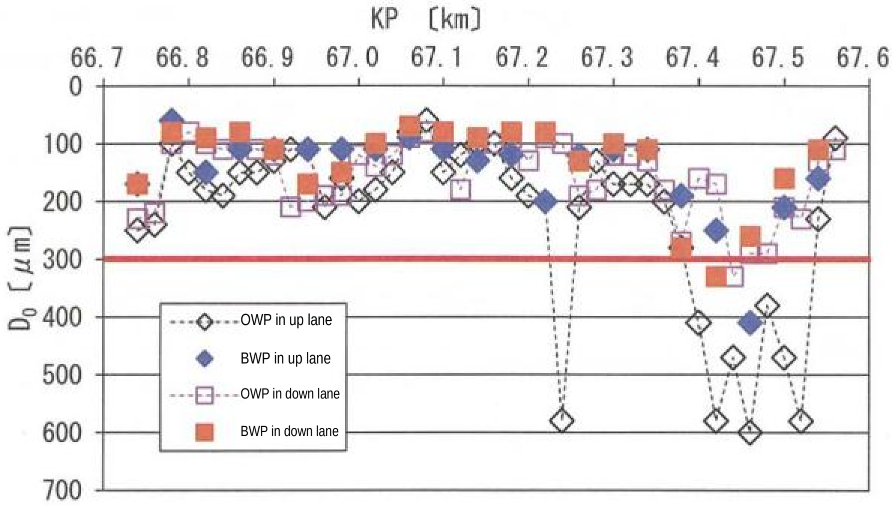


Figure-3.2.5: Example of survey results by FWD measurement (deflection)

Photograph-3.2.1: Measurement of asphalt pavement surface with FWD

Photograph-3.2.2: Measurement of concrete pavement surface with FWD

3-3 Evaluation

Major damage to asphalt pavement includes cracking, rutting, and reduction of surface roughness. Other damage includes faulting, potholes, and stripping. In addition to the aforementioned damage, porous asphalt suffers from aggregate scattering, void choking, void clogging, flow due to stripping of binder course, and other damage unique to this type. Major damage to concrete pavement includes cracking, and damage to joints (protrusion and scattering of joint filler, edge defects, and faulting). Other damage to concrete includes rutting, potholes, scaling, and polishing.

Such pavement damage is caused by various factors, such as service use fatigue, materials, design, and construction. These factors often affect each other, regardless of damage types (damage occurrence modes). In order to determine whether maintenance and repair are necessary, or to select and design maintenance and repair methods, it is essential to ascertain the conditions and causes of damage to precisely evaluate pavement conditions. For details of the major modes and causes of pavement damage, refer to “Appendix 4: Modes of Damage to Asphalt Pavement and Causes Thereof” and “Appendix 5: Modes of Damage to Concrete Pavement and Causes Thereof.”

This section describes how to evaluate pavement condition methods based on the results of pavement surveys.

3-3-1 Damage classification and evaluation classes

Pavement damage is roughly classified into road surface damage and structural damage. Road surface damage is caused by conditions present in the surface or only affecting the road surface portions. Structural damage develops in the binder or layers underneath, or under the concrete slab, and affects the surface or binder, or it develops from road surface damage, directly disturbing the pavement’s structure and function and thus affecting durability.

Road surface damage is often handled by maintenance. Road surface damage to asphalt is sometimes handled by surface or surface and binder maintenance. Since road surface damage may affect the structure while it is in service, maintenance should be performed as soon as possible. In contrast, structural damage not only affects the surface and binder and concrete slabs of asphalt, but also may reach as deep as its base and subgrade. Pavement structure and other factors are thus often examined to handle structural damage. It is therefore essential to refer to the pavement survey results to determine whether the damage is road surface or structural in nature and to consider an appropriate maintenance and repair method. Pavement damage should be classified as road surface damage or structural damage based on the occurrence modes, causes, and other factors according to Appendices 4 and 5.

3-3-2 Evaluation of damage

When discussing the necessity, design, and implementation of maintenance and repair, “cracking” and “rutting” are considered to be the major types of damage to asphalt, while “cracking” and “faulting at joints” are considered to be the major types of damage to concrete. Maintenance and repair methods for handling major damage are selected according to survey results. This section describes evaluation methods for major types of damage and the classifications (hereafter, classes for selecting a construction method L, M, and H), separately for asphalt and concrete. In addition, this section refers to damage other than major types as “other types of damage” and gives an overview of methods for evaluating such other types of damage as well as classes for selecting a construction method.

(1) Evaluation of asphalt pavement damage

1) Cracking

(I) Road surface survey evaluation

Road surface survey evaluation uses cracking levels determined by visual inspection and crack ratios determined by surface characteristics surveys to decide whether to implement maintenance and repair. Maintenance and repair methods are selected in consideration of damage inferred from cracks’ locations and modes, roadside environments, past construction records, and other factors.

A maintenance and repair method should be selected by referring to criteria for the classes for selecting a construction method listed in **Table-3.3.1**. **Photograph-3.3.1** shows example photographs for estimating crack ratios from the results of visual inspections.

For cracking portions classified as M or H, it is desirable to evaluate their conditions in the depth direction in detail by structural surveys and to select and design a repair method based on the results.

Table-3.3.1: Criteria for classes for selecting a construction method based on crack ratios

(a) Motorways

	L	M	H
Crack ratio (%)	Approx. 10 or lower	Approx. 10 to 20	Approx. 20 or higher

(b) Ordinary roads

	L	M	H
Crack ratio (%)	Approx. 15 or lower	Approx. 15 to 35	Approx. 35 or higher

Note 1: Classes L, M, and H are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.

Note 2: The values corresponding to L, M, and H have been determined based on the *Guidelines for Road Maintenance and Repair*, records of maintenance and repair activities, and other data.

Note 3: Different criteria are applied to porous asphalt.

Some cracking may be structural even when classified as class L. Whether damage is road surface or structural in nature is determined from the type and mode of cracking. **Table-3.3.2** shows cracking modes and damage classifications. Refer to this table when determining crack damage classifications. For a method for calculating the crack ratio, refer to "S029 Methods for measuring cracking on paved road surfaces" in the *Handbook of Pavement Survey and Test Methods*. For the details of cracking modes, cracking location examples, and other related matters, refer to Appendix 4.

Table-3.3.2: Cracking modes and damage classifications

Cracking mode		Damage classification	
		Road surface damage	Structural damage
Fatigue cracking	Linear cracking		⊙
Rutting	Linear cracking	⊙	○
Cracking at construction joints	Linear cracking	⊙	
Reflection cracking	Linear cracking		⊙
Cracking due to thermal stress	Linear cracking	○	○
Cracking due to decreased subgrade or base course bearing capacity	Alligator cracking		⊙
Cracking due to subgrade or base course settlement	Alligator cracking		⊙
Cracking due to asphalt mixture degradation and aging	Alligator cracking	○	○
Cracking due to frost heaving	Linear cracking		⊙
Cracking due to decreased subgrade or base course bearing capacity during thawing	Alligator cracking		⊙
Cracking around structures	Alligator cracking	○	○
Cracking due to binder course stripping	Alligator cracking	○	○

(Note) ⊙: Damage is highly likely to be classified into this category. ○: Damage may be classified as both categories.

Crack ratio: approx. 5%

Crack ratio: approx. 20%

Crack ratio: approx. 35%

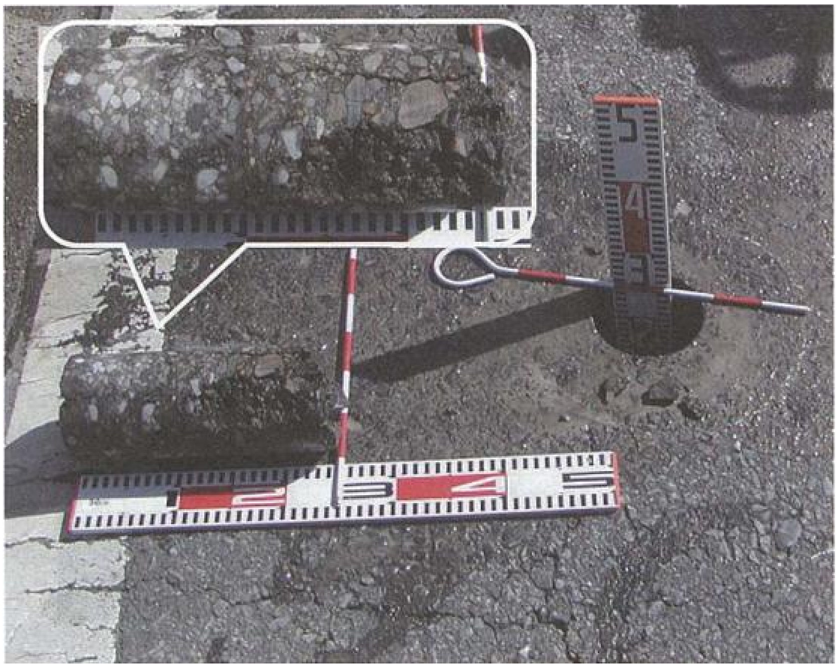
Photograph-3.3.1: Photographic examples of estimated crack ratios levels by visual inspection

(II) Evaluation based on structural surveys

Structural surveys of cracking portions are implemented to classify pavement damage more precisely as road surface or structural in nature. They include cutting core sampling, open-cut, deflection measurement with FWD, and evaluating the interior of asphalt and the condition of subgrade in detail. The following describes evaluation methods for existing asphalt by these structural surveys.

(i) Evaluation by core sampling and open-cut surveys

Core sampling and open-cut survey evaluation includes the following: 1. visual inspections to identify layers reached by cracks; 2. strength tests of asphalt mixtures and other materials; 3. measurement of asphalt amounts and degradations; 4. measurement of grading of asphalt mixtures and other materials. Causes of cracking are identified based on the results of these activities. **Photograph-3.3.2** shows an example of a cracking evaluation by core sampling.



Photograph-3.3.2: Example of fatigue cracking on asphalt pavement

In one case where damage was classified as non-structural, cores were sampled from portions that developed alligator cracking that was not accompanied by sinking. Evaluation of the sampled cores revealed various characteristics; for example, 1) most cracks were only on the surface, 2) the penetration of asphalt collected from the surface was markedly small, and 3) the strength of the binder mixture and properties of the collected asphalt mixture were normal. The damage was caused by degradation of the surface mixture and was judged to be road surface damage.

(ii) Evaluation based on deflection measured with FWD

Deflection measured by surveys with FWD can be used to evaluate pavement soundness. Deflection evaluation methods are classified roughly into methods for obtaining characteristic pavement values by substituting measured deflection into an empirical formula or other equation and methods for obtaining the elastic moduli of pavement layers.

i) Methods for obtaining characteristic pavement values

Bearing capacities of pavement and subgrade, equivalent remaining thickness, and the elastic modulus of asphalt mixture layers can be determined from measured deflection.

Whether the pavement damage is road surface or structural in nature is determined comprehensively from these characteristic values, surface characteristics survey results, and other data.

a) Pavement bearing capacity

Deflection (D_0) occurring immediately below loading points is used to evaluate the soundness of the pavement's bearing capacity. For example, if deflection D_0 is larger than 0.4 mm in pavement classified as traffic volume class N_6 shown in **Table-3.3.3**, the pavement will be judged to be lacking in bearing capacity.

Table-3.3.3: Allowable deflection corresponding to each traffic volume class[1)]

Traffic volume class	N_3	N_4	N_5	N_6	N_7
D_0 (mm)	1.3	0.9	0.6	0.4	0.3

[Note] D_0: Deflection occurring immediately below loading points

b) Subgrade bearing capacity

The CBR of subgrade can be estimated using Equation (3.3.1).[2)]

This equation is formulated from $E = 10/D_{150}$, a relational expression between the elastic modulus E of subgrade and D_{150}, and $E = 10 \times CBR$.

This equation thus may yield unrealistic values for certain soil types, such as sandy soil whose elastic modulus and CBR vary significantly depending on its moisture content and compaction level, and gravel soil having a CBR of 20% or higher.

$$CBR \text{ of subgrade } (\%) = \frac{1}{D_{150}} \qquad \cdots\cdots \qquad (3.3.1)$$

where, D_{150}: Deflection at a point 150 cm away from the loading point (mm).

c) Equivalent remaining thickness

The equivalent remaining thickness can be estimated using Equation (3.3.2).[3)] Equivalent remaining thickness (T_{A0}) refers to the remained value determined based on pavement's damage condition with respect to the equivalent thickness of the hot mixture for surface and binder courses. It is used as a reference value in "3-4-4 (1) 1) Design using equivalent remaining thickness (T_{A0})."

$$T_{A0} = -25.8\log\ (D_0 - D_{150}) + 11.1 \qquad \cdots\cdots \qquad (3.3.2)$$

where, T_{A0} : Equivalent remaining thickness (cm);
D_0 : Deflection occurring immediately below the loading point (mm); and
D_{150} : Deflection at a point 150 cm away from the loading point (mm).

d) Elastic moduli of asphalt mixture layers

The elastic moduli of asphalt mixture layers can be estimated using Equation (3.3.3).[3)] Estimated values can be used to evaluate layers' soundness.

The elastic moduli of normal asphalt mixture layers are said to be approximately 6,000 MPa at 20°C in general. Asphalt mixture layers are judged to be normal when their elastic moduli exceed this value.

$$E_{as} = \frac{2352 \times (D_0 - D_{20})^{-1.25}}{h_{as}} \quad \cdots\cdots \quad (3.3.3)$$

where, E_{as} : Elastic modulus of asphalt mixture layer (MPa);
D_0 : Deflection occurring immediately below the loading point (mm);
D_{20} Deflection at a point 20 cm away from the loading point (mm); and
h_{as} : Thickness of asphalt mixture layer (cm).

ii) Method for estimating the elastic modulus of each pavement layer

For known pavement structures, each layer's elastic modulus can be estimated based on measured deflection. This estimation is generally performed using inverse analysis programs.[4), 5)] The estimated elastic modulus of each layer is used to implement the following types of evaluations and other activities.

- Each pavement layer can be diagnosed by comparing its estimated elastic modulus with the typical elastic moduli of pavement materials.
- Structural design by theoretical design methods can be implemented based on estimated elastic moduli.
- Structural design can be implemented by estimating the coefficient of relative strength of each layer from its estimated elastic modulus and evaluating the equivalent remaining existing pavement thickness by an empirical design method.

2) Rutting

(II) Evaluation based on road surface surveys

Rutting evaluations based on road surface surveys are used to determine whether to implement maintenance and repair (based on the levels of rut depths estimated by visual inspection and rut depths obtained by surface characteristics surveys) and select maintenance and repair methods in consideration of the inferred causes of rutting from its shapes and occurrence modes, roadside environments, previous construction records, and other factors.

Maintenance and repair methods should be selected by referring to the criteria for classes for selecting a construction method listed in **Table-3.3.4**. **Table-3.3.5** relates the water accumulation and water splashing levels visually observed to estimation of rut depths. **Photograph-3.3.3** shows examples.

Selection of maintenance and repair methods, road surface design, and structural design are implemented as described in the following section based on the classes for selecting a construction method. For rutting portions classified as M or H, it is desirable to evaluate the conditions of the interior pavement in detail by structural surveys and to select and design a repair method based on the results.

Table-3.3.4: Criteria for classes for selecting a construction method based on rut depth

(a) Motorways

	L	M	H
Rut depth (mm)	Approx. 15 or less	Approx. 15 to 25	Approx. 25 or more

(b) Ordinary roads

	L	M	H
Rut depth (mm)	Approx. 20 or less	Approx. 20 to 35	Approx. 35 or more

Note 1: Classes L, M, and H are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.

Note 2: The values corresponding to L, M, and H have been determined based on the *Guidelines for Road Maintenance and Repair*, records of maintenance and repair activities, and other data.

Table-3.3.5: Criteria for rutting levels when evaluating by visual inspection (At a traveling speed of approx. 40 km/h)

Survey items	Classes for selecting a construction method (ordinary roads)		
	L Approx. 20 mm or less	M Approx. 20 to 35 mm	H Approx. 35 mm or more
Condition of water accumulation	Water has formed a moist film.	Some water has accumulated.	Water has obviously accumulated.
Water splashing level	Sprays of water are observed.	Small sprays of water are observed.	Large sprays of water are observed, reaching adjacent lanes or sidewalks.

Note: These criteria have been determined based on the *Handbook on Pavement Survey and Test Methods*, records of maintenance and repair, and other data.

Rut depth: approx. 15 mm

Rut depth: approx. 30 mm

Rut depth: approx. 40 mm

Photograph-3.3.3: Photographic examples of estimated levels of rut depths by visual inspection

Since rutting classified as class L may be structural damage in some cases, whether the damage is road surface or structural in nature is determined from rutting modes. **Table-3.3.6** lists rutting modes and damage classifications. Refer to this table when determining rutting damage classifications. For the rutting mode details, location examples of rutting, and other related matters, refer to Appendix 4.

Table-3.3.6: Rutting modes and damage classifications

Rutting mode	Damage classification	
	Road surface damage	Structural damage
Subgrade or base course compressive deformation		⊙
Asphalt mixture plastic deformation	⊙	○
Asphalt mixture abrasion	⊙	

(Note) ⊙: Damage is highly likely to be classified into this category. ○: Damage may be classified as both categories.

(II) Evaluation based on structural surveys

Structural surveys of rutting portions are implemented by more precise classification of pavement damage as road surface or structural in nature. They include cutting core sampling, open-cut, and evaluating the interior of asphalt and the condition of subgrade in detail. The following describes evaluation methods for rutting by these structural surveys.

Evaluation of rutting portions by core sampling and open-cut surveys includes the following: 1. identification of layers reached by rutting; and 2. judgment on whether the conditions of the base course and layers underneath have contributed to rutting. For example, rutting is classified into the following categories through observation of pavement cross-sections collected by care sampling and the open-cut method: 1. rutting caused by flow has formed only on the surface; 2. rutting caused by flow has reached as deep as the binder; and 3. rutting has been caused by settlement of the base course and layers underneath. Such evaluation results can be used as reference data to determine whether damage is road surface or structural in nature as well as to select repair methods and implement structural design.

3) Evaluation of other types of damage

Other types of asphalt damage include reduction of surface roughness, faulting, and potholes. Such damage is evaluated mainly based on the results of road surface surveys. The following lists some examples of evaluation methods for such damage. Whether to implement maintenance and repair for such damage should be determined based on the predetermined criteria for classes for selecting a construction method, trafficability during patrols, and other factors. Since portions suffering from partial damage, such as potholes, may have developed structural damage, structural surveys should be performed to select a repair method.

(I) Reduction of surface roughness

Surface roughness, which may cause bad ride quality, noise, and vibration when reduced, requires appropriate maintenance and administration. It is evaluated in terms of pavement’s longitudinal irregularity level. The surface roughness of long sections (e.g., with respect to longitudinal irregularities) should be evaluated by measuring with a device such as a 3-meter profilometer.

Reduced surface roughness is generally classified as road surface damage, but in some cases, it is classified as structural damage due to insufficient bearing capacity or other causes.

(II) Faulting

Faulting leads to bad ride quality and causes moving vehicles to generate noise and vibration, as well as structural damage in some cases.

Thus, it is essential to implement appropriate maintenance and administration on faulting on road surfaces, with consideration given to roadside environments, traffic conditions, and other factors. Emergency actions (e.g., maintenance) may be required if the faulting is serious.

Faulting is generally classified as road surface damage but, in some cases, it is classified as damage due to insufficient compaction of the base course and layers underneath or as structural damage.

(III) Potholes

Potholes not only cause bad ride quality but also may lead to traffic accidents. Emergency actions (e.g., maintenance) must be implemented as soon as any pothole is found.

Locations where potholes frequently occur may have developed structural damage, but potholes are generally classified as road surface damage. In porous asphalt pavement and bridge deck pavement, however, stripping of binder mixture causes potholes to form. In bridge deck pavement, blistering sometimes develops into potholes. Repair methods for handling potholes should therefore be selected based on the results of structural surveys (e.g., core sampling).

(IV) Stripping

When stripping has started, the fine-grained fraction of filler, fine aggregate, or other materials often oozes onto pavement surfaces as seen in **Photograph-3.3.4**. Cutting core sampling or open-cut should be performed to check whether stripping has started or not as soon as such phenomena are observed.

Whether stripping has started is technically judged on-site based on the results of visual inspection of conditions and other road surface aspects, sampled cores, open-cut cross sections, water resistance evaluation by strength tests on sampled mixtures, and measurement of the amounts and grading of asphalt by extraction tests.

When porous asphalt mixture is used in surface courses, the insufficient water resistance of the binder mixture may lead to early surface damage. The water resistance performance of binder courses should thus be confirmed in advance by laboratory tests.

Photograph-3.3.4: Oozing of fine-grained fraction of filler, fine aggregate, etc. onto pavement

(V) Polishing

Reduced skid resistance may lead to traffic accidents. Where polishing has developed, reduced skid resistance must be evaluated by measuring skid resistance in nearby areas. **Table-3.3.7** lists criteria for classes for selecting a construction method based on skid resistance (surface characteristics surveys) measured when polishing is observed on roads at a traveling speed of 60 km/h. The criteria have been determined based on skid resistance measured with a skid resistance measuring vehicle. For skid resistance measured with other devices, refer to *Pavement Performance Evaluation Methods — Essential and Principal Performance Indices—* (2013 edition).

Polishing is generally classified as road surface damage.

Table-3.3.7: Criteria for classes for selecting a construction method based on skid resistance

Measurement method	Level of reduction in skid resistance (skid resistance coefficient: μ60)	
	M	H
Skid resistance measuring vehicle	Approx. 0.25 to 0.33	Approx. 0.25 or less

Note 1: Classes M and H are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.

Note 2: The values corresponding to M and H have been determined based on the *Guidelines for Road Maintenance and Repair*, records of maintenance and repair activities, and other data.

(VI) Corrugation

The level of damage due to corrugation is evaluated from the viewpoints of irregularities and their occurrence scale (area). However, no clear criteria have been defined for judging whether to implement maintenance and repair. Such judgment is made based on trafficability for patrol cars and other data.

Corrugation is generally classified as road surface damage (refer to “Attached photograph-3.2.19: Example of corrugation” in Appendix 4).

(VII) Depressions

The level of damage due to depressions in asphalt pavement is evaluated from road surface sinking and its occurrence scale (area). However, no clear criteria have been defined for judging whether to implement maintenance and repair. Such judgment is made based on trafficability for patrol cars and other data.

Depressions are generally classified as road surface damage. However, since they may be accompanied by binder course deformation, a maintenance and repair method should be selected based on measured data, such as each layer’s thickness measured by core sampling (refer to “Attached photograph-3.2.21: Example of depressions” in Appendix 4).

(VIII) Bumps

The level of damage due to bumps on asphalt pavement is evaluated from the rise in the road surface and its occurrence scale (area). However, no clear criteria have been defined for judging whether to implement maintenance and repair. Such judgment is made based on trafficability for patrol cars and other data (refer to “Attached photograph-3.2.20: Example of bumps” in Appendix 4).

Bumps are generally classified as road surface damage. However, since they may be accompanied by binder course deformation, a maintenance and repair method should be selected based on measured data such as each layer’s thickness measured by core sampling.

(IX) Road surface collapse

Road surface collapse not only damages roads but may also paralyze road functions and roadside environments, leading to accidents harmful to humans. In particular, administration of underground portions to detect cavities is essential to prevent road surface collapse. Since cavities have various causes, such as deterioration and degradation of buried objects and natural phenomena, effective and efficient measures should be implemented to prevent collapse by combining visual inspection through everyday road patrols and cavity surveys with an underground cavity-detecting vehicle.

Levels of underground cavities are evaluated based on the position data of abnormal signals from cavities and other data obtained by electromagnetic radar and information related to the pavement, such as foundations, groundwater levels, pavement structures, underground objects, previous construction records, and traffic volume.

4) Evaluation of damage unique to porous asphalt pavement

Damage unique to porous asphalt pavement includes aggregate scattering, void choking, void clogging, and partial bumps (lateral flow).

(I) Aggregate scattering

No survey method has been established for aggregate scattering, and thus no evaluation method has been established either.

Aggregate scattering may progress into potholes, lead to vibration and noise when vehicles travel over it, and damage traveling or parked vehicles. Appropriate maintenance and administration must be implemented in consideration of roadside environments, traffic conditions, and other factors.

Aggregate scattering is generally classified as road surface damage.

(II) Void choking and void clogging

No direct method for quantitative field measurement of the levels of void choking and void clogging in porous asphalt pavement has been established, and thus no evaluation method has been established either.

Whether void plugging has occurred is generally judged based on the results of visual inspection, the amount of seepage water measured by field permeability tests, noise levels measured with a tire-road surface noise measuring vehicle, and other data. However, the relationship between void plugging and the amount of seepage water or noise levels has yet to be elucidated.

Whether void plugging has been caused by void choking or void clogging is generally determined based on the results of a visual inspection or observation of sampled cores.

Void choking and void clogging are generally classified as road surface damage.

(III) Partial bumps (lateral flow)

Whether partial bumps have been caused by insufficient bonding between the surface and binder courses or stripping of the binder course must be determined through comprehensive surveys, including visual inspections and mixture tests performed on samples collected by open-cut surveys and core sampling.

For example, when surface and binder courses are not bonded in sampled cores despite the fact that the binder course mixture has a sufficient thickness, insufficient bonding between the surface and binder courses can be regarded to be the cause of partial bumps.

If binder course materials are judged to be insufficient in terms of water resistance when performing the water resistance evaluation described in "(V) Stripping, 3) Evaluation of other types of damage," it is necessary to consider a construction method that will prevent water from spreading into the binder course as well as maintenance and repair of the portion including the binder course.

If stripping or plastic deformation is observed in the binder course as illustrated in **Attached Figure-3.2.6**, the binder course can be judged to be substantially damaged. In such a case, the portion including the binder course must be repaired.

(2) Evaluation of damage to concrete pavement

1) Cracking

(I) Evaluation based on road surface surveys

Cracking evaluation based on road surface surveys employs cracking levels determined by visual inspections and cracking index values obtained by surface characteristics surveys to determine whether to perform maintenance and repair. Maintenance and repair methods are selected by considering damage causes presumed from the locations and modes of cracks, roadside environments, past construction records, and other factors.

A maintenance and repair method should be selected by referring to the criteria for classes for selecting a construction method listed in **Table-3.3.8**. **Photograph-3.3.1** shows reference photographs for estimating the level of the cracking index from the results of visual inspection.

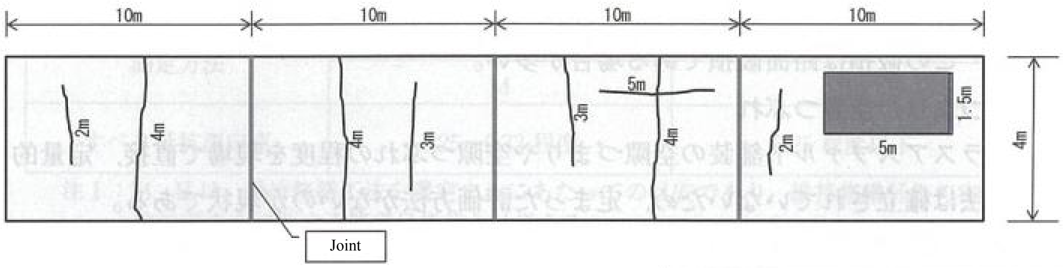
For cracking portions classified as M or H, it is desirable to evaluate their conditions in detail in the depth direction by performing structural surveys and to select and design a repair method based on the results.

Table-3.3.8: Criteria for classes for selecting a construction method based on the cracking index (ordinary roads)

	L	M	H
Cracking index (cm/m^2)	Approx. 30 or lower	Approx. 30 to 50	Approx. 50 or higher

Note 1: Classes L, M, and H are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.

Note 2: The values corresponding to L, M, and H have been determined based on the *Guidelines for Road Maintenance and Repair*, records of maintenance and repair activities, and other data.



$$\text{Cracking index } (cm/m^2) = \frac{\text{Sum of crack lengths } (cm) + \dfrac{\text{Patching area } (m^2) \times 100}{0.3(m)}}{\text{Area of the section subject to survey } (m^2)}$$

Area surveyed : $4 \times 10 \times 4 = 160$ (m^2)
Transverse cracking : $(2+4+4+3+3+4+2) \times 100 = 2,200$ (cm)
Longitudinal cracking : $5 \times 100 = 500$ (cm)
Patching area : $1.5 \times 5 = 7.5$ (m^2)

Cracking index
$(2,200+500+7.5 \times 100/0.3)/160 = 32.5$ (cm/m^2)
(Class for selecting a construction method: M)

Figure-3.3.1: Example of cracking evaluation by visual inspection

The level of damage due to cracks can be evaluated by analyzing the widths and lengths of cracks as well as the widths of edge defects based on the results of surface characteristics surveys. **Table-3.3.9** lists criteria for classes for selecting a construction method based on transverse cracking in ordinary concrete pavement and roller compacted concrete pavement.

**Table-3.3.9: Criteria for classes for selecting a construction method based on transverse cracking[6)]
(Ordinary concrete or roller-compacted concrete pavement)**

Class for selecting a construction method	Criteria
L	Crack widths are approx. 3 mm or less without edge defects or faulting.
M	Crack widths are approx. 3 to 6 mm with edge defect widths approx. 75 mm or less and faulting approx. 6 mm or less.
H	Crack widths are approx. 6 mm or more with edge defect widths approx. 75 mm or more or faulting approx. 6 mm or more.

Note: Classes L, M, and H are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.

For concrete pavement, some types of cracking in some occurrence modes may be structural damage even when classified as class L. Whether damage is road surface damage or structural damage is determined from the occurrence conditions and other conditions of cracks. **Table-3.3.10** shows cracking modes and damage classifications. Refer to this table when determining crack damage classifications. For the details of cracking modes in concrete pavement, examples of cracking locations, and other related matters, refer to Appendix 5.

Table-3.3.10: Cracking modes and damage classifications

Cracking mode	Damage classification	
	Road surface damage	Structural damage
Transverse cracking	-	⊙*
Longitudinal cracking	-	⊙
Y-shaped or cluster-type cracking**	⊙	○
Edge cracking	-	⊙
Durability cracking (hereafter, D-Cracking)	⊙	○
Sheet and alligator cracking	-	⊙
Cracking due to drying	⊙	-
Arc cracking	○	⊙
Setting shrinkage cracking	⊙	-
Irregular (restricted) cracking	○	⊙

(Note) ⊙: Damage is highly likely to be classified into this category.
○: Damage may be classified as both categories.
*: Except for continuously reinforced concrete pavement
**: Type of cracking unique to continuously reinforced concrete pavement

Continuously reinforced concrete pavement is designed to suppress cracks to widths of 0.5 mm or less through the aid of longitudinally arranged reinforcements by dispersing crack development caused by drying shrinkage and temperature changes in concrete. Large crack widths due to edge defects in cracking portions on pavement surfaces accordingly do not generally lead to structural problems. Thus, in many cases, transverse cracking in continuously reinforced concrete pavement is not included in damage as classified above. However, edge defects in cracking portions may grow and expand to adversely affect the traveling performance and safety of vehicles or cause large amounts of noise to be generated by traveling vehicles. Decreases in the load transfer rate in cracking portions sometimes increase slab deflection and expand cracking widths, consequently causing edge defects to grow. Therefore, the progress of edge defects due to transverse cracking must be observed and evaluated.

(II) Evaluation based on structural surveys

Types of structural surveys of cracking portions include core sampling, open-cut, and deflection measurement with FWD. The internal conditions of concrete slabs (the level of corrosion of steel and reinforcements and the conditions of concrete slab bottoms) can be ascertained by core sampling. The condition of the portion below concrete slabs (e.g., the presence or absence of cavities), the load transfer performance of the cracking portions, and other properties can be observed by deflection measurement with FWD. Deflection of 0.4 mm or less in response to a load of 49-kN is generally adopted as the criterion for cavity detection performed after maintenance and repair of cavities below concrete slabs. Deflection D_0 measured with FWD can thus be used as a criterion for judging whether there are cavities below concrete slabs. Load transfer is effective when the load transfer rate is 80% or higher. If it is 65% or lower, the dowel bars may be damaged, the base course's bearing capacity may have decreased, or cavities may be present. **Figure-3.3.2** illustrates an evaluation workflow for transverse cracking portions based on deflection and the load transfer rate. **Figure-3.3.3** illustrates how to measure the load transfer rate with FWD.

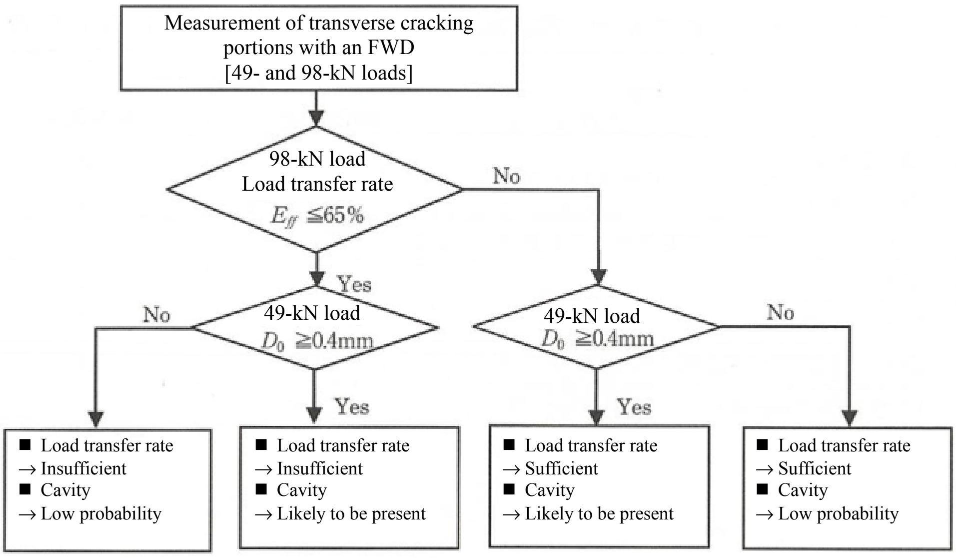
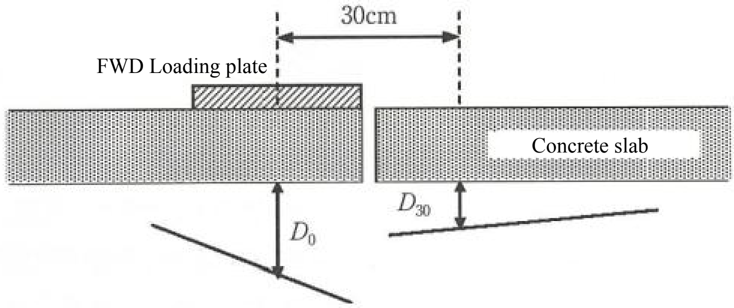


Figure-3.3.2: Evaluation workflow for transverse cracking portions based on deflection and the load transfer rate[7), 8)]



$$E_{ff} = \frac{D_{30}}{(D_0+D_{30})\ /2} \times 100\ (\%)$$

E_{ff} : Load transfer rate (%)
D_0 : Deflection immediately below the loading point (mm)
D_{30} : Deflection 30 cm away from the loading point (mm)

Figure-3.3.3: How to measure the load transfer rate with FWD[8)]

2) Faulting at joints and in cracking portions

(I) Evaluation based on road surface surveys

Methods for maintenance and repair of faulting on concrete pavement at its joints and in its cracking portions should be selected based on the amount of faulting measured during surface characteristics surveys. **Table-3.3.11** lists criteria for classes for selecting a construction method based on the amount of faulting. When classified as M or H, the presence or absence of cavities, the load transfer rate, and other properties should be evaluated for the faulting portions by structural evaluation, including deflection measurement with FWD.

Table-3.3.11: Criteria for classes for selecting a construction method based on the amount of faulting

	L	M	H
Amount of faulting (mm)	Approx. 10 or less	Approx. 10 to 15	Approx. 15 or more

Note 1: Classes L, M, and H are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.

Note 2: The values corresponding to L, M, and H have been determined based on the *Guidelines for Road Maintenance and Repair*, records of maintenance and repair activities, and other data.

Causes of concrete pavement faulting are presumed based on the locations and occurrence modes of faulting, roadside environments, maintenance and repair records, and other factors. For reference, **Table-3.3.12** lists criteria for classes for selecting a construction method based on the results of evaluation by visual inspection of joints and cracking portions.

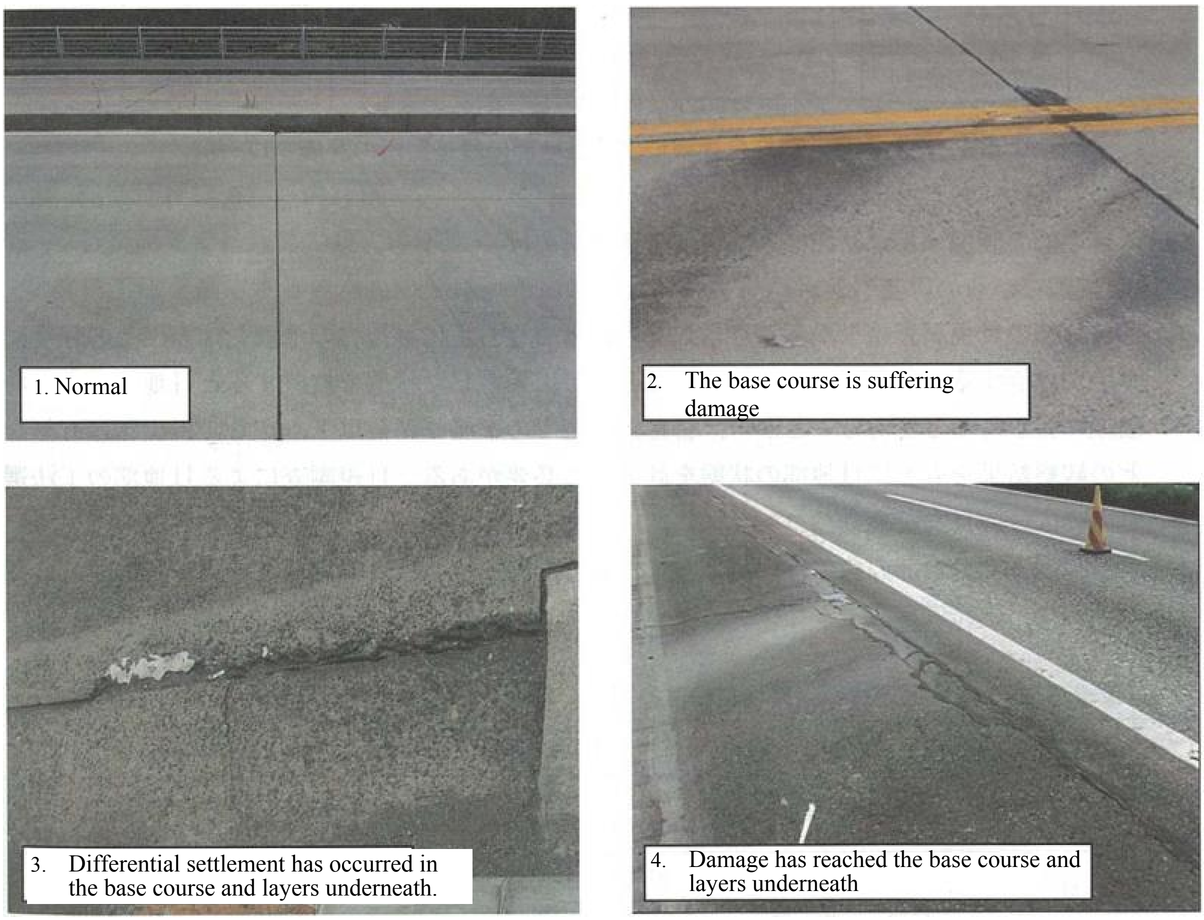
Faulting in joints suggests the base course or portion under the base course may be damaged. Thus, in such cases, it is essential to ascertain the detailed conditions of faulting portions by surface characteristics surveys and structural surveys as well as to implement appropriate actions.

Table-3.3.12: Conditions (faulting and pumping) of joints and cracking portions as well as criteria for classes for selecting a construction method

Faulting	Pumping*	Damage level		Class for selecting a construction method
No	No	Normal	(Refer to **Photograph-3.3.5**-1.)	-
	Yes	The base course is suffering damage.	(Refer to **Photograph-3.3.5**-2.)	L
Yes	No	Differential settlement has occurred in the base course and layers underneath.	(Refer to **Photograph-3.3.5**-3.)	M
	Yes	Damage has reached the base course and layers underneath.	(Refer to **Photograph-3.3.5**-4.)	H

* For the definition of pumping, refer to Appendix 5.

Note: Classes L, M, and H are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.



1. Normal

2. The base course is suffering damage

3. Differential settlement has occurred in the base course and layers underneath.

4. Damage has reached the base course and layers underneath

Photograph-3.3.5: Examples of joint conditions

(II) Evaluation based on structural surveys

The presence or absence of cavities in faulting portions at joints should be determined by using this criterion: deflection of 0.4 mm or less in response to a 49-kN load. The load transfer rate in the faulting portions should be evaluated in accordance with the following examples: 1. load transfer is effective when the load transfer rate is 80% or higher; 2. load transfer is insufficient if the load transfer rate is 65% or lower. **Figure-3.3.4** depicts an evaluation workflow for faulting portions at joints based on deflection and the load transfer rate.

Methods for maintenance and repair of concrete pavement faulting are selected based on the results of these surveys.

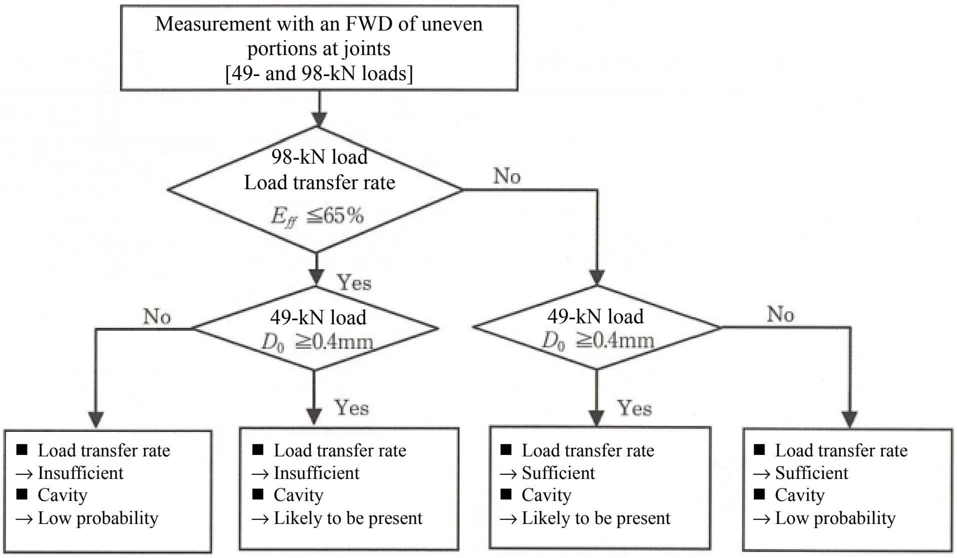


Figure-3.3.4: Evaluation workflow for faulting portions at joints based on deflection and the load transfer rate[7), 8)]

3) Damage to joints (protrusion/scattering of joint filler and edge defects)

(I) Evaluation based on visual inspection

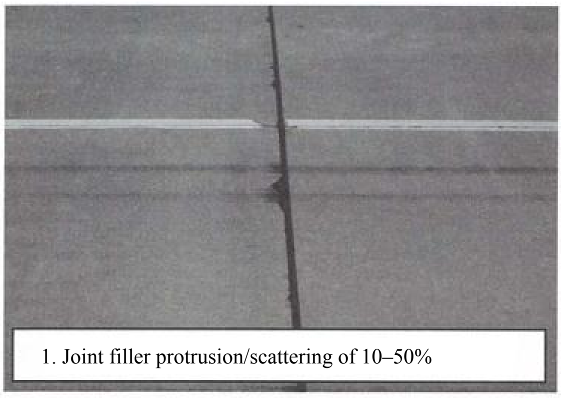
Damage to joints, particularly the scattering and protrusion of joint filler, is evaluated based on the results of visual inspection of joints. Scattering and protrusion of joint filler may result in substantial damage to joints if left unattended. Therefore, joint conditions must be evaluated based on observation results, such as whether there is any ooze from lower layers (under the base course) near joints. **Table-3.3.13** lists criteria for classes for selecting a construction method based on visual inspection of joints.

If edge defects are detected by visual inspection, surface characteristics surveys should be performed to ascertain the details.

Table-3.3.13: Criteria for classes for selecting a construction method based on joint conditions (protrusion/scattering of joint filler)[9)]

Class for selecting a construction method	Criteria (protrusion/scattering of joint filler and surface discoloration near joints)
L	Protrusion/scattering of joint filler is less than 50%. No surface discoloration is observed (**Photograph-3.3.6**-1).
M	Protrusion/scattering of joint filler is 50% or more. Surface discoloration is observed (**Photograph-3.3.6**-2).

Note: Classes L, M, and H are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.



1. Joint filler protrusion/scattering of 10–50%

2. Joint filler protrusion/scattering of 50% or more

Photograph-3.3.6: Examples of damage to joints

(II) Evaluation based on surface characteristics surveys

When edge defects are detected by visual inspection, surface characteristics surveys must be performed to evaluate them. A maintenance and repair method should be selected based on the lengths and widths of the edge defects measured in surface characteristics surveys by referring to **Table-3.3.14**.

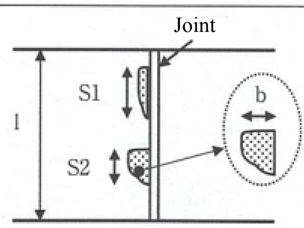
Table-3.3.14: Criteria for classes for selecting a construction method based on edge defects at joints[9)]

Class for selecting a construction method	Criteria
L	Widths of edge defects are less than 150 mm, or the edge defect rate is less than 50%.
M	Widths of edge defects are 150 mm or more, or the edge defect rate is 50% or higher.

<Remarks>

l: Joint length (cm) S: Edge defect length (cm)
b: Edge defect width (mm)

$$\text{Edge defect rate (\%)} = \frac{\text{Sum of edge defect lengths (S1 + S2)}}{\text{Joint length}} \times 100$$



Note: Classes L and M are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.

4) Other types of damage to concrete pavement

Other types of damage to concrete pavement include rutting, potholes, and polishing. Such damage is evaluated mainly based on the results of road surface surveys. The following are examples of evaluation methods. Whether to perform maintenance and repair on these other types of damage should be determined based on the predetermined criteria for classes for selecting a construction method, maneuverability during patrols, and other factors.

(I) Rutting

Rutting evaluations based on road surface surveys are used to determine whether to perform maintenance and repair based on rutting levels estimated by visual inspection and rut depths obtained by surface characteristics surveys as well as to select a maintenance and repair method by considering the causes of rutting presumed from its shapes and occurrence modes, roadside environments, previous construction records, and other factors.

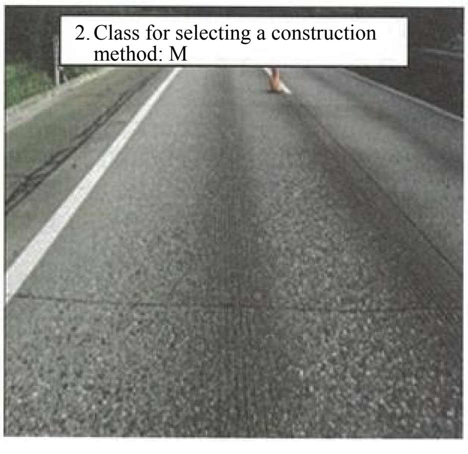
The results of visual inspections of rutting should be evaluated based on the results of visual observation and observation during vehicle traveling in consideration of the safety and ride quality of traveling vehicles, effects on roadside environments and adjacent lanes, and other factors. Evaluation results are used to determine whether to perform emergency maintenance and repair as well as whether to surface characteristics surveys.

In rutting evaluations based on visual inspections, a maintenance and repair method is selected based on rut depths estimated from the rutting and service conditions. **Table-3.3.15** lists criteria for classes for selecting a construction method based on rutting levels observed by visual inspection. When rutting is classified as M or H, it is desirable to carry out surface characteristics surveys to quantitatively it. However, rutting is rarely classified as M or H in Japan, where the use of spike tires is prohibited.

Table-3.3.15: Criteria for estimating rutting levels by visual inspection (Traveling speed: approx. 40 km/h)

Survey item	Class for selecting a construction method (ordinary roads)		
	L Approx. 20 mm or less	M Approx. 20 to 35 mm	H Approx. 35 mm or larger
State of water accumulation	Water has formed a moist film.	Some water has accumulated.	Water has obviously accumulated.
Water splashing level	Sprays of water are observed.	Small sprays of water are observed.	Large sprays of water are observed, reaching adjacent lanes or sidewalks.
Sample photographs	**Photograph-3.3.7**-1	**Photograph-3.3.7**-2	-

Note: These criteria have been determined based on the *Handbook on Pavement Survey and Test Methods*, records of maintenance and repair, and other data.



Photograph-3.3.7: Examples of rutting levels

Table-3.3.16 lists criteria for classes for selecting a construction method based on rut depths determined by surface characteristics surveys. Selection of maintenance and repair methods, road surface design, and structural design are performed as described in the following section based on the classes for selecting a construction method.

Table-3.3.16: Criteria for classes for selecting a construction method based on rut depths

(a) Motorways

	L	M	H
Rut depth (mm)	Approx. 15 or less	Approx. 15 to 25	Approx. 25 or larger

(b) Ordinary roads

	L	M	H
Rut depth (mm)	Approx. 20 or less	Approx. 20 to 35	Approx. 35 or larger

Note 1: Classes L, M, and H are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.
Note 2: The values corresponding to L, M, and H have been determined based on the *Guidelines for Road Maintenance and Repair*, records of maintenance and repair activities, and other data.

(II) Polishing (decreasing skid resistance)

Polishing decreases the skid resistance of concrete pavement slabs, adversely affecting the safety of traveling vehicles. Thus, quick action is required if polishing is detected.

Table-3.3.17 lists criteria for classes for selecting a construction method based on skid resistance (surface characteristics surveys) measured when polishing is observed on roads with a traveling speed of 60 km/h. The criteria were determined based on measurements of skid resistance with a skid resistance measuring vehicle. When measuring skid resistance with other devices, refer to *Pavement Performance Evaluation Methods —Essential and Principal Performance Indices—* (2013 edition).

Polishing is generally classified as road surface damage.

Table-3.3.17: Criteria for classes for selecting a construction method based on skid resistance

Measurement method	Level of decrease in skid resistance (skid resistance coefficient: μ60)	
	M	H
Skid resistance measuring vehicle	Approx. 0.25 to 0.33	Approx. 0.25 or less

Note 1: Classes M and H are used as criteria for selecting maintenance and repair methods. They differ from the target administrative values used to determine whether to perform maintenance and repair.
Note 2: The values corresponding to M and H have been determined based on the *Guidelines for Road Maintenance and Repair*, records of maintenance and repair activities, and other data.

(III) Potholes

The level of damage due to potholes is evaluated mainly by visual inspection. Potholes not only adversely affect vehicles' traveling performance and ride quality but may also cause traffic accidents. Thus, quick action is required if potholes are detected. Potholes are generally classified as road surface damage.

3-4 Design

In this section, design refers to the series of the following activities: surveying and evaluating sections extracted for maintenance and repair; (1) defining performance indices by examining performance requirements and (2) analyzing the results of damage level evaluation and presuming damage causes based on the data obtained by such surveys and evaluations; and determining the portion of concrete upon which to carry out maintenance and repair based on the results of (1) and (2) above.

Road surface design and structural design (including present condition, surveys, evaluations, and selection of construction methods) can be considered to be the implementation plan for maintenance and repair.

In actual design under some road conditions or to satisfy some required performance levels, matters such as maintenance sections and construction methods may be determined without defining performance indices, regardless of (1) and (2) above. Even in such cases, however, present condition of road surfaces and examination of required performance are always important. It is desirable to establish evaluation and design procedures appropriate to the areas of the relevant roads by accumulating data on design processes and road surface evaluations related to the roads and to standardize the procedures for maintenance and repair over wider areas.

This section considers the series of procedures in maintenance and repair implementation plans to be "design" and describes various construction methods for handling different damage levels, required performance specifications, road surface design, and structural design.

3-4-1 Types of maintenance and repair methods and selection of methods appropriate to damage levels

Prior to maintenance and repair, damage classification (whether road surface damage or structural damage) and damage level evaluation must be appropriately performed based on survey results, and damage causes must be identified. It is important to select an appropriate maintenance and repair method to remove and eliminate any identified causes. **Figure-3.4.1** shows an example of this process for asphalt pavement. As indicated in this example, damage must be evaluated not only in the transverse and longitudinal directions but also in the depth direction; through this, the portions subject to maintenance and repair must be determined. Since different methods have different characteristics in terms of quality, cost, environmental impact, durability, and other aspects, it is essential to select a maintenance and repair method after giving consideration to the effectiveness of the portions' combinations and characteristics. Repair of the binder course and layers underneath may be performed even in the event of road surface damage.

Maintenance and repair methods for daily service roads should be selected by considering these matters as well as traffic volume and roadside environments.

The following lists typical maintenance and repair methods for asphalt and concrete pavement as well as examples of performing selection based on the results of damage level evaluation.

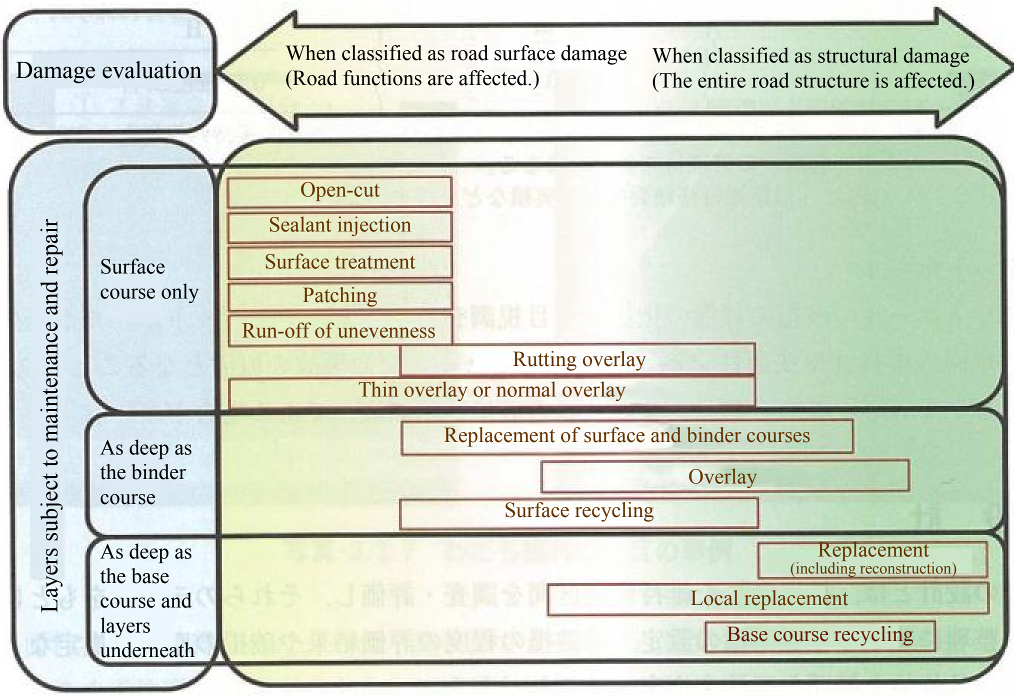


Figure-3.4.1: Examples of application of maintenance and repair methods to asphalt pavement (diagram prepared based on Reference 10)

(1) Asphalt pavement

Table-3.4.1 lists major maintenance and repair methods for asphalt pavement.

Table-3.4.1: Overview of maintenance and repair methods for asphalt pavement[10)]

Method	Overview
Patching and run-off of faulting	• Fills potholes, depressions, faulting, etc. in emergencies. • Uses hot/cold mixtures based on bituminous or resin binder, etc. as pavement materials.
Sealant injection	• Fills relatively wide cracks with joint-sealing compound, etc. • Sometimes performed as a preventive maintenance method. • Generally uses hot compound as filler. Other types used include emulsion, cutback, and resin, etc. • Uses materials appropriate for crack widths and depths.
Cutting	• Cuts and removes protrusions, etc. on road surfaces to eliminate unevenness and faulting. • Often performed as overlay pretreatment or surface treatment.
Surface treatment	• Forms a sealing layer thinner than 3 cm on pavement. • Sometimes used as a preventive maintenance method.
Washing of void choking	• Recovers the draining and noise reduction functions of porous asphalt pavement, etc. by removing mud and dust, etc. captured in its voids. • Captured matter is removed by spraying pressurized water toward pavement to wash off the matter or other approaches. • This method is considered effective when performed before pavement function declines substantially.
Thin overlay	• Placing of hot mixture thinner than 3 cm on pavement. • Sometimes performed as a preventive maintenance method for wearing courses, etc.
Rutting overlay	• Placing of hot mixture thinner than 3 cm only on the rutting portions of pavement. • Applied mainly to portions worn by abrasion, etc.; unsuitable for portions with rutting formed by flows. • Often performed as leveling before overlay.
Replacement (Including reconstruction)	• Replaces all or part of existing pavement's base course. • Replacement and stabilization of subgrade or base course are sometimes performed.
Local replacement	• Used to locally replace the surface course, binder course, or base course if it is judged that maintenance of existing pavement that has been locally substantially damaged cannot be achieved by other methods. • Generally performed on portions that have developed large local cracks when performing replacement of surface and binder courses or overlay.
Overlay	• Placing of hot mixture 3 cm of thicker on pavement. • If local defective portions are included, local replacement, etc. will be performed first.
Replacement of surface and binder courses (Mill and overlay)	• Replaces pavement layers as deep as surface or binder course. • The method is called mill and overlay when removing asphalt mixture layers by cutting.
Base course recycling	• Uses a road stabilizer or other device to crush asphalt mixture layers on-site; to mix crushed materials with cement, asphalt emulsion, and other additional materials; and to compact the mixture to construct stabilized base course.
Surface recycling	• Scarifies and loosens asphalt mixture layers on-site while heating them, mixes the loosened materials with additional asphalt mixture and rejuvenators whenever necessary, and spreads and compacts the materials to reconstruct surface courses.

Maintenance and repair methods for asphalt pavement must be selected so as to minimize pavement waste based on damage levels and classifications by considering section design. If multiple types of damage are involved, the characteristics and levels of each type of damage must be considered to determine whether to apply one method to all damage types, to apply different methods to each damage type, or to combine approaches. However, it is desirable to apply the same method to each 200-m section whenever possible. **Table-3.4.2** lists types of damage to asphalt pavement and guidelines for selecting maintenance and repair methods according to the classes for selecting a construction method. For the details of each method, refer to Chapter 4. Symbols L, M, and H in **Table-3.4.2** correspond to the classes for selecting a construction method described in "3-3 Evaluation." For some damage types, the available methods may be restricted.

Table-3.4.2: Types of damage to asphalt pavement and guidelines for selecting maintenance and repair methods according to the classes for selecting a construction method

Damage to asphalt pavement \ Maintenance and repair method		Damage classification	Maintenance method							Repair method					
			Patching and run-off of faulting	Sealant injection	Open-cut	Surface treatment	Washing of void choking	Thin overlay	Rutting overlay	Replacement	Local replacement	Overlay	Replacement of surface and binder courses (Open-cut overlay)	Base course recycling	Surface recycling
Cracking	● Linear cracking • Fatigue cracking • Rutting • Cracking at construction joints • Reflection cracking • Cracking due to thermal stress • Cracking due to frost heaving	Road surface damage/ Structural damage		L, (M)						M, H	L, M	M, H	M, H	M, H	M, H
	● Alligator cracking • Cracking due to decrease in bearing capacity or settlement of subgrade or base course • Cracking due to stripping of binder course	Road surface damage/ Structural damage	L, M							M, H	L, M		M, H	M, H	
	● Cracking due to frost heaving and thawing	Structural damage		L, M						M, H	L, M			M, H	M
	● Cracking due to degradation or aging of asphalt mixtures	Road surface damage/ Structural damage	L			M, H		M, H					M, H		M, H
	● Cracking around structures	Road surface damage/ Structural damage	○	○							⊙				
Rutting	Rutting due to compressive deformation of subgrade or base course	Structural damage	L			L		L, M		M, H	M, H			M, H	
	Rutting due to plastic deformation of asphalt mixtures	Road surface damage/ Structural damage	L		M	L		L, M				M, H	M, H		M
	Rutting due to abrasion of asphalt mixtures	Road surface damage	L			L		L, M	M, H			M, H	M, H		M
Decrease in surface roughness	Longitudinal irregularities	Road surface damage/ Structural damage	○					○		⊙		○	○	⊙	○
Other types of damage	Faulting	Road surface damage/ Structural damage	○		○						⊙				
	Potholes	Road surface damage/ Structural damage	○								⊙				
	Stripping	Road surface damage/ Structural damage								⊙	⊙		○, ⊙		
	Polishing (decreased skid resistance)	Road surface damage				M, H		H				H	H		H
	Corrugation	Road surface damage						○				○	○		
	Depressions	Road surface damage/ Structural damage	○								⊙				
	Bumps	Road surface damage/ Structural damage	○		○						⊙		○, ⊙		
Damage unique to porous asphalt pavement	Scattering of aggregates	Road surface damage	○			○							○		
	Void choking	Road surface damage					○						○		
	Void clogging	Road surface damage											○		
	Partial bumps (lateral flow)	Structural damage									⊙		⊙		
Remarks	L, M, and H : Classes for selecting a construction method (M) : Method applied only to road surface damage ○ : Method applied to road surface damage ⊙ : Method applied to structural damage														

(Note) The symbols used in this table denote classes for selecting a construction method to use for selecting maintenance and repair methods and do not indicate the necessity of performing maintenance and repair. Judgment as to whether to perform maintenance and repair should be made based on an evaluation of the damage to the relevant portions. A method appropriate to the actual damage should be selected when maintenance and repair are required.

(2) Concrete pavement

Table-3.4.3 lists major maintenance and repair methods for concrete pavement.

Table-3.4.3: Overview of maintenance and repair methods for concrete pavement[10)]

Method	Overview
Patching	• Fills defects and smoothens faulting, etc. on concrete slabs with materials to recover the surface roughness, etc. of roads as an emergency measure. • Cement-based, asphalt-based, or resin-based material is used to patch and treated as mortar or concrete depending on its thickness. It is essential to securely bond concrete with the patching material.
Sealing	• Injects or charges joint-sealing compound or other sealants to prevent rainwater from intruding through joints or cracks when joint sealing material has suffered damage (e.g., falling or stripping due to degradation or cracking, etc.) or when concrete slabs have cracked.
Surface treatment	• Places thin pavement on concrete slabs to restore maneuverability for vehicles, pavement skid resistance, and slab water resistance, etc. when slabs have been subjected to raveling, polishing, separation (scaling), or hair cracking near surfaces, etc. • Uses the same materials and procedure as patching.
Surface texturing	• Uses a machine or chemicals to roughen concrete slab surfaces. • Performed primarily to restore the skid resistance of concrete slab surfaces. • Uses a shot-blasting machine or water-jetting machine, etc. to perform roughing. • Uses acids to perform roughing.
Grooving	• Uses a grooving machine to form grooves 6 mm deep and 6 mm wide as well as grooves 6 mm deep and 9 mm wide at 20 to 60 mm intervals along road surfaces. • Performed to prevent hydroplaning during rain and to increase skid resistance. • Grooves are formed in the longitudinal or transverse direction. The longitudinal direction is generally chosen to ease construction. • Grooves formed in the longitudinal direction are effective in preventing accidents caused by sideslips and crosswinds. Grooves formed in the transverse direction are effective in shortening stopping distances and suitable for steep roads and portions of roads near crossings, etc.
Injection method	• Eliminates voids and hollows formed between concrete slabs and base courses by injection and filling or pushes settling slabs back up to their normal positions. • Injects asphalt- or cement-based materials. Cold-type asphalt-based materials are generally used.
Bar stitching	• Cuts grooves in cracking portions of concrete slabs in a direction perpendicular to the cracking direction and embeds deformed bars, flat bars, or other pieces of steel into the grooves to connect the slabs on both sides of the bars. • Uses pieces of steel having a cross-section and length whose load transfer performance is equivalent to that of dowel bars, and uses high-strength cement mortar or resin mortar for filling.
Replacement	• Performed when concrete slabs have been damaged over a wide area. • Replacement with concrete or asphalt mixture is selected depending on the areas to be replaced, conditions of the subgrade and base courses, and traffic volume, etc.
Local replacement	• Replaces local portions (including slabs and base courses) when reliable load transfer cannot be expected due to cracking that has been occurred along edges, across slabs, or in other portions of the slabs in their thickness directions. • Performed so that load transfer performance can be ensured without impairing continuity of reinforcements when continuously reinforced concrete slabs have suffered structural damage due to transverse cracks accompanied by reinforcement fractures.
Overlay	• Increases pavement load carrying capacity by placing asphalt mixtures or additional concrete atop existing concrete slabs. • Patching and measures against reflection cracking*, etc. must be implemented for defective portions beforehand to minimize the impacts on existing slabs. • Local replacement, the injection method, and bar stitching, etc. are also used as necessary.

* Measures against reflection cracking include installation of cracking suppression sheets and placement of asphalt mastic mixture, etc.

Maintenance and repair methods for concrete pavement should also be selected by considering damage levels and classifications. If multiple types of damage are involved, the characteristics and levels of each type of damage must be considered to determine whether to apply one method to all damage types, to apply different methods to each damage type, or to combine approaches. **Table-3.4.4** lists types of damage to concrete pavement and guidelines for selecting maintenance and repair methods according to the classes for selecting a construction method. For the details of each method, refer to Chapter 4. Symbols L, M, and H in **Table-3.4.4** correspond to the classes for selecting a construction method described in "3-3 Evaluation." For some damage types, the available methods may be restricted.

Table-3.4.4: Types of damage to concrete pavement and guidelines for selecting maintenance and repair methods according to the classes for selecting a construction method

Damage to concrete pavement \ Maintenance and repair method		Damage classification	Maintenance method							Repair method		
			Patching	Sealing	Surface treatment	Surface texturing	Grooving	Injection method	Bar stitching	Replacement	Local replacement	Overlay
Cracking	Cracking index	Structural damage		L					L, M	M, H	L, M	M, H
	Transverse cracking*	Structural damage	M	L, M					L, M	H	H	
Damage to joints	Faulting (erosion)	Structural damage	L, M, H					L, M		H	M, H	
	Protrusion and scattering	Road surface damage		L, M								
	Edge defects	Structural damage	L, M	L								
Other types of damage	Rutting	Road surface damage			L		L					M, H
	Polishing	Road surface damage			M, H	M, H	M, H					M, H
	Potholes	Road surface damage/ Structural damage	□								□	
Remarks	L, M, and H: Classes for selecting a construction method □: Method applied to damage *: Excludes transverse cracks occurring on continuously reinforced concrete pavement.											

Note: The symbols used in this table denote classes for selecting a construction method to use for selecting maintenance and repair methods and do not indicate the necessity of performing maintenance and repair. Judgment as to whether to perform maintenance and repair should be made based on an evaluation of the damage to the relevant portions. A method appropriate to the actual damage should be selected when maintenance and repair are required.

3-4-2 Specification of required performance

When formulating maintenance and repair implementation plans, road surface design and structural design are performed to satisfy the required performance of sections extracted for maintenance and repair. This process is nearly identical to that for pavement construction planning. In maintenance and repair implementation plans, however, performance levels to be restored, functions to be additionally provided, and other goals are determined based on the results of performance degradation evaluation, and the required performance is newly specified according to such goals. Once the required performance has been determined, corresponding performance indices are determined, allowing design goals to be defined.

Specifically, the functions required for road surfaces, lifecycle costs, environmental conservation and improvement, policies on administration of peripheral facilities, and other factors must be considered based on the required performance specified during the construction stage, design conditions, actual pavement conditions, current traffic situations, and roadside environments. With the aim of ensuring safety for road users and smooth, comfortable traffic through maintenance and repair, the appropriate levels of required performance must be determined to satisfy the diverse requests of road users and residents in roadside areas.

This section describes matters to consider when specifying the levels of required performance as well as performance indices corresponding to the specified levels of required performance.

(1) Matters to consider when specifying the levels of required performance

The following matters must be clarified or ascertained in order to specify appropriate levels of required performance. The required performance should reflect matters selected based on road sections extracted for maintenance and repair as well as various conditions.

1) Required performance during the construction stage and design conditions

Required performance during the construction stage and design conditions must be clarified to the extent possible to ascertain actual pavement conditions. These matters are essential when specifying new required performance based on an understanding of how the following matters to consider have changed from the construction stage.

2) Actual pavement conditions

Damage to pavement must be examined to identify damage causes and the degree of performance degradation. These matters are essential for specifying the required performance as well as selection and design of maintenance and repair methods appropriate for such performance.

3) Traffic situations and roadside environments

Traffic volume, road usage by various transportation groups, the numbers of houses and commercial facilities, and other aspects of the usage situations in roadside areas must be clarified. If these matters have changed from those clarified during the construction stage, specifying new required levels of performance in implementation plans for maintenance and repair may improve the economic efficiency or transportation safety and ride quality for road users and residents in roadside areas.

For example, when, compared to the construction stage, the number of residents has increased in a roadside area and consequently the sizes of transportation groups of pedestrians and cyclists have increased, the surface course material may be changed from a dense graded asphalt mixture to a porous asphalt mixture through maintenance and repair in order to improve traveling safety by increasing visibility during the rain and to improve comfort by preventing water from splashing toward pedestrians.

4) Functions required for road surfaces

After giving consideration to the necessary matters, it is important to specify which road surface functions are to be provided for pavement through maintenance and repair from the perspectives of traffic safety, roughness, comfort, environmental conservation and improvement, and other factors. Since road surface functions directly affect traffic for road users and residents in roadside areas, their requests must be satisfied. Target road surface functions are used as basic conditions for setting design periods, pavement performance indices, and other goals.

5) Lifecycle costs

The lifecycle of pavement refers to the series of activities performed during the period from pavement construction to the next time construction is necessary. Expenses related to such a lifecycle are called lifecycle costs. Road administrators repeatedly carry out a series of activities (surveys, planning, construction, and maintenance and repair) during the course of each lifecycle. Maintenance and repair consist of a series of activities, and the lifecycle costs of the maintenance and repair methods to be applied is estimated and used as a condition in planning such activities.

6) Environmental conservation and improvement

Reduction in environmental burdens, use of resources-saving construction methods, reduction of the amount of pavement waste, promotion of recycling, and other activities must be considered to conserve and improve the environment.

Reduction in environmental burdens should be considered separately from the three perspectives of earth/social environments, urban environments, and roadside/road space environments. **Table-3.4.5** lists example measures to reduce environmental burdens. It is essential to select the optimal measures for each case as well as to reflect the effects expected from such measures in the required levels of performance.

Table-3.4.5: Example measures to reduce environmental burdens[11)]

Classification		Technical measures	Major effects
Earth/social environments	Suppression of global warming	Intermediate temperature setting technologies, cold pavement, and semi-hot pavement	Reduction of CO_2 emissions
	Long-term use of resources (Extension of pavement service life)	Composite pavement	Reinforcement of pavement structure
		Improved asphalt	Enhancement of mixture durability
	Use of resource-saving technologies	Stabilization of subgrade and base courses	Use of low-quality materials
Urban environments	Reduction of traffic congestion due to construction	Long-life pavement	Reduction of road construction work amounts
		Short-construction-period pavement	Shortening of construction periods
	Groundwater recharge	Permeable pavement	Permeation of rainwater into the ground and suppression of rainwater outflow
	Suppression of increases in road surface temperature	Water-retentive, greening, and soil-based pavements	Suppression of road surface temperature increases through vaporization heat
		Heat-blocking pavement	Suppression of road surface temperature increases through the reflection of infrared rays
Roadside/road space environments	Reduction of road vibrations	Retention of surface roughness and elimination of faulting	Reduction of impacts on traffic and vibrations
		Reinforcement of subgrade and base courses	Suppression of vibration propagation
		Vibration-reducing pavement	Suppression of vibration generation and propagation
	Reduction of road surface noise	Low-noise and drainage pavements	Suppression of generation of tire-road surface noise
	Prevention of water splashing	Drainage and permeable pavements	Permeation of rainwater into the ground

Note: Measures under research and development are also included.

7) Policies on administration of peripheral facilities

Policies on administration of lifelines and other peripheral facilities are closely related to design periods, designed daily volume for pavement, pavement performance, and other factors; they substantially affect implementation plans for maintenance and repair. Thus, administrative policies must be clarified prior to planning. For example, when maintenance and repair in a location are expected to significantly affect road users and residents in roadside areas, a policy of specifying a high level of durability as the required performance may be effective in reducing the amount of future maintenance and repair work. If such a policy is expected to have only a small effect, maintenance and repair should be performed frequently by selecting a method that reduces the expense of each maintenance and repair operation.

(2) Pavement performance indices

Pavement performance indices are defined as indices corresponding to prescribed levels of required performance. Design goals can be specified in maintenance and repair implementation plans using such performance indices, as is done during the construction stage.

Required performance is prescribed mainly by considering road surface functions that directly affect road users and specific road surface needs. Some performance indices correspond to these levels of required performance. Other performance indices are required by road administrators for examining the structural soundness of pavement, carrying out appropriate pavement administration, and providing road users with certain levels of services through pavement.

Figure-3.4.2 lists examples of pavement performance indices for roadways and marginal strips. These indices are described in the *Guidelines for Pavement Design and Construction* (2006 edition) as examples of road surface function performance indices that directly affect road users and specific road surface needs.

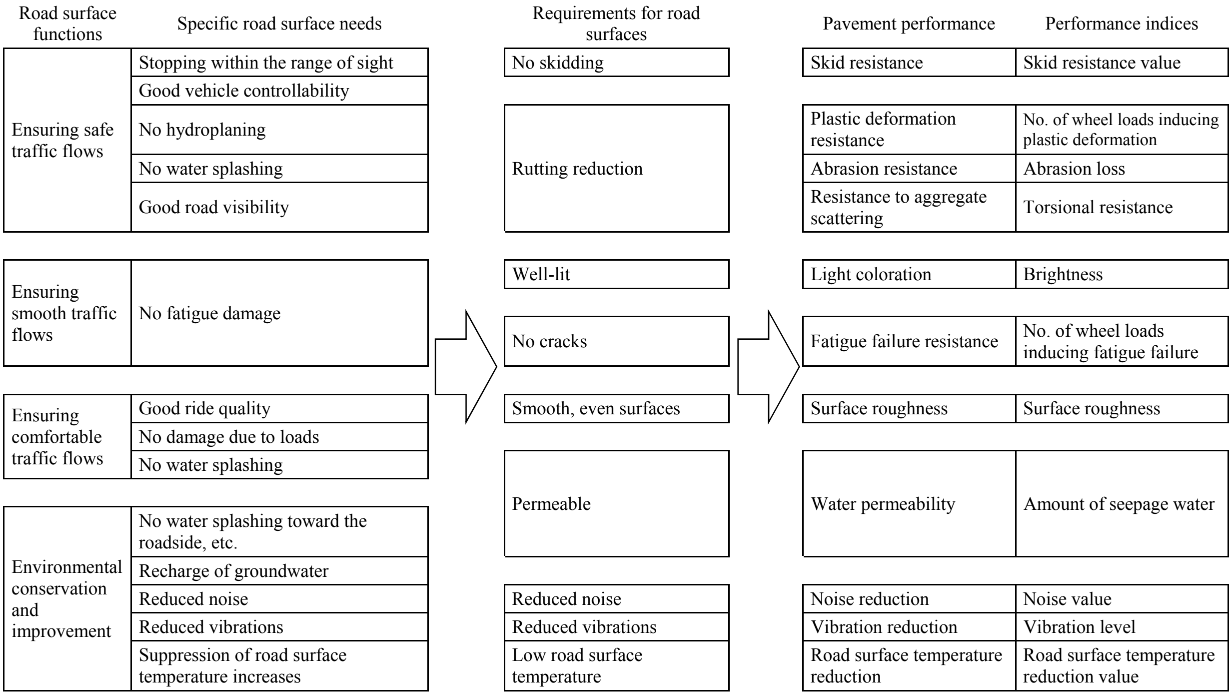


Figure-3.4.2: Examples of pavement performance indices for roadways and marginal strips[11)]

1) Number of wheel passes causing fatigue failure

The number of wheel passes causing fatigue failure generally refers to the number of 49-kN wheel loads that are repeatedly applied to a paved road surface until the pavement cracks due to fatigue damage. It is specified for each paved section in which each pavement layer has uniform thickness and is made of the same material. Criteria for the number of wheel passes causing fatigue failure (standard load: 49 kN) immediately after completion of pavement construction are listed in technical standards. *Guidelines for Pavement Design and Construction* (2006 edition) also specifies criteria for pavement having a designed daily volume of less than 100 vehicles/day per direction as shown in **Table-3.4.6**. When the design period of pavement is other than 10 years, the number of wheel passes causing fatigue failure can be calculated by multiplying the corresponding value listed in **Table-3.4.6** by the ratio of the design period to 10 years. However, the number of wheel passes causing fatigue failure can be specified without reference to **Table-3.4.6** when integrating pavement into structures other than pavement to ensure a load carrying capacity as seen in bridges, elevated roads, tunnels, and other roads with similar structures.

For details on the number of wheel passes causing fatigue failure, refer to the *Guidelines for Pavement Design and Construction* (2006 edition) and *Pavement Performance Evaluation Methods —Essential and Principal Performance Indices—* (2013 edition).

Table-3.4.6: Criteria for the number of wheel passes causing fatigue failure (standard load: 49 kN)[11)]

Traffic volume class	Designed daily volume for pavement (Unit: Vehicles/day per direction)	No. of wheel loads inducing fatigue failure (Unit: times/10 years)
N_7	3,000 or more	35,000,000
N_6	1,000 to 3,000	7,000,000
N_5	250 to 1,000	1,000,000
N_4	100 to 250	150,000
N_3	40 to 100	30,000
N_2	15 to 40	7,000
N_1	Less than 15	1,500

2) Number of wheel passes causing plastic deformation

The number of wheel passes causing plastic deformation generally refers to the number of 49-kN wheel loads that are repeatedly applied to a paved road surface at a surface course temperature of 60°C until the paved road surface develops 1-mm downward displacement. It is specified for each paved section in which each pavement layer has uniform thickness and is made of the same material. Criteria for the number of wheel passes causing plastic deformation immediately after completion of pavement construction must be specified to be greater than or equal to the values listed in **Table-3.4.7** according to the road classification and designed daily volume for pavement. However, the number of wheel passes causing plastic deformation can be specified without reference to these criteria for roads in snowy regions, for roads for which road construction work is scheduled to be performed in the near future, and for other special reasons of absolute necessity.

For details on the number of wheel passes causing plastic deformation, refer to the *Guidelines for Pavement Design and Construction* (2006 edition) and *Pavement Performance Evaluation Methods — Essential and Principal Performance Indices—* (2013 edition).

Table-3.4.7: Criteria for the number of wheel passes causing plastic deformation (ordinary roads; standard load: 49 kN)[11)]

Classification	Designed daily volume for pavement (Unit: Vehicles/day per direction)	No. of wheel loads inducing plastic deformation (Unit: times/mm)
Type 1, Type 2, Type 3 Classes 1 & 2, and Type 4 Class 1	3,000 or more	3,000
	Less than 3,000	1,500
Other		500

3) Surface roughness

Surface roughness is specified for each paved section having surface course of uniform thickness and made of the same material. Surface roughness immediately after completion of pavement construction is generally specified to be 2.4 mm or less. However, when environmental conservation (vibration and noise) of roadside areas is specified as part of the required performance, a value appropriate for such requirement can be selected for surface roughness.

4) Amount of seepage water

The amount of seepage water is specified for each paved section having surface course of uniform thickness and made of the same material. When drainage pavement, permeable pavement, or other pavement having a structure that allows rainwater to permeate into layers below the road surface is selected, the amount of seepage water immediately after completion of pavement construction must be specified to be greater than or equal to the values listed in **Table-3.4.8** according to the road classification. However, the amount of seepage water can be specified without reference to these criteria for roads in snowy regions, for roads for which road construction work is scheduled to be performed in the near future, and for other special reasons of absolute necessity.

Table-3.4.8: Criteria for the amount of seepage water (ordinary and small-scale roads)[11)]

Classification	Amount of seepage water (unit: ml/15 s)
Type 1, Type 2, Type 3 Classes 1 & 2, and Type 4 Class 1	1,000
Other	300

5) Pavement performance indices defined on an as-needed basis

Roads that are safer and more comfortable for traffic may be realized by reflecting changes in roadside environments during their service periods, requests of road users, and other matters differing from those during the construction stage in terms of required performance, when implementation plans for maintenance and repair are formulated. Performance indices defined on an as-needed basis include noise values and skid resistance. For target values and details, refer to *Pavement Performance Evaluation Methods: Separate Volume*, previous cases and measured values, and other data.

3-4-3 Road surface design

In road surface design for maintenance and repair of pavement, appropriate repair methods are selected after considering design conditions and present condition (e.g., evaluation of damage to pavement and identification of damage causes) before designing road surfaces that deliver the required levels of performance. Specifically, maintenance and repair methods, materials, thickness, and other factors appropriate for the surface course of the target road section are determined by considering construction conditions for the section as well as the condition of existing pavement and level of performance required for the road surface.

The following is a procedure for determining repair methods in road surface design.

1. Carrying out of surveys on damage to pavement, damage causes, etc. and present condition
2. Determination of the level of performance required for the road surface
3. Examination of construction conditions for the section subject to maintenance and repair
4. Determination of the designed daily volume for pavement, definition of performance indices, and determination of target values for the performance indices
5. Selection of materials and method for the surface course; determination of its thickness

The following must be considered in road surface design.

1. The purposes of maintenance and repair must be clarified (e.g., emergency actions for pavement (life extension), recovery of pavement functions, and addition of new functions).
2. In road surface design, the materials and construction methods to use for surface courses and their thicknesses are determined. Various types of materials are available to satisfy the values specified for road surface performance indices, and various types of construction methods can be applied. Thus, an appropriate design must be implemented independently for each case. Data on materials, pavement structures, construction methods, records of service use, and other matters related to past road surface designs under similar conditions should be used.
3. When road surface performance may be affected by pavement structure, the structure of each pavement layer must be considered. For example, asphalt pavement must be examined from the perspectives of rutting caused by plastic deformation of its binder course, base course formed by bituminous stabilization, and other layers; the performance of the impermeable layer of porous asphalt pavement; the water permeability of permeable pavement layers; and other factors. Concrete

pavement must be examined from the perspectives of materials, their combinations, slab surface treatments, overlay using asphalt mixtures, and other factors.

4. Values that must be achieved within a specific time period after service use begins are specified for some road surface performance indices on an as-needed basis. Possible surface course materials and thicknesses as well as construction methods are selected so that the selected conditions satisfy the specified values. Optimal conditions are subsequently selected by considering economic effectiveness and other factors as well as referring to past cases and other matters.
5. Some specified road surface performance items may be affected by construction work and the performance of binder courses (e.g., surface roughness). Thus, it is necessary to consider which construction devices to select, the range of influence on performance, and other factors.
6. When performance indices specified for the surfaces of roads with almost no large vehicle traffic volume are dust- or water-proofed (a sealing layer is formed to prevent permeation of rainwater, etc.), surface course subjected to bituminous surface treatment may be used.

(1) Road surface performance indices and their target values

The required level of performance of pavement for maintenance and repair is determined in accordance with "3-4-2: Specification of required performance." After determining the required performance, indices used to measure such performance quantitatively and their target values must be determined.

Table-3.4.9 lists examples of road surface performance items and their corresponding performance indices; **Table-3.4.10** lists examples of performance indices and their target values.

Table-3.4.9: Examples of road surface performance items and performance indices

Road surface performance	Road surface performance indices	Definition	Measurement method
Plastic deformation resistance	No. of wheel loads inducing plastic deformation*	The number of 49-kN wheel loads that are repeatedly applied to a paved road surface at a surface course temperature of 60°C until the paved road surface develops 1-mm downward displacement	Dynamic stability measurement for the number of wheel passes causing plastic deformation with a wheel tracking tester (*Pavement Performance Evaluation Methods —Methods for Evaluating Essential and Principal Performance Indices*— 1-2)
Surface roughness	Surface roughness*	The standard deviation of the difference in elevation between the paved road surface and the ideal flat paved road surface at any one point on each 1.5-m segment of either of two parallel straight lines 1 m away from the center line of the roadway	Measurement of surface roughness with a 3-meter profilometer and with a surface characteristics survey vehicle (*Pavement Performance Evaluation Methods —Methods for Evaluating Essential and Principal Performance Indices*— 1-3)
Water permeability	Amount of seepage water**	The amount of water that permeates through a circular area 15 cm in diameter from the road surface into the lower layers over 15 seconds	On-site measurement of the amount of seepage water with a permeameter (*Pavement Performance Evaluation Methods —Methods for Evaluating Essential and Principal Performance Indices*— 2-1)
Noise reduction	Noise value	The value obtained when rounding to the nearest whole number the equivalent noise level of tire-road surface noise measured with a paved road surface measuring vehicle by a specified method	Tire-road surface noise measurement of noise values with a paved road surface noise measuring vehicle (*Pavement Performance Evaluation Methods —Methods for Evaluating Essential and Principal Performance Indices*— 3-1)
Skid resistance	Skid resistance value	The skid friction coefficient measured with a skid resistance measuring vehicle and the dynamic friction coefficient measured with a DF tester	Skid friction coefficient measurement with a skid resistance measuring vehicle and dynamic friction coefficient measurement with a DF tester (*Pavement Performance Evaluation Methods —Methods for Evaluating Essential and Principal Performance Indices*— 3-2)

Road surface performance	Road surface performance indices	Definition	Measurement method
Vibration reduction	Vibration level reduction value	Road traffic vibration reduction realized through repair construction	Road traffic vibration measurement for vibration level reduction values (*Pavement Performance Evaluation Methods: Separate Volume —Methods for Evaluating Performance Indices Defined as Needed*— 1-7)
Abrasion resistance	Abrasion loss	The level of abrasion loss in surface courses caused by tire chains, etc. in snowy regions, etc.	Measurement of abrasion loss with a raveling tester (chain-rotating tire and reciprocating sample type) (*Pavement Performance Evaluation Methods: Separate Volume —Methods for Evaluating Performance Indices Defined as Needed*— 1-1)
Resistance to aggregate scattering at intersections	Torsional aggregate scattering value	The level of aggregate scattering occurring when pavement having a surface course made of porous asphalt mixture is distorted by tires	Measurement of torsional aggregate scattering values with a torsional aggregate scattering tester (*Pavement Performance Evaluation Methods: Separate Volume —Methods for Evaluating Performance Indices Defined as Needed*— 1-3)
Resistance to aggregate scattering in cold regions	Impact aggregate scattering value	The level of aggregate scattering occurring when vehicles, etc. equipped with tire chains travel over pavement made with a porous asphalt mixture in snowy regions, etc.	Cantabro test for measuring impact aggregate scattering values (*Pavement Performance Evaluation Methods: Separate Volume —Methods for Evaluating Performance Indices Defined as Needed*— 1-2)
Light coloration	Road surface lightness	Degree of brightness of the road surface color	Road surface lightness measurement with a colorimeter (*Pavement Performance Evaluation Methods: Separate Volume —Methods for Evaluating Performance Indices Defined as Needed*— 1-4)
Easy ice sheet separation	Adfreezing tensile strength	Degree of ease of separating ice sheets from road surfaces in winter	Measurement of adfreezing tensile strength with a tensile tester (*Pavement Performance Evaluation Methods: Separate Volume —Methods for Evaluating Performance Indices Defined as Needed*— 1-5)
Road surface temperature reduction	Road surface temperature reduction value	Difference in road surface temperature between reference pavement and pavement for which road surface temperature increases are suppressed	On-site measurement of road surface temperature with a thermometer to determine road surface temperature reduction values as well as measurement of sample surface temperatures under lamp irradiation to determine road surface temperature reduction values (*Pavement Performance Evaluation Methods: Separate Volume —Methods for Evaluating Performance Indices Defined as Needed*— 1-6)
(Note) The "*" symbol indicates a required performance index for road surfaces. The "**" symbol indicates a performance index for road surfaces that is defined when a structure allowing rainwater to permeate into the layers below the surface is selected. Other road surface performance indices are defined on an as-needed basis.			

Table-3.4.10: Examples of performance indices and their target values[12)]

Required performance item	Performance index	Target value example
Plastic deformation resistance	No. of wheel loads inducing plastic deformation	3,000 (times/mm) or more
Surface roughness	Standard deviation (σ) determined from values measured with a 3-meter profilometer	1.5 (mm) or less
Water permeability	Amount of seepage water measured with a permeameter on-site	1,000 (ml/15 s) or more
Noise reduction	Noise value measured with a paved road surface noise measuring vehicle	89 (dB) or less
Skid resistance	Skid friction coefficient (μ) measured with a DF tester	0.3 (μ60) or larger
Surface temperature reduction	Road surface temperature reduction value determined by sample surface temperature measurement under lamp irradiation	10 (°C) or higher

(2) Selection of surface course materials

Surface course materials must be selected by considering defined performance indices and their target values. Regarding the selection, refer to the examples listed in **Table-3.4.11**.

Table-3.4.11: Examples of materials for road surface (surface course) construction and typical expected performance[12)]

Expected performance	Material type, etc.	
	Material classification	Typical materials, construction method, etc.
Plastic deformation resistance	Asphalt-based materials	(1) Semi-flexible pavement
		(2) Polymer-modified asphalt mixture
	Cement-based materials	(1) Pavement/fiber-reinforced concrete
		(2) Precast slab
Surface roughness	Asphalt-based materials (Mixture type)	(1) Continuously-graded/gap-graded mixtures
		(2) Cold mixture
	Asphalt-based materials (Surface treatment type)	(1) Thin surfacing
Water permeability	Asphalt-based materials (Mixture type)	(1) Porous asphalt mixture
	Cement-based materials	(1) Porous concrete
	Resin-based material	(1) Permeable resin mortar
	Wood-based material	(1) Wood chips and bark
		(2) Wooden blocks
	Soil-based material	(1) Clay, loam, and dust
		(2) Composite/artificial soil
		(3) Lawns
Drainage	Asphalt-based materials (Mixture type)	(1) Porous asphalt mixture
	Cement-based materials	(1) Porous concrete
	Resin-based material (Mixture type)	(1) Permeable resin mortar
Noise reduction	Asphalt-based materials (Mixture type)	(1) Porous asphalt mixture
	Cement-based materials	(1) Porous concrete
	Resin-based material (Mixture type)	(1) Permeable resin mortar
		(2) Thin surfacing with rubber- or resin-based pavement
Skid resistance	Asphalt-based materials (Mixture type)	(1) Continuously-graded/gap-graded mixtures
		(2) Open-graded mixture
		(3) Cold mixture
	Asphalt-based materials (Surface treatment type)	(1) Chip seal
		(2) Micro surfacing
		(3) Thin surfacing
	Cement-based materials	(1) Porous concrete
	Resin-based material (Surface treatment type)	(1) Neat construction method
Abrasion resistance	Asphalt-based materials (Mixture type)	(1) Filler-containing mixture
		(2) Crushed-stone and mastic mixture
	Cement-based materials	(1) Pavement/fiber-reinforced concrete
Resistance to aggregate scattering	Resin-based material (Mixture type)	(1) Permeable resin mortar
	Resin-based material (Surface treatment type)	(1) Drainage topcoat method
Impact absorption	Resin-based material (Mixture type)	(1) Thin surfacing with rubber- or resin-based pavement
	Wood-based material	(1) Wood chips and bark
		(2) Wooden blocks
	Soil-based material	(1) Clay, loam, and dust
Road surface temperature reduction	Asphalt-based materials (Mixture type)	(1) Water retentive pavement
	Cement-based materials	(1) Pavement concrete
	Soil-based material	(1) Clay, loam, and dust
		(2) Composite/artificial soil
		(3) Lawns
	Resin-based material (Surface treatment)	(1) Heat-blocking pavement
Light coloration	Asphalt-based materials	(1) Semi-flexible pavement
	Cement-based materials	(1) Pavement/fiber-reinforced concrete
		(2) Precast slab
	Resin-based material (Mixture type)	(1) Petroleum-resin-based binder
		(2) Resin mixture and mortar
		(3) Permeable resin mortar
	Resin-based material (Neat type)	(1) Neat construction method
		(2) Drainage topcoat method
	Block- or tile-based materials	(1) Interlocking block
		(2) Lithic/porcelain tiles
		(3) Brick
		(4) Natural stone block

3-4-4 Example of road surface design

This section describes a concrete example of road surface design for pavement.

It is desirable to perform road surface design for maintenance and repair of pavement by considering not only the relevant construction work but also workability for future maintenance and repair work as well as other related matters.

(1) Example of a road surface design to achieve the required noise reduction

The road classification of this example is Type 4, Class 1.

1) Requirements for pavement

Requests of road users, etc. regarding the design of the road surface pavement were as follows.

- Improvement of the roadside environment (noise reduction)

2) Conditions for road surface design

Table-3.4.12 lists conditions for road surface design that were determined from the road classification, designed daily volume for pavement, and required performance for the road surface.

Table-3.4.12: Conditions for road surface design (based on Reference 12)

Performance index	Target performance index value	Remarks
Road surface design period	(Target: five years)	Since a sufficient amount of performance data is not available, the period has been roughly estimated.
Designed daily volume for pavement	3,000 vehicles/day per direction	
No. of wheel loads inducing plastic deformation	5,000 times/mm or more	Rutting, etc. must be suppressed for the noise measurement to be performed one year later.
Surface roughness	1.2 mm or less	Jolting of vehicles must be suppressed, and the amount of noise must be reduced.
Noise value	89 dB or less	Measurement must be performed with a paved road surface noise measuring vehicle.

3) Selection of surface (binder) course materials and thickness

Based on the specified noise value, porous asphalt mixture was selected to form the road surface. Accordingly, the binder course materials were determined as well as the materials and thickness of the surface course and the method to be applied.

For the porous asphalt mixture used in the surface course, an amount of seepage water of 1,000 ml/15 s or more (determined from the road classification) was imposed as an additional condition for the road surface design.

1) **Table-3.4.13** shows an example of how to select materials by considering performance indices and their target values.

2) **Table-3.4.14** shows an example of how to select surface (binder) course materials and thickness as well as method to apply.

Table-3.4.13: Example of how to select materials by considering performance indices and their target values (based on Reference 12)

Performance index	How to select materials
1. No. of wheel loads inducing plastic deformation	A porous asphalt mixture able to withstand a number of wheel passes causing plastic deformation of 5,000 times/mm or more must be selected.
2. Surface roughness	Irregularities resulting from construction must be minimized by continuous, constant-speed construction or other approaches.
3. Noise value	A porous asphalt mixture having a percentage of air voids of approximately 20% or higher must be selected while also giving consideration to aggregate grain sizes, grading, and other factors.
4. Amount of seepage water	A porous asphalt mixture having a percentage of air voids of 20% or higher must be selected.

Table-3.4.14: Example of how to select surface and binder course materials and thickness as well as the method to apply (based on Reference 12)

Item	Description
Materials 1. Surface course 2. Binder course 3. Tack coating material	1. A porous asphalt mixture based on special (high-durability) polymer-modified asphalt for small-grain mixtures was selected to offer a number of wheel passes causing plastic deformation of 5,000 times/mm or more. The target percentage of air voids is 20% or higher. The maximum grain size was determined to be 8 mm based on past data. 2. Since the surface course is to be formed as low-noise pavement from the porous asphalt mixture, the binder course must be formed as an impermeable layer from a dense-graded asphalt mixture (13) based on Type II polymer-modified asphalt, with consideration also given to traffic volume. 3. Rubber-containing asphalt emulsion is used as a tack coating material to increase the watertightness of the binder course's upper surface and to securely bond the surface and binder courses.
Thickness of each layer 1. Surface course 2. Binder course	1. The surface course thickness is 5 cm based on past data. 2. The binder course thickness is 5 cm based on past data.

(2) Example of road surface design to achieve the required road surface temperature reduction

The road classification in this example is Type 3, Class 2.

1) Requirements for pavement

Requests of road users, etc. regarding the design of the road surface pavement were as follows.

- Road surface temperature reduction

2) Conditions for road surface design

Table-3.4.15 lists conditions for road surface design that were determined from the road classification, designed daily volume for pavement, and required performance for the road surface.

Table-3.4.15: Conditions for road surface design (based on Reference 12)

Performance index	Target performance index value	Remarks
Road surface design period	(Target: five years)	Since a sufficient amount of performance data is not available, the period has been roughly estimated.
Designed daily volume for pavement	5,000 vehicles/day per direction	
No. of wheel loads inducing plastic deformation	3,000 times/mm or more	Determined from the road classification and designed daily volume for pavement.
Surface roughness	2.4 mm or less	In accordance with the *Technical Standards*.
Road surface temperature reduction value	6°C reduction of peak temperature	A value 6°C lower than the pavement's maximum road surface temperature based on use of a dense-graded asphalt mixture is set as the target value for the performance index.

3) Selection of surface (binder) course materials and thickness

Based on the specified road temperature reduction value, water-retentive pavement was selected to form the road surface.

1) **Table-3.4.16** shows an example of how to select materials by considering performance indices and their target values.
2) **Table-3.4.17** shows an example of how to select surface (binder) course materials and thickness as well as method to apply.

Table-3.4.16: Example of how to select materials by considering performance indices and their target values (based on Reference 12)

Performance index	How to select materials
1. No. of wheel loads inducing plastic deformation	A porous asphalt mixture able to withstand a number of wheel passes causing plastic deformation of 3,000 times/mm or more must be selected.
2. Surface roughness	Irregularities resulting from construction must be minimized by continuous, constant-speed construction or other approaches.
3. Road surface temperature reduction value	The temperature will be reduced by the vaporization heat of moisture retained in a water-absorbing, -retentive material input into the voids of the porous asphalt mixture. In order to ensure a maximum amount of retained water of 3.0 kg/m^2 or more, the target percentage of air voids in the porous asphalt mixture was set to 23%.

Table-3.4.17: Example of how to select surface and binder course materials and thickness as well as the method to apply (based on Reference 12)

Item	Description
Materials 1. Surface course 2. Binder course 3. Tack coating material	1. A porous asphalt mixture (13) based on Type H polymer-modified asphalt was selected to offer a number of wheel passes causing plastic deformation of 3,000 times/mm or more. The target percentage of air voids is 23%. 2. Since the surface course is to be formed as water-retentive pavement from the porous asphalt mixture, the binder course must be formed as an impermeable layer from a dense-graded asphalt mixture (13).
Thickness of each layer 1. Surface course 2. Binder course	1. The surface course thickness is 5 cm based on the maximum amount of retained water and past data. 2. The binder course thickness is 5 cm based on past data.

3-4-5 Structural design

In structural design for maintenance and repair of pavement, appropriate repair methods are selected by considering damage to pavement, damage causes, and design conditions, after which a pavement structure suited to the selected method is determined. For maintenance and repair of pavement, it is important to ascertain the actual situation accurately and to implement appropriate measures to enable pavement to deliver its expected performance. When the selected method so requires, structural design of the target pavement's cross-section is implemented.

This section describes two typical structural design methods for existing asphalt pavement: design using equivalent remaining thickness (T_{A0}) and design using road surface deflection. It also describes two structural design methods for existing concrete pavement: design for repair using concrete and design for repair using asphalt mixtures. Typical design examples are also included.

(1) Structural design for existing asphalt pavement

1) Design using equivalent remaining thickness (T_{A0})

Equivalent remaining thickness (T_{A0}) refers to the remained value determined based on pavement's damage condition with respect to the equivalent thickness of hot mixtures for surface and binder courses. Once subgrade conditions and designed daily volume for pavement have been determined, the design for the existing pavement is implemented using an approach similar to the T_A method described in "Attached Table 1, Technical Standards for Pavement Structures and Their Descriptions." T_{A0} is calculated using the conversion factors listed in **Table-3.4.18**.

Table-3.4.18: Conversion factors for calculating T_{A0} listed in the *Pavement Design Handbook*

Layer	Existing pavement materials	Condition of each layer	Conversion factor	Remarks
Surface and binder courses	Hot asphalt mixtures	When slight damage may become moderate	0.9	The conversion factor reaches its maximum when damage is slight and its minimum when damage is severe. When damage is moderate, its value is determined based on the damage condition.
		When moderate damage may become severe	0.85–0.6	
		When damage is severe	0.5	
Base course	Bituminous stabilization (hot mixing)		0.8–0.4	The conversion factor takes its maximum value when pavement is in a state regarded as equivalent to the newly constructed stage, and varies depending on the damage condition.
	Cement and bituminous stabilization		0.65–0.35	
	Cement stabilization		0.55–0.3	
	Lime soil stabilization		0.45–0.25	
	Hydraulic mechanically stabilized slag		0.55–0.3	
	Crushed stone for mechanical stabilization		0.35–0.2	
Subbase course	Crusher-run, steel slag, sand, etc.		0.25–0.15	
	Cement/lime soil stabilization		0.25–0.15	
Cement concrete slab		When damage is slight or moderate	0.9	
		When damage is severe	0.85–0.5	

[Note] Criteria for judging pavement damage conditions

Slight damage: Pavement delivers nearly full performance and presently requires no repairs.
(The crack ratio is approximately 15% or lower.)

Moderate damage: Pavement delivers nearly full performance but requires local and functional repairs.
(The crack ratio is approximately 15–35%.)

Severe damage: Overlay or other large-scale repair work is required.
(The crack ratio is approximately 35% or higher.)

The equivalent remaining thickness (T_{A0}) is the total of the value obtained by multiplying the thickness of each layer by its conversion factor estimated by referring to **Table-3.4.18**. For example, T_{A0} is calculated for the entire thickness of the pavement when overlay is to be used, but it is calculated for the thickness of the portion not to be replaced when a method such as replacement and base course recycling is to be used.

Specifically, the equivalent thickness (T_A) of the pavement cross-section is calculated from among Equations (3.4.1) to (3.4.3) depending on reliability, after which the equivalent thickness (t) required for maintenance and repair is calculated from Equation (3.4.4).

For 90% reliability: $$T_A = \frac{3.84N^{0.16}}{CBR^{0.3}} \quad \cdots\cdots \quad (3.4.1)$$

For 75% reliability: $$T_A = \frac{3.43N^{0.16}}{CBR^{0.3}} \quad \cdots\cdots \quad (3.4.2)$$

For 50% reliability: $$T_A = \frac{3.07N^{0.16}}{CBR^{0.3}} \quad \cdots\cdots \quad (3.4.3)$$

Equivalent thickness required for maintenance and repair:

$$t\ (\text{cm}) = T_A - T_{A0} \quad \cdots\cdots \quad (3.4.4)$$

where, *N*: No. of wheel loads inducing fatigue failure (times); and *CBR*: Design CBR of subgrade.

2) Design using road surface deflection

Several approaches to performing structural evaluation are available for design using road surface deflection. In one approach, pavement deflection measured with a Benkelman beam, etc. is compared with the deflection of a pavement structure whose performance has been demonstrated in actual application. In another approach, the elastic modulus and other indices of each layer of the pavement and subgrade are calculated with the aid of multi-layer elastic analysis of the pavement surface's deflection shape measured with FWD. **Figure-3.4.3** depicts structural evaluation based on deflection shapes. Measured deflection shapes can be used to estimate not only the pavement's overall bearing capacity but also the strength of each pavement layer.

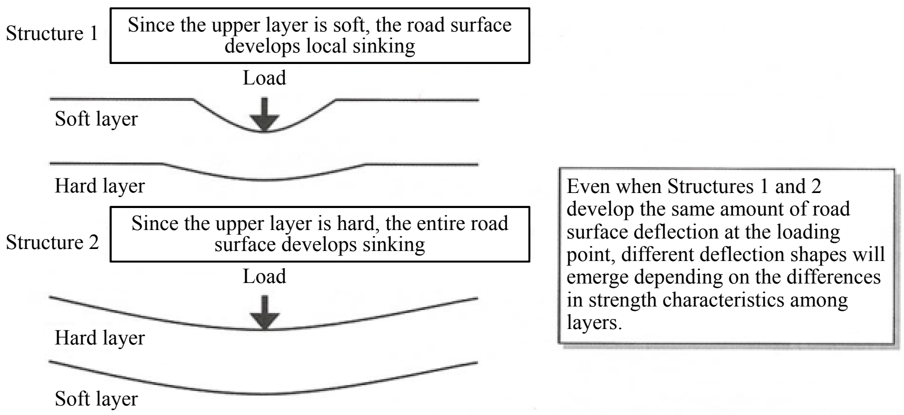


Figure-3.4.3: Structural evaluation of pavement based on the amount and shape of deflection[8)]

In recent years, FWD tests have been widely used for structural evaluation of existing pavement. FWD tests of road pavement generally apply 49-kN loads to a loading plate 300 mm in diameter and measure deflection with seven or more deflection sensors. Deflection D_0 occurring immediately below FWD's loading points is used as an index for evaluating pavement's structural bearing capacity. The values listed in **Table-3.4.19** are used as criteria for judging whether bearing capacities are sufficient.

Table-3.4.19: Examples of allowable deflection in FWD tests according to traffic volume class[1)]

Traffic volume class	N_3	N_4	N_5	N_6	N_7
D_0 (mm)	1.2	0.9	0.6	0.4	0.3

[Note 1] D_0: Deflection occurring immediately below loading points

[Note 2] Allowable deflection values are converted values corresponding to 49-kN loads at 20°C.

In structural design, several approaches based on FWD tests are available for performing structural evaluation of existing pavement. **Figure-3.4.4** illustrates a typical evaluation workflow. The T_A method is the empirical design method mentioned in the workflow. For the specific design method, refer to the design example. For a theoretical design method based on multi-layer elastic analysis, refer to the *Pavement Design Handbook* and other reference materials.

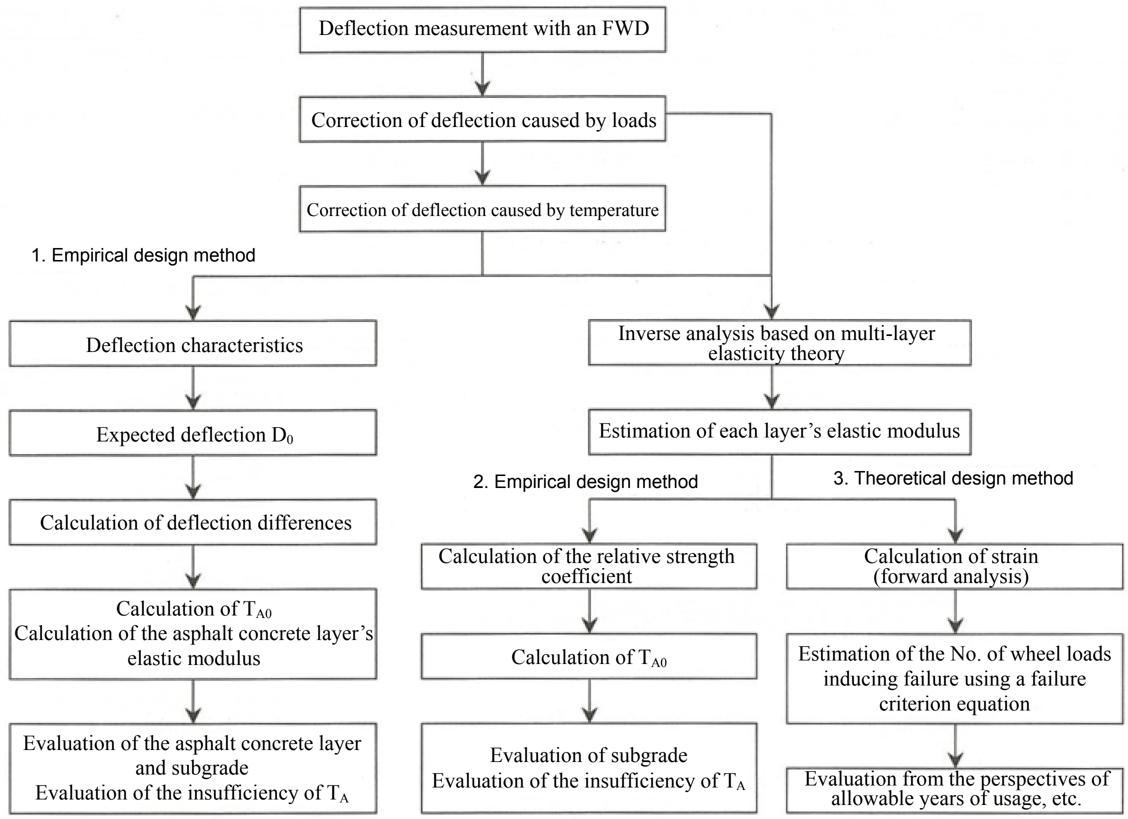


Figure-3.4.4: Structural evaluation workflow by FWD tests[8)]

(2) Structural design for existing concrete pavement

1) Design for repair using concrete

Replacement and overlay are among the repair methods which necessitate structural design when existing concrete pavement is the target pavement.

When existing concrete pavement is to be replaced using concrete, structural design of its cross-section is carried out in the same manner as for construction of new concrete pavement. For actual methods, refer to the *Pavement Design Handbook*.

Methods for overlaying concrete on existing concrete pavement include the separated raising method, direct raising method, and bond raising method. The separated raising method forms a separation layer to reduce the impacts of existing slabs' behavior. The direct raising method applies overlay directly to existing slabs' surfaces. The bond raising method treats existing slabs' surfaces by shot blasting or other approaches to completely bond new and old concrete slabs. These three methods, however, have rarely been applied in actual repairs, and no complete structural design methods have been established for them.

Compared to the other two methods, the bond raising method forms a thin overlay, and it is applied to existing concrete pavement having relatively slight damage. This section describes the bond raising method and a design method for the bond raising method using steel fiber reinforced concrete.

(I) Design of overlay thickness

When overlaying steel fiber reinforced concrete (SFRC) with the bond raising method, the required concrete slab thickness can be calculated using Equation (3.4.5). However, it is empirically desirable to set the thickness to approximately 5 cm or more.

$$h_0 = h_d - C\left[\left(\frac{h_d}{h_{ad}}\right)h_e\right] \qquad \cdots\cdots \qquad (3.4.5)$$

where,
- h_0 : Required thickness of the SFRC slab to be overlaid (cm);
- h_d : Thickness of the SFRC slab designed based on the design bending strength of the SFRC to be overlaid, on the assumption construction will be directly performed on the existing base course (cm);
- h_{ad} : Thickness of the concrete slab designed based on the design bending strength of the concrete in the existing concrete slab, on the assumption construction will be directly performed on the existing base course (cm);
- h_e : Thickness of the concrete slab of the existing concrete pavement (cm); however, the concrete slab thickness after cutting must be used if the existing concrete slab has been cut;
- C : Factor determined based on the condition of the existing concrete pavement with reference to **Table-3.4.20**.

Table-3.4.20: Standard values of C[12)]

Value of C	Condition of existing concrete pavement
1.00	When the existing concrete slab is in good condition with no or almost no structural cracks (its cracking index value is approximately 0 to 3 cm/m^2)
0.75	When the existing concrete slab has developed initial cracks at its joints or edges, etc., though the cracks are not widening (its cracking index value is approximately 3 to 10 cm/m^2)

(II) Locations of joints of concrete slabs to be overlaid

New and old concrete slabs behave as a single structure at the joints of concrete slabs to be overlaid by the bond raising method. Such joints thus must be formed at the joints of existing concrete slabs in principle. Since load transfer and other joint functions must be achieved at the joints of existing slabs, components such as dowel bars and tie bars are generally not used.

2) Design for repair using asphalt mixture

As described above, replacement and overlay are among the repair methods which necessitate structural design when existing concrete pavement is the target pavement.

When existing concrete pavement is to be replaced using asphalt mixture, the structural design of its cross-section is carried out in the same manner as for construction of new asphalt pavement. For actual methods, refer to the *Pavement Design Handbook*.

When overlaying asphalt mixture on existing concrete pavement, the structural design of pavement cross-sections must be implemented by referring to “3-4-4 1) Design using equivalent remaining thickness (T_{A0})." In this method, equivalent remaining thickness (T_{A0}) is estimated using factors corresponding to the damage conditions of pavement concrete slabs (**Table-3.4.18**), and the thickness of the asphalt mixture to be overlaid is determined based on a comparison of the estimated equivalent remaining thickness with the required equivalent thickness (T_A) of pavement cross-sections. According to current thinking, overlay thickness should be 8 cm or more.

To prevent existing concrete slabs from adversely affecting overlaid asphalt mixture layers, measures such as patching and measures against reflection cracking should be implemented before overlaying, and application of local replacement, the injection method, bar stitching, or other methods should be considered as necessary.

Reflection cracks are often caused by some joint conditions and cracking of existing concrete slabs; they tend to occur more frequently for thinner overlaid layers. Although it is difficult to completely prevent all cracks, the following measures are effective.

1. For overlay thicknesses of 10 cm or more, an open-graded asphalt mixture or crushed-stone and mastic mixture having a thickness of approximately 5 cm should be placed on concrete slabs to suppress reflection cracking.
2. Sheets, crushed-stone and mastic mixture, or other materials should be placed as a stress-absorbing membrane interlayer (sand cushion) on concrete slabs to suppress reflection cracking by absorbing any displacements occurring in asphalt mixture layers.
3. Dummy joints should be formed by cutting asphalt mixture layers immediately above the concrete slab joints.

3-4-6 Examples of structural design

This section shows some examples of design for maintenance and repair.

Each maintenance and repair process is subject to different constraints in terms of conditions, such as the pavement damage situation, the time and money available for surveys, and applicable equipment. Thus, it is essential to plan surveys and other activities elaborately in detail in advance so that they can be carried out efficiently and effectively.

(1) Example 1 (design using T_{A0})

1) Required performance (present condition)

The target portion to be repaired was designed by an empirical design method and has been used for 25 years. The road has frequently undergone maintenance and repair carried out using various methods, and different portions have different maintenance and repair records. Since the target portion was surrounded by urban areas, repair was performed without changing the road surface height.

Table-3.4.21 lists the performance items (design conditions) required for the pavement and the structure of the existing pavement.

Table-3.4.21: Required performance items (design conditions) and structure of the existing pavement

<table>
<tr><th colspan="2">Item</th><th>Design condition</th></tr>
<tr><td colspan="2">Pavement design period</td><td>10 years</td></tr>
<tr><td colspan="2">No. of lanes</td><td>Two lanes each way</td></tr>
<tr><td colspan="2">Traffic volume class</td><td>N_6</td></tr>
<tr><td colspan="2">Designed daily volume for pavement (vehicles/day per direction)</td><td>1,000</td></tr>
<tr><td colspan="2">No. of wheel loads inducing fatigue failure (times/10 years)</td><td>7,000,000</td></tr>
<tr><td colspan="2">Reliability (%)</td><td>90</td></tr>
<tr><td colspan="2">Design CBR</td><td>8</td></tr>
<tr><td colspan="2">Roadside environment</td><td>DID (densely inhabited district)</td></tr>
<tr><td colspan="2">T_A (cm)</td><td>26</td></tr>
<tr><td colspan="3">Structure of the existing pavement</td></tr>
<tr><td>Surface and binder courses</td><td>Hot asphalt mixture</td><td>10 cm</td></tr>
<tr><td rowspan="2">Base course</td><td>Bituminous stabilization</td><td>9 cm</td></tr>
<tr><td>Crushed stone for mechanical stabilization</td><td>15 cm</td></tr>
<tr><td>Subbase course</td><td>Crusher-run</td><td>15 cm</td></tr>
<tr><td>Subgrade</td><td>Gravel soil</td><td>-</td></tr>
<tr><td>Others</td><td colspan="2">• The existing surface course was formed from porous asphalt mixture. Porous asphalt mixture will be used during the repair to form the surface course to achieve environmental conservation and noise reduction.
• The road surface height cannot be changed.</td></tr>
</table>

2) Survey of actual conditions of existing pavement

The target portion, whose surface course was formed from porous asphalt mixture, developed substantial rutting with void choking. A number of complaints about water splashing during rain were received from pedestrians and car drivers using the road.

Against such a backdrop, the road's damage condition was visually observed from sidewalks, and the rut depth was measured at important points using a leveling cord. The results of observation and rut depth measurement were as follows.

- Rut depth generally ranged from approximately 25 to 30 mm but often exceeded 40 mm at points near intersections and other locations. A number of traffic signals are present along the route, leading to frequent traffic congestion. The road's narrow traffic lanes cause the wheels of large vehicles to pass over the same portions. These road characteristics presumably contributed to the occurrence of rutting. Since bumps were formed around vehicles' running paths in the rutting portions, the principal cause of rutting was judged to be flow of the surface course.
- Cracks occurred mainly along vehicles' running paths. Though such cracks were observed only in limited locations, they formed large, local alligator cracks mainly in locations with large amounts of rutting. In such locations, traces of recovery work (presumably for potholes) were observed.
- In sections where local alligator cracks occurred, rutting caused by flow also developed similarly to other locations, and shapes were observed that appeared to be formed due to the sinking of the bottoms of rutting portions.
- White ejecta were observed in both vehicles' running paths in many locations along the target section to be repaired after rainfall.

These results suggested the rutting was caused mainly by deformation due to flow of the surface course's porous asphalt mixture layer. Ejecta observed after rainfall suggested the possibility that the binder course suffered from stripping. In addition, the bearing capacities of the binder course and layers underneath were likely to be insufficient in sections with alligator cracks.

3) Additional surveys for identifying damage causes

To identify damage causes, core sampling was carried out at important points. Since it was necessary to ascertain cracking depth and the actual flow conditions of the asphalt mixture layer, cores were sampled at the centers of traffic lanes and vehicles' running paths in each location. In addition, open-cut surveys were performed for structural evaluation of pavement in sections containing alligator cracks from the perspective of equivalent remaining thickness T_{A0}. The results of these additional surveys were as follows.

[Results of observation and testing of cut cores]

- Cracks had formed in the surface course's porous asphalt mixture layer. Cracks were also observed in part of the binder course. During core sampling, the surface course separated from the other portions in many of the sampled cores.
- The cross-sections of transversely sampled cores were compared to check the actual flow conditions of the asphalt mixture layer. Flow occurred mainly in the surface course, but slight flow was also observed in the binder course.
- Since stripping was observed in the upper portion of the binder course, a special indirect tensile test was performed on the binder course to evaluate its water resistance. The test results revealed low water resistance.
- An extraction test was performed on the layer formed by asphalt stabilization to measure penetration of the asphalt. The measured penetration was approximately 40. Since no stripping or other abnormalities were observed in the cross-sections of the sampled cores, the layer was deemed to be in normal condition.

[Results of open-cut surveys of sections with alligator cracks]

- Many of the cracks reached layers below the binder course, and some penetrated through the layer formed by bituminous stabilization.
- Stripping of the binder course was in an advanced stage, and the bond between the surface and binder courses had been lost.
- No looseness or other abnormalities were observed in the crushed-stone base course.

The design CBR as measured by a CBR test on subgrade was 6, which was lower than the initial design CBR, 8.

4) Examination of pavement structure and selection of maintenance and repair method

The results of the surveys on the existing pavement suggested that layers with cracks, stripping, and other damage in an advanced stage would adversely affect the pavement's durability after repair, so it was decided to replace those layers. Since the surface course was to be formed from porous asphalt mixture, layers as deep as the binder course would be replaced because they had suffered from stripping.

For sections with alligator cracks, T_{A0} was calculated using the conversion factors determined by referring to **Table-3.4.18** based on the damage conditions of individual layers identified by open-cut surveys. **Table-3.4.22** lists the results.

Table-3.4.22: Results of T_{A0} calculation for portions with alligator cracks

Layer	Material	Thickness	Coefficient of relative strength	Equivalent thickness
Surface and binder courses	Hot asphalt mixture	10	0.5	5.0
Base course	Bituminous stabilization	9	0.6	5.4
	Crushed stone for mechanical stabilization	15	0.35	5.25
Subbase course	Crusher-run	15	0.25	3.75
			Total	19.4

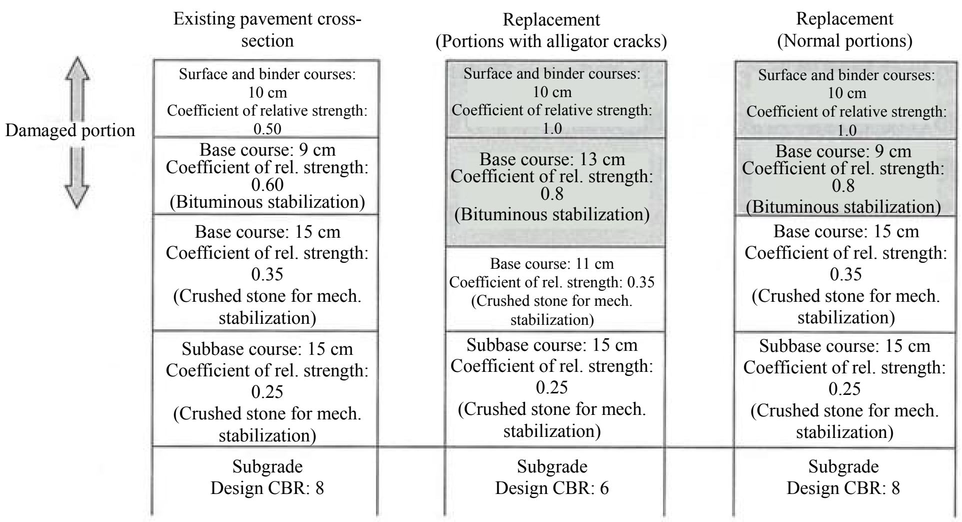
In sections with alligator cracks, the subgrade CBR was less than the design CBR, and damage was relatively severe compared to that observed in other portions. Cross-sections were accordingly improved so as to have the required equivalent thickness corresponding to a design CBR of 6, which was measured by open-cut surveys. The coefficient of relative strength of such sections was 28 cm.

Since traffic control aimed at improvement of this narrow area was expected to have significant effects, a pavement structure was selected so as to ensure the required equivalent thickness with the minimum modification to the base course and layers underneath by making the surface and binder courses as well as the layer formed by bituminous stabilization thicker than those of the existing pavement.

Figure-3.4.5 depicts the cross-section of the selected pavement structure. Improved portions are shaded, while portions having no alligator cracks are illustrated as normal portions.

In sections with alligator cracks, the thickness of the layer formed by bituminous stabilization was increased by 4 cm, while that of the crushed-stone layer for mechanical stabilization in the existing base course was reduced by 4 cm.

The porous asphalt mixture used for the existing pavement was selected to form the surface course. Dense-graded mixture using a binder of Type II polymer-modified asphalt was selected to form the binder course in order to increase the resistance to stripping and flow.



$$T_A = 10\times0.5 + 9\times0.6 + 15\times0.35 + 15\times0.25 = 19.4$$

$$T_A = 10\times1.0 + 13\times0.8 + 11\times0.35 + 15\times0.25 = 28 \geqq 28$$

$$T_A = 10\times1.0 + 9\times0.8 + 15\times0.35 + 15\times0.25 = 26.2 \geqq 26$$

Figure-3.4.5: Example of design of cross-sections to repaired

(2) Example 2 (design using road surface deflection)

1) Required performance (present condition)

The target portion to be repaired was designed by an empirical design method and has been used for 11 years. Pavement repair was planned to remove severe damage to the road surface. Since the target portion was surrounded by urban areas, repair was performed without changing the road surface height.

Table-3.4.23 lists the performance items (design conditions) required for the pavement and the structure of the existing pavement.

Table-3.4.23: Required performance items (design conditions) and structure of the existing pavement

Item	Design condition
Pavement design period	10 years
No. of lanes	Two lanes each way
Traffic volume class	N_5
Designed daily volume for pavement (vehicles/day per direction)	400
No. of wheel loads inducing fatigue failure (times/10 years)	1,000,000
Reliability (%)	90
Design CBR (%)	6
Roadside environment	DID (densely inhabited district)
T_A (cm)	21

Structure of the existing pavement		
Surface and binder courses	Hot asphalt mixture	10 cm
Base course	Crushed stone for mechanical stabilization	10 cm
Subbase course	Crusher-run	30 cm
Subgrade	Sandy soil containing silt	-
Others	• Numerous complaints were received about water splashing. • The road surface height cannot be changed.	

2) Survey of actual conditions of existing pavement

According to the records of maintenance and repair for the sections to repair, surface course replacement was implemented on some sections in the sixth and ninth years after service use began. A road surface survey was performed on the section's down lane as part of a periodic survey. Moreover, visual observation was performed from sidewalks to ascertain the damage condition in detail. The results were as follows.

- Most cracks were linear cracks that developed mainly around vehicles' running paths. They widened into alligator cracks in some portions. In sections that had undergone repair, few cracks were observed; however, fine reflection cracks were formed mainly around vehicles' running paths, and fine-grained ejecta from the cracks were observed.
- Since bumps were formed around vehicles' running paths in rutting portions, the cause of rutting was judged to be flow of asphalt mixture. In sections that had undergone repair, rutting was deep compared to that of typical portions, and depressions were formed in vehicles' running paths.

This fact suggested that the pavement's bearing capacity was insufficient, particularly in those sections that had undergone repair. Thus, structural evaluation with FWD was planned in order to ascertain the actual condition.

3) Surveys with FWD

Figure-3.4.6 shows examples of a road surface characteristics survey and structural survey with FWD. In the diagrams, Section A is a section that had undergone repair. Data on road surface characteristics was obtained from a previous periodic survey.

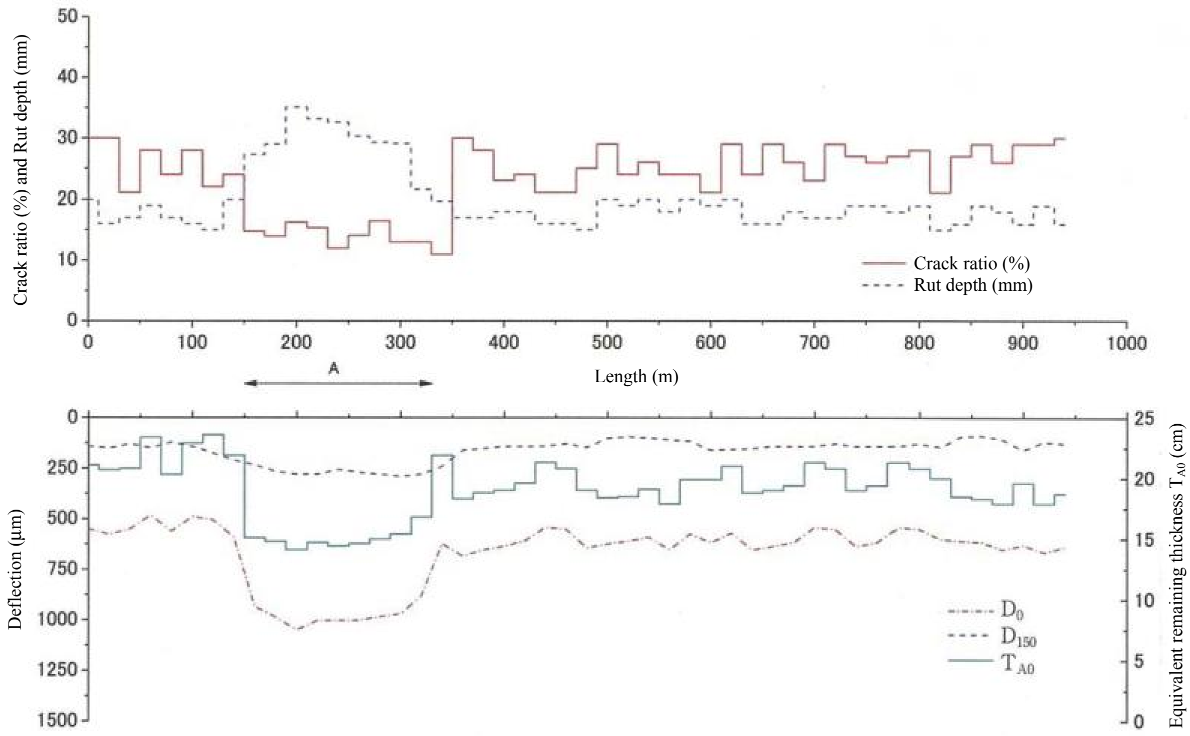


Figure-3.4.6: Examples of results of a survey on damage to existing pavement and its structural evaluation

Above, the lower diagram shows the results of measurement with FWD for surface deflection occurring immediately below the loading point (D_0) and surface deflection at a point 150 cm away from the loading point (D_{150}). The values of D_0 have been converted to values under the standard load (49 kN) at the standard temperature (20°C).

It is thought that D_0 can be related to the pavement's overall bearing capacity (including subgrade), that D_{150} can be related to the subgrade's bearing capacity, and that the value obtained by subtracting D_{150} from D_0 can be related to the pavement's load distribution capacity. Thus, these values were selected to perform structural evaluation of the pavement. The evaluation results were as follows.

(I) Evaluation using D_0

D_0 was used as the index to evaluate the pavement's overall bearing capacity. The pavement was judged to have the required bearing capacity when it was 0.6 mm (**Table-3.4.19**) or less. **Figure-3.4.6** shows that the bearing capacities of all portions except Section A were not substantially insufficient. In Section A, however, D_0 was larger than that of the surrounding portions, substantially exceeding 0.6 mm. It was thus concluded that the pavement in Section A was lacking in terms of bearing capacity.

(II) Evaluation using D_{150}

D_{150} was used as the index to evaluate the subgrade's bearing capacity. The CBR of subgrade was estimated from Equation (3.4.6), which expresses the relationship between D_{150} (mm) and CBR.

$$CBR \text{ of subgrade } (\%) = \frac{1}{D_{150}} \quad \cdots\cdots \quad (3.4.6)$$

where, D_{150}: Deflection at a point 150 cm away from the FWD's loading point (mm).

The design CBR calculated from the CBR of subgrade was 6 for portions other than Section A. This value is equal to the design CBR realized during the construction stage.

For Section A, the design CBR was 3, which is substantially less than the design CBR realized during the construction stage. Thus, design for the pavement in Section A was implemented under the condition of a design CBR of 3.

(III) Evaluation using $D_0 - D_{150}$

It is thought that pavement's equivalent thickness T_A can be related to the value obtained by subtracting deflection D_{150} (at a point 150 cm away from the loading point) from deflection D_0 (occurring immediately below the loading point). Equation (3.4.7) has been proposed[13)] as an equation to make use of $D_0 - D_{150}$ (mm) to estimate the equivalent remaining thickness (T_{A0}) of existing pavement. The equivalent thickness of the existing pavement was evaluated using this equation. **Figure-3.4.6** shows the results of T_{A0} calculation.

$$T_{A0} \text{ (cm)} = -25.8 \log (D_0 - D_{150}) + 11.1 \quad \cdots\cdots \quad (3.4.7)$$

where, D_0 : Deflection occurring immediately below the FWD's loading point (mm); and

D_{150} : Deflection at a point 150 cm away from the FWD's loading point (mm).

The target equivalent thickness for sections having a design CBR of 6 (sections other than Section A) was 21 cm, and that for the section having a design CBR of 3 (Section A) was 26 cm.

The pavement was judged to lack in bearing capacity when the equivalent remaining thickness calculated from $D_0 - D_{150}$ was less than these values.

In most portions other than Section A, T_{A0} was not substantially less than 21 cm. Throughout the entire evaluated section, the conversion factors for the surface and binder courses had fallen, and cracking had occurred. It was therefore concluded that the required equivalent thickness would be nearly completely recovered by replacing these layers.

On the other hand, it was concluded that Section A, where T_{A0} was substantially less than 26 cm, required replacement or other large-scale repair.

The elastic moduli of the pavement layers in Section A were estimated from the results of measurement with FWD and the thicknesses of the layers measured by the open-cut survey to evaluate the existing pavement's bearing capacity in detail.

The coefficient of relative strength of each existing pavement layer is generally determined from damage conditions and other factors. In this evaluation, however, the elastic modulus of each typical asphalt pavement layer was selected based on the results of measurement with FWD, and the coefficient of relative strength was estimated[14)] from the selected elastic modulus. If the estimated coefficients of relative strength deviate from their corresponding ranges in **Table-3.4.18**, they must be set to values within these ranges. **Table-3.4.24** lists the coefficients of relative strength thus estimated from elastic moduli. It also shows the equivalent remaining thickness T_{A0} of the existing pavement calculated from the estimated coefficients of relative strength.

The listed elastic moduli for the surface and binder courses are less than those for the normal asphalt mixture. This fact suggests their strength had substantially degraded.

Table-3.4.24: Elastic moduli and coefficients of relative strength calculated for Section A based on FWD measurement results

Item	Elastic modulus* (MPa)	Pavement thickness (cm)	Est. coefficient of relative strength a_i	Remarks
Surface and binder courses	1,450	10	0.60	(10 × 0.60 = 6.0)
Base course	220	10	0.30	(10 × 0.30 = 3.0)
Subbase course	100	30	0.22	(30 × 0.22 = 6.6)
Subgrade	35	-	-	The CBR estimated from the elastic modulus of subgrade is 3.5. For a design CBR of 3, the required T_A is thus 26.
Equivalent remaining thickness T_{A0} of existing pavement			15.6	
Shortfall of T_A			25.2 − 15.6 = 9.6	

* Converted elastic modulus corresponding to a temperature of 20°C

The same analysis performed on portions other than those of Section A yielded the values listed in **Table-3.4.25**.

Table-3.4.25: Elastic moduli and coefficients of relative strength calculated for portions other than Section A based on FWD measurement results

Item	Elastic modulus* (MPa)	Pavement thickness (cm)	Est. coefficient of relative strength a_i	Remarks
Surface and binder courses	2,500	10	0.70	(10 × 0.70 = 7.0)
Base course	350	10	0.35	(10 × 0.35 = 3.5)
Subbase course	150	30	0.25	(30 × 0.25 = 7.5)
Subgrade	75	-	-	The CBR estimated from the elastic modulus of subgrade is 7.5. For a design CBR of 6, the required T_A is thus 21.
Equivalent remaining thickness T_{A0} of existing pavement			18.0	
Shortfall of T_A			21 − 18.0 = 3.0	

The evaluation method described in this section is applied primarily when evaluating asphalt pavement. When applying it to evaluate concrete pavement, different conditions must be considered. If the coefficients of relative strength estimated from the elastic moduli of layers deviate from the ranges listed for various materials in **Table-3.4.18**, the upper or lower limits of the ranges may be used for evaluation.

4) Additional surveys for identifying damage causes

The results of the aforementioned structural evaluation with FWD suggested that the pavement in Section A substantially lacked in bearing capacity. To directly examine the damage condition of Section A, an open-cut survey was carried out to ascertain the conditions of the surface and binder courses, base course, and subgrade; moreover, a CBR test was performed on the subgrade. In addition, core sampling was performed near cracks in portions other than Section A to ascertain the depths to which cracks had reached as well as the condition of the asphalt mixture. The results were as follows.

- In Section A, the base course and subgrade exhibited high water content and the design CBR determined from the sampled subgrade soil was 3. Most cracks penetrated through the surface and binder courses.
- In cores sampled from portions other than Section A, cracks often reached the binder course, and alligator cracks penetrated through the binder course.

5) Examination of pavement structure and selection of maintenance and repair methods

The above surveys revealed that most cracks reached as deep as the binder course. It was therefore concluded that since reflection cracking would occur, durability could not be ensured merely by replacing the surface course.

Evaluation with FWD revealed that pavement in portions other than Section A lacked 3 cm in equivalent thickness. However, replacement of the surface and binder courses would boost their coefficients of relative strength from 0.7 to 1.0, increasing equivalent thickness by $(1.0 - 0.7) \times 10 = 3.0$, thus enabling equivalent thickness to reach its target value, 21 cm.

Based on this conclusion, it was decided to replace the surface and binder courses in portions other than Section A. Since numerous complaints about water splashing had been received, Type II polymer-modified asphalt having high flow resistance was selected as the binder for the surface and binder courses in order to suppress rutting.

For Section A, a repair method that would substantially recover the pavement cross-section's bearing capacity needed to be selected. To this end, a repair cross-section having the required bearing capacity was designed using the coefficients of relative strength estimated from the results of measurement with FWD.

Since the height of the portions to be repaired could not be changed, repair of cross-sections using three selected methods that do not change the road surface height were examined. **Figure-3.4.7** illustrates design examples of these. The portions to improve are shaded in the figure.

A theoretical design method based on the multi-layer elasticity theory is available to verify the adequacy of examined pavement cross-sections. For details, refer to the *Pavement Design Handbook*.

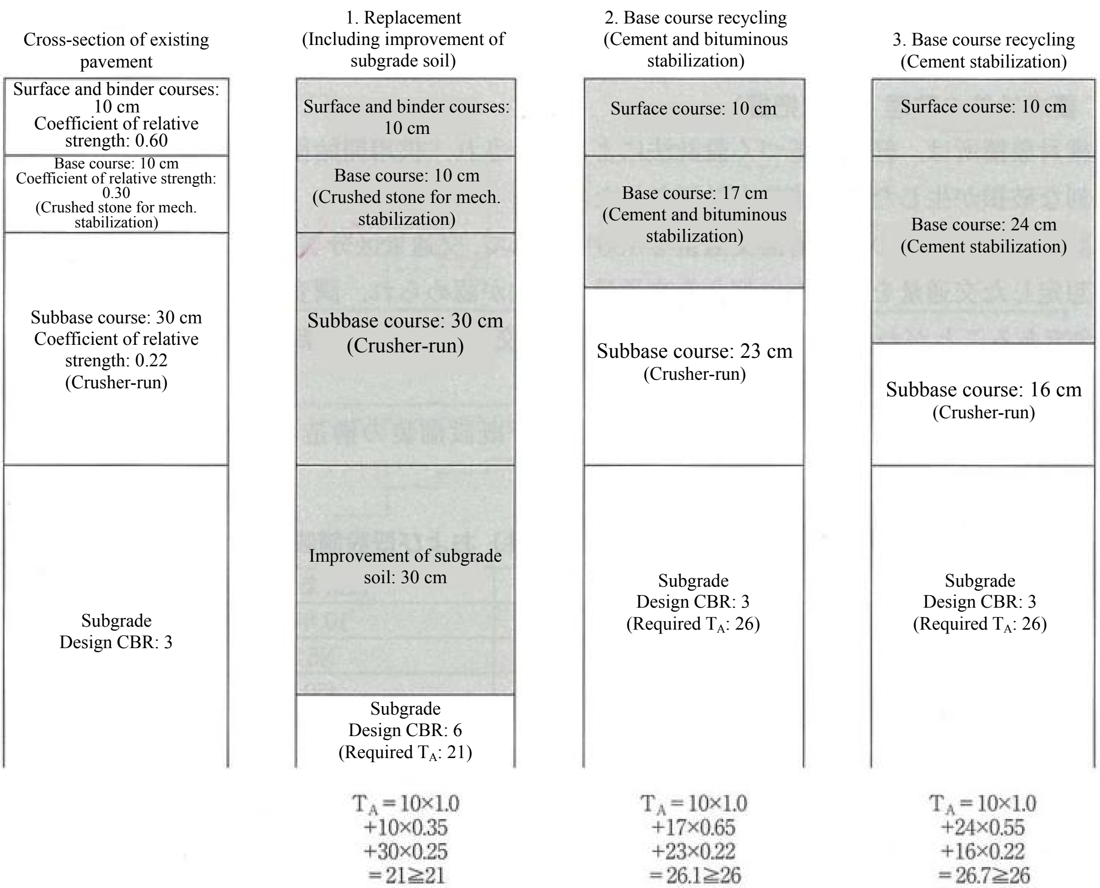


Figure-3.4.7: Examples of design of repair cross-sections

The characteristics of the three selected methods are as follows.

[1. Replacement (including improvement of subgrade soil)]

Replacement is performed to replace all pavement layers. Since the CBR of subgrade was less than the initial design CBR, its soil was improved beforehand. In the design example, the upper 30-cm portion of subgrade was improved with concrete to become soil with a CBR of 20, and the CBR of subgrade was thereby boosted to 6. This approach allowed the base course and layers above to be reconstructed without changing the thickness of the existing pavement.

[2. Base course recycling (cement and bituminous stabilization)]

Base course recycling (cement and bituminous stabilization) crushes the existing asphalt mixture and base course materials for reuse as aggregate. Cement and bituminous material (e.g., asphalt emulsion and foamed asphalt) are mixed with the aggregate on-site to achieve stabilization. In the design example, the asphalt mixture was removed to ensure the thickness of the surface and binder courses, and stabilization was carried out using only the existing base course material as aggregate. The required equivalent thickness was realized by ensuring a 17-cm stabilized base course and reconstructing 10-cm surface and binder courses.

[3. Base course recycling (cement stabilization)]

Base course recycling (cement stabilization) was designed in a manner similar to 2. Since the coefficient of relative strength of the stabilized layer differed from that in 2, the improved thickness became 24 cm.

In the end, one of the three methods was selected after comprehensively considering the constraint imposed by the road surface height, constraints due to traffic control, repair expenses, constraints due to the locations of buried objects, constraints due to road construction, the schedule for future work in accordance with road occupancy, consideration of the roadside environment, and other matters.

A theoretical design method based on the multi-layer elasticity theory is available to verify the adequacy of examined pavement cross-sections. For details, refer to the *Pavement Design Handbook*.

(3) Example 3 (design using road surface deflection)

1) Required performance (present condition)

The target portion to be repaired was designed by an empirical design method and has been used for three years. Repair was planned since its road surface suffered severe damage.

The structure of the route concerned was designed in accordance with traffic volume class N_4 so as to satisfy a designed daily volume of 150 vehicles. However, the actual traffic volume on the route substantially exceeded the expected level. According to a survey, the required designed daily volume was 450 vehicles. This value suggested that the route needed to have a traffic volume class of N_5.

Table-3.4.26 lists the performance items (design conditions) required for the pavement and the structure of the existing pavement.

Table-3.4.26: Required performance items (design conditions) and structure of the existing pavement

Item		Design condition
Pavement design period		10 years
Traffic volume class		N_5
Designed daily volume for pavement (vehicles/day per direction)		450
No. of wheel loads inducing fatigue failure (times/10 years)		1,000,000
Reliability (%)		90
Design CBR (%)		8
Roadside environment		Mountainous district
T_A (cm)		19
Structure of existing pavement		
Surface course	Hot asphalt mixture	5 cm
Base course	Crushed stone for mechanical stabilization	15 cm
Subbase course	Crusher-run	15 cm
Subgrade	Gravel soil	-
Others	• The road surface height can be changed.	

2) Survey of actual conditions of existing pavement

Damage conditions were observed from sidewalks as part of preparations for designing maintenance and repair. The results were as follows.

- Most cracks were observed mainly around vehicles' running paths; in many portions, they had widened into alligator cracks.
- Deep rutting had occurred as well as sinking in vehicles' running paths.
- Traces of pothole recovery were observed in many portions.

It was obvious the pavement's bearing capacity was insufficient for the traffic load, leading to rapid damage. Thus, the pavement required substantial structural improvement. Since structural design had to be performed by considering the structural damage to the existing pavement, structural evaluation with FWD was carried out.

3) Survey with FWD

Table-3.4.8 shows the results of a structural survey with FWD. It also contains data on road surface characteristics.

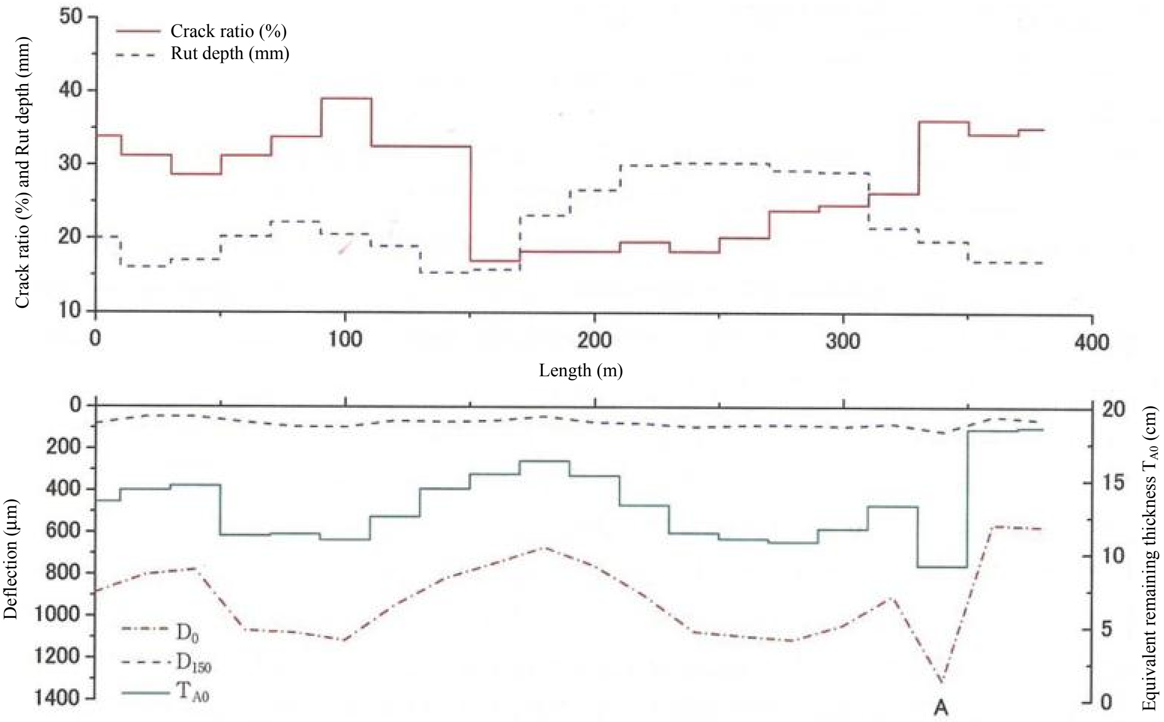


Figure-3.4.8: Examples of results of a survey on damage to existing pavement and its structural evaluation

Pavement soundness was evaluated on the premise that deflection occurring immediately below the FWD's loading points (D_0) was 0.9 mm in accordance with the design condition of traffic volume class N_4. At most points, D_0 values measured with FWD exceeded 0.9 mm. The equivalent remaining thickness T_{A0} estimated from the deflection determined by measurement with FWD, $D_0 - D_{150}$, was less than the design-stage equivalent thickness, 14 cm, in most portions. Both measurement results suggested that the pavement lacked in bearing capacity.

The CBR of subgrade was subsequently estimated from deflection D_{150} measured with FWD, and the design CBR was calculated from the estimated CBR. The obtained design CBR was 8, which was equal to its initial value.

The evaluated section contained many portions having a crack ratio in excess of 35%. This fact suggested that the surface course had substantially decreased in strength. For a coefficient of relative strength of 0.5, which was determined by considering the pavement's damage condition, replacing the surface course would increase the equivalent thickness by $(1 - 0.5) \times 5 = 2.5$ cm. The equivalent thickness obtained by adding this thickness to the equivalent remaining thickness T_{A0} estimated from measurement with FWD exceeded 14 cm, the design-stage equivalent thickness, for most portions of the existing pavement. This fact suggested that the base course and layers underneath retained their normal bearing capacities.

4) Additional surveys for identifying damage causes

Although traffic volume exceeding the design value caused damage to occur early for the section concerned, evaluation based on measurement with FWD suggested that the subgrade and base course retained their construction-stage bearing capacities. To observe the conditions of the base course and layers underneath directly, an open-cut survey was carried out at Point A, where large deflection was measured with FWD.

However, no distinctive abnormalities were found in such layers, and the CBR of sampled subgrade soil was 7.6.

Since the CBR of subgrade was as high as the construction-stage design CBR, the design CBR for the section concerned was set to 8, the same as its construction-stage value. Though the CBR at Point A was less than the design CBR, this deviation was judged to be within the normally observed range of variation.

5) Examination of pavement structure and selection of maintenance and repair methods

Based on the aforementioned survey results, it was concluded that the existing base course and layers underneath retained their construction-stage bearing capacities.

For a design CBR of 8 with traffic volume class N_5, the target T_A was 19 cm, so a pavement structure and repair method were selected to achieve this value.

Since the section's road surface height could be increased, the two methods shown in **Figure-3.4.9** were identified as candidates, after which a repair cross-section formed with these methods was designed. The portions to improve are shaded in the figure.

The characteristics of these methods are as follows.

[1. Surface course replacement]

Surface course replacement replaces only the existing surface course; use of this method would ensure the required bearing capacity by reconstructing a total of 10 cm of surface and binder courses after removing the existing surface course, thus raising the road surface by 5 cm.

[2. Base course recycling (cement and bituminous stabilization)]

Base course recycling (cement and bituminous stabilization) crushes the existing asphalt mixture and base course materials for reuse as aggregate. Cement and bituminous material (e.g., asphalt emulsion and foamed asphalt) are mixed with the aggregate on-site to achieve stabilization. Since the section's road surface height could be changed, stabilization would be implemented by crushing and mixing 5 cm of the existing surface course and 6 cm of the existing base course. The required bearing capacity would be ensured by reconstructing a 5-cm surface course atop the 11-cm stabilized layer, raising the road surface by 5 cm.

A method was selected by comprehensively considering expenses, constraints due to the locations of buried objects, constraints due to road construction, the schedule for future work in accordance with road occupancy, and other matters. For example, surface course replacement (1) is generally advantageous when exclusively considering costs, whereas base course recycling (2) has the advantage of re-using all pavement waste on-site.

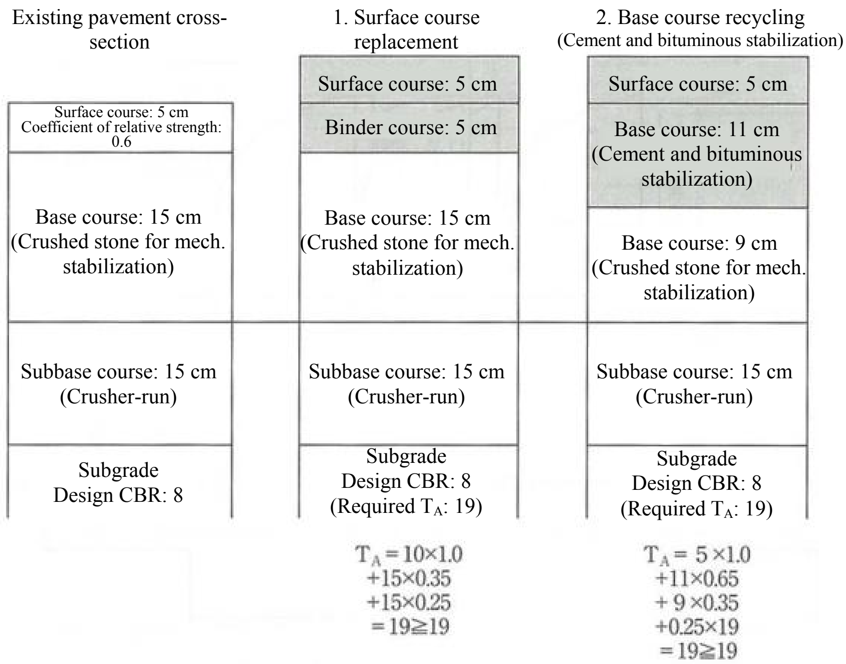


Figure-3.4.9: Example of design of cross-sections to repaired

3-4-7 Design considering LCC

As described in Chapter 2, the ideal form of pavement administration is intended "to achieve administration that is easy-to-understand and transparent to road users and taxpayers" and "to achieve efficient administration that yields optimal effects at minimal costs." To this end, management approaches to series of pavement administration activities are effective. Management approaches enable optimal, flexible design of maintenance and repair of pavement in accordance with the circumstances at hand. Such characteristics are essential for narrowing down candidate maintenance and repair methods as described in the preceding section. The following describes how to select a maintenance and repair method from the perspective of lifecycle costs (LCC).

(1) Selection based on a comparison of the timing of performance recovery by design

When it is necessary to recover pavement performance that has degraded during service use to its original level, recovery during an early stage is advantageous in terms of LCC as illustrated in the lower-left diagram in **Figure-3.4.10**. However, the case illustrated in the lower-right diagram may occur in some situations.

(2) Selection based on a comparison of service lives achieved by maintenance and repair methods

Figure-3.4.11 illustrates an example of a comparison between methods when the ratio of service lives achieved by them is 1:2. This example suggests that maintenance and repair methods for recovering degraded pavement performance can be selected from the perspective of LCC by considering future maintenance and repair work as well as expenses for maintenance and repair at that point in time, depending on the specified design period.

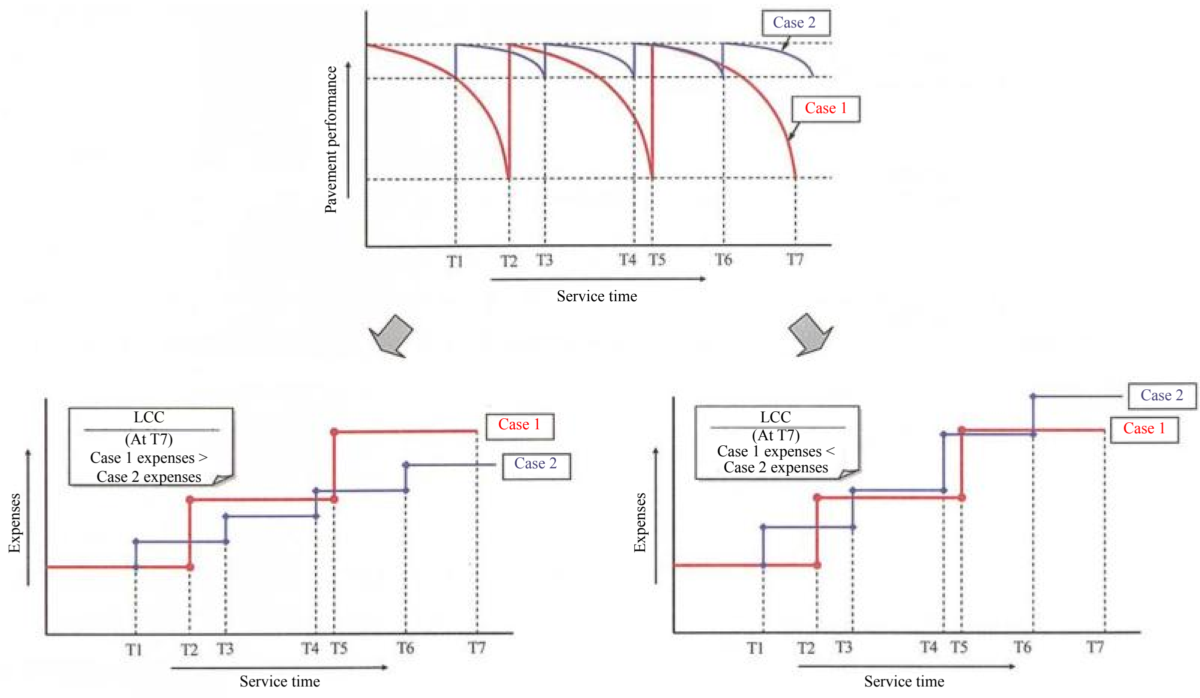


Figure-3.4.10: Concept of LCC (1)

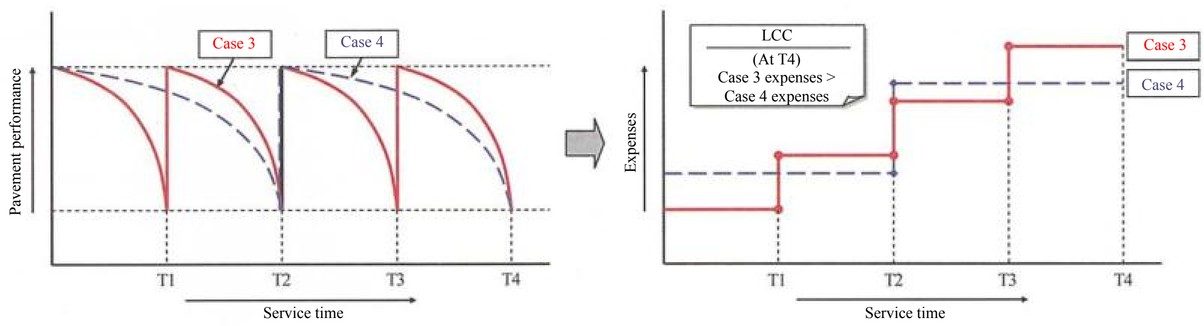
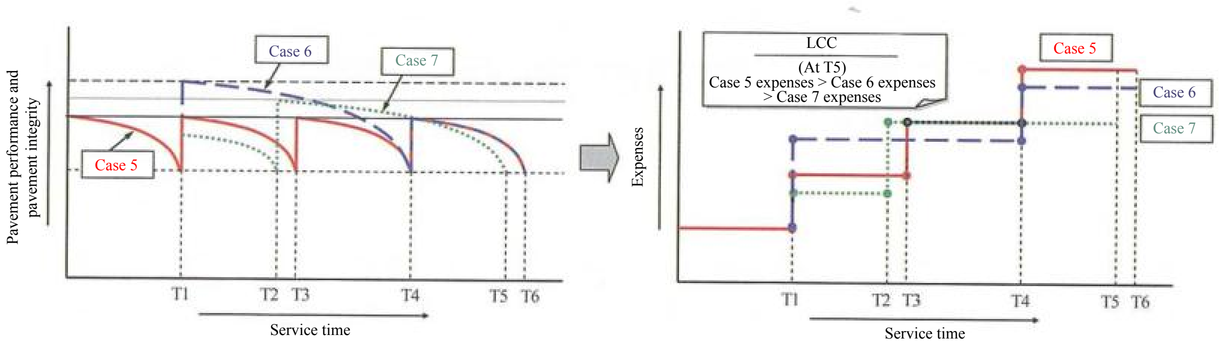


Figure-3.4.11: Concept of LCC (2)

(3) Selection of a method based on evaluation of cost effectiveness

In design for recovering pavement performance, it is also required to compare and examine the cost effectiveness of applicable maintenance and repair methods based on the currently-required performance by considering the performance level to recover and the timing of recovery, as illustrated in **Figure-3.4.12**.



* Case 5: To recover to the initial performance level
Case 6: To recover to a level higher than the initial performance level
Case 7: To recover to a level less than the initial performance level first, and then subsequently to a level higher than the initial performance level

Figure-3.4.12: Concept of LCC (3)

In the design of maintenance and repair, it is always important to evaluate the performance of existing pavement and to forecast the pavement performance that will be achieved by maintenance and repair work in an appropriate, accurate manner. Such evaluation and forecasting can be achieved with the aid of a database enriched by accumulated data and appropriate use thereof during each stage.

[References]

1) Road Management Technology Center: FWD Operation Manual (Draft), March 1996
2) Teruhiko Maruyama, Kenji Himeno, and Masanori Hayashi: A Survey of Soundness of Pavement by Deflection Measurement with FWD, *Hoso* (Pavement), Vol. 24-9, pp. 3–8, September 1989
3) Nagato Abe, Teruhiko Maruyama, Kenji Himeno, and Masanori Hayashi: Structural Evaluation of Pavement Using the Deflection Evaluation Index, Journal of JSCE, No. 460 V-18, pp. 41–48, February 1993
4) Kiyoshi Fujinami and Kunihito Matsui: Development of BALM for Windows, Software for Static Structural Diagnosis of Pavement, 27th Collection of Papers of the Japan Road Association, No. 20P08, September 2007
5) Tomotaka Aoki, Kenji Himeno, and Tomoo Otani; Development of Forward and Inverse Analysis Programs for Windows 95/98 Based on Multi-layer Elastic Analysis, 23rd Collection (C) of Papers of the Japan Road Association, pp. 494–495, October 1999
6) Japan Cement Association: Technical Materials for Repair of Concrete Pavement (2005 edition), p. 30, August 2005
7) Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism: Common Specifications for Civil Engineering Work, Vol. 3, Common Volume for Civil Engineering Work, pp. 3–113, April 2013
8) Committee on Pavement Engineering, JSCE: Handbook on Operation of FWD and Small FWD, Pavement Engineering Library 2, December 2002
9) Federal Highway Administration (FHWA): Distress Identification Manual for Long-term Pavement Performance Program, June 2003
10) Japan Road Association: Pavement Construction Handbook (2006 edition), February 2006
11) Japan Road Association: Guidelines for Pavement Design and Construction (2006 edition), February 2006
12) Japan Road Association: Pavement Design Handbook, February 2006
13) Japan Society of Civil Engineers: Basis of Pavement Engineering (Pavement Engineering Library 7), p. 226, April 2012
14) Hisashi Fujinaga, Masakazu Orui, and Norihiro Kikuchi: Structural Evaluation with FWD and Application to Pavement Repair Design, 11th Hokuriku Road Pavement Conference, June 2009

Chapter 4: Implementation of Maintenance and Repair

4-1 Overview

This chapter describes typical maintenance and repair methods for asphalt pavement, porous asphalt pavement, and concrete pavement, listing the materials to be used, site conditions for application, considerations on implementation, and other related matters for each method.

An appropriate method to implement actual maintenance and repair must be selected from among these maintenance and repair methods by properly considering damage to existing pavement, road and roadside conditions, pavement bearing capacity, constraints on construction, past repair records, and other factors. Appropriate designing must also be implemented as necessary.

This guidebook chiefly concerns maintenance and repair of pavement, but like maintenance and repair, road construction is implemented in various cases, (e.g., to provide new functions to satisfy new needs for pavement or to change the number of wheel passes causing fatigue failure to meet increased traffic volume). Road construction is also implemented to realize recovery after works relative to road occupancy for burying pipelines for electricity, gas, water supply/sewage, and other utilities. This chapter outlines various types of road construction and describes considerations on road construction and other matters with the aid of tables, photographs, and diagrams.

Road construction for maintenance and repair differs from construction of new pavement in that traffic control must be imposed to secure work zones along service routes. Thus, the influence of construction on traffic (e.g., traffic congestion during traffic control) must be minimized and appropriate measures must be taken to ensure safety and environmental conservation.

4-1-1 Maintenance and repair methods

Maintenance refers to repeatedly performed mending or light mending which is implemented to recover road surface performance or delay the advance of degradation in structural pavement strength. Repair is implemented to ensure performance that satisfies administrative requirements when maintenance is either not economical or is not expected to lead to sufficient recovery. At times, preventive maintenance is performed before pavement has suffered damage.

Table-4.1.1 lists the types of typical maintenance methods, while **Table-4.1.2** lists the types of typical repair methods.

Table-4.1.1: Types of maintenance methods

Maintenance method type		Asphalt pavement	Porous asphalt pavement	Concrete pavement
Patching and run-off of faulting	Hot mixing method	○	○	○
	Cold mixing method	○	○	○
Sealant injection		○		
Sealing				○
Cutting		○		
Surface treatment	Fog seal	○		
	Chip seal	○		
	Slurry seal	○		○
	Micro surfacing	○		○
	Carpet coating	○		○
	Resin surface treatment	○		○
	Drainage topcoat method		○	
	Permeable resin mortal filling		○	
Washing of void choking			○	
Surface texturing				○
Grooving		○		○
Thin overlay		○		○
Overlay on rutting		○		○
Road surface maintenance with in-place surface recycling machines, etc.		○		
Injection method				○
Bar stitching				○

Table-4.1.2: Types of repair methods

Maintenance method type	Asphalt pavement	Porous asphalt pavement	Concrete pavement
Replacement	○	○	○
Local replacement	○	○	○
Overlay	○		○
Replacement of surface and binder courses (mill and overlay)	○	○	
In-place base course recycling	○	○	
In-place surface recycling	○		
Thin concrete overlay	○		○

4-1-2 Materials for maintenance and repair

Various materials are used to perform maintenance and repair of pavement. Materials suitable for the environmental and construction conditions must be selected by considering their characteristics, damage causes, and the scale and urgency of construction.

Table-4.1.3 lists examples of materials for maintenance, while **Table-4.1.4** lists examples of materials for repair.

Table-4.1.3: Examples of materials for maintenance

Maintenance method type		Material
Patching and run-off of faulting	Hot mixing method	Hot asphalt mixture
	Cold mixing method	Asphalt emulsion-based mixture
		Cut-back asphalt-based mixture
		Resin-based mixture
		Cement mortar (ordinary, high early strengthening, and very rapid setting materials)
		Cement concrete (ordinary, high early strengthening, and very rapid setting materials)
		Resin mortar and resin concrete
Sealant injection Sealing		Hot asphalt-based sealant
		Asphalt emulsion-based sealant
		Resin-based sealant
Surface treatment	Fog seal	Asphalt emulsion
	Chip seal	Asphalt emulsion and aggregate
	Slurry seal	Slurry seal mixture
	Micro surfacing	Micro surfacing mixture
	Carpet coating	Hot asphalt mixture
	Resin surface treatment	Resin and hard aggregate
	Drainage topcoat method	Resin and hard aggregate
	Permeable resin mortal filling	Permeable resin mortar
Thin overlay		Hot asphalt mixture
Overlay on rutting		Hot asphalt mixture
		Resin mortar
Road surface maintenance with in-place surface recycling machines, etc.		Hot asphalt mixture
Injection method		Asphalt-based and cement-based grout
Bar stitching		Steel, cement mortar, resin-based grout, and resin mortar

Table-4.1.4: Examples of materials for repair

Maintenance method type	Material
Replacement	Hot asphalt mixture
	Pervious cement mixture for semi-flexible pavement
	Cement concrete (ordinary, high early strengthening, and very rapid setting materials)
	Precast concrete slab
Local replacement	Hot asphalt mixture
	Cement concrete (ordinary, high early strengthening, and very rapid setting materials)
Overlay	Hot asphalt mixture
	Cement concrete (ordinary, high early strengthening, and very rapid setting materials)
	Reinforced concrete with fiber
Replacement of surface and binder courses (mill and overlay)	Hot asphalt mixture
	Pervious cement mixture for semi-flexible pavement
In-place base course recycling	Cement, asphalt emulsion, and foamed asphalt
In-place surface recycling	Hot asphalt mixture and rejuvenator
Thin concrete overlay	Reinforced concrete with fiber

For repair of surface courses, appropriate materials and methods must be selected to realize the required road surface performance. **Table-4.1.5** lists examples of the types of performance expected from road surfaces as well as the materials and methods, etc. available for realizing such performance.

Table-4.1.5: Examples of types of performance expected from road surfaces as well as the materials and methods, etc. available for realizing such performance

Type of performance expected from road surface	Material classification	Materials, methods, etc.
Plastic deformation resistance	Asphalt-based material	Semi-flexible pavement and polymer-modified asphalt mixture
	Cement-based material	Cement concrete for pavement and reinforced concrete with fiber Precast concrete slab
Surface roughness	Asphalt-based material	Continuous-grading/gap-graded asphalt mixture and cold mixture Thin surfacing
Water permeability	Asphalt-based material	Porous asphalt mixture
	Cement-based material	Porous concrete
	Resin-based material	Permeable resin mortar
Drainage	Asphalt-based material	Porous asphalt mixture
	Cement-based material	Porous concrete
	Resin-based material	Permeable resin mortar
Noise reduction	Asphalt-based material	Porous asphalt mixture
	Cement-based material	Porous concrete
	Resin-based material	Permeable resin mortar
Skid resistance	Asphalt-based material	Gap-graded and open-graded asphalt mixtures Chip sealing, micro surfacing, and thin surfacing
	Cement-based material	Porous concrete
	Resin-based material	Neat construction method
Abrasion resistance	Asphalt-based material	Filler-containing asphalt mixture and crushed stone/mastic mixture
	Cement-based material	Cement concrete for pavement and reinforced concrete with fiber
Resistance to aggregate scattering	Resin-based material	Permeable resin mortar and drainage topcoat method
Road surface temperature reduction	Asphalt-based material	Water-retentive pavement (using porous asphalt mixture and water-retaining materials)
	Cement-based material	Porous concrete
	Resin-based material	Heat-shield pavement
Light coloration	Asphalt-based material	Semi-flexible/rolled asphalt pavement using light-colored aggregate
	Cement-based material	Cement concrete for pavement and reinforced concrete with fiber Precast concrete slab
	Resin-based material	Resin mixture and mortar, permeable resin mortar, neat construction method Drainage topcoat method
	Block-type material	Interlocking blocks, bricks, natural stone blocks
Colorability	Asphalt-based material	Asphalt mixture using dye or colored aggregate
		Semi-flexible pavement using colored cement milk
	Resin-based material	Resin mixture and mortar, permeable resin mortar, neat construction method Drainage topcoat method

4-2 Maintenance methods

Maintenance refers to repeatedly performed mending or light mending which is implemented to recover road surface performance or delay the advance of degradation in structural pavement strength. Major maintenance methods include patching, sealant injection, and surface treatment.

4-2-1 Patching and run-off of faulting

Patching and run-off of faulting (hereafter, patching) is implemented as a provisional measure to recover trafficability for vehicles by filling potholes, faulting portions, local cracks, and settlement as well as other depressed portions with patching material. Patching is implemented by directly filling damaged portions with material in place or after removal. The direct filling method is used as an emergency measure.

Asphalt mixtures for patching include hot asphalt mixtures (hot-mixed type) and cold asphalt mixtures based on cold-mixed type cut-back asphalt and asphalt emulsion. Cold-setting materials for patching include resin-based mixtures, asphalt emulsion-based mixtures, and cement-based materials. In recent years, all-weather materials, which can be used even when rainwater or other moisture sources are present, and slurry-type materials, which require neither compaction nor run-off, have been developed as advanced cold-setting materials. Cement-based materials are used mainly for concrete pavement. Such materials are not always produced in plants as final products; they are provided in various types of packing. For use in small quantities or emergency use, some are supplied in the form of measured packages of a series of raw materials to facilitate easy mixing of the raw materials. Others are supplied in the form of packed products. Appropriate patching materials should be selected by considering damage levels, urgency, traffic conditions, economic efficiency, existing pavement types, and other relevant conditions. **Table-4.2.1** lists major patching materials and their applications.

Table-4.2.1: Major patching materials and their applications

Material type			Application		
			Dense graded asphalt pavement	Porous asphalt pavement	Concrete pavement
Hot-mixed type	Hot asphalt mixture		○	○	△
Cold-mixed type	Cold asphalt mixture		○	○	△
	Cold-setting material	Resin-based material	○	○	○
		Asphalt emulsion-based material	○	○	△
		Cement-based material	△	△	○
		All-weather material	○	○	△

○: Applicable; △: Applicable under some conditions

(1) Patching with hot-mixed type material

General patching with hot-mixed type material, which uses ordinary hot asphalt mixture, realizes high durability at a low cost.

For this type of patching, dense graded[13] or fine graded[13] asphalt mixture is generally used. When forming pavement having a thickness of 3 cm or more for roadways, fine graded asphalt mixture[13] offers superior durability. However, the same type of material as used in existing pavement is sometimes selected after considering damage levels and road surface performance. Note that since this type of patching uses hot asphalt mixture, special consideration must be given to prevent decreases in material temperature in some types of construction, such as small-scale construction or construction for interspersed portions.

The following outlines an example procedure for patching with hot asphalt mixture.

1. Cut out and remove the damage-affected portions (which consist of the damaged portions and surrounding defective portions) with a cutter or breaker as shown in **Figure-4.2.1** as necessary. **Photograph-4.2.1** depicts the removal of a damage-affected portion.
2. Carefully clean away any dirt, mud, or other foreign materials from the work area and surrounding environs.
3. Dry the construction portion (if wet) with a burner or other device.
4. Apply a tack coat thoroughly to side faces and the bottom. Adjust the amount of bituminous tack-coat material that accumulates in the depressed portions on the bottom using a wiper (e.g., a cloth) to remove excess tack-coat material. Leave the tack-coat material untouched until it has completely decomposed. Asphalt emulsion (PK-4) is generally used as tack-coat material. However, blown, rubber-based, or other special bituminous material may be used to form a thin tack coat or to form a tack coat to prevent local cracking as shown in **Photograph-4.2.2**.
5. Fill in the depressed portions with the required amount of material; spread the material while giving consideration to extra banking. When the spreading thickness is 7 cm or more, form the material in two layers. Coarse aggregate that is left at joints with the existing pavement is likely to become scattered. Remove such aggregate with a rake or other piece of equipment, or use a sieve to give an elaborate finish to such joints using only the fine-grained fraction of material.
6. Roll edges with a smoother, blade, or similar device; then, compact the entire portion with a road roller or similar device taking care to prevent material from protruding from the portion. In small-scale construction, the entire portion is sometimes compacted with a blade or similar device as shown in **Photograph-4.2.3**. In such cases, a rammer should also be used to compact any thick portions. In this type of construction as well, compaction must be performed from the edges to the center.
7. End traffic control when pavement surface temperature has decreased to approximately 50°C or lower. Before ending traffic control, a seal coat may be formed by scattering sand and stone dust over asphalt emulsion applied to the edges in order to prevent scattering of material, etc. and to protect the joints.

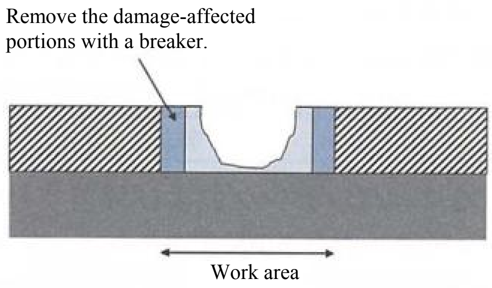


Figure-4.2.1: Construction cross-section around the damage-affected portion

Photograph-4.2.1: Removal of the damage-affected portion

Photograph-4.2.2: Application of special bituminous material

Photograph-4.2.3: Compaction with a blade

(2) Patching with cold asphalt mixture

Cold asphalt mixture is generally supplied in the form of packed products. Different cold asphalt mixture products have different properties; many can be stored for several months and offer excellent portability. Thus, cold asphalt mixture products should be stored as a preparation for emergencies.

Although cold asphalt mixture takes longer to develop strength than hot asphalt mixture, it is compacted by traffic, allowing traffic control to be ended early. However, since pavement formed from some products may be deformed by large vehicle traffic, data and documents provided by mixtures' manufacturers should be referenced when making a selection.

Patching with cut-back asphalt material is basically implemented in accordance with the same procedure as used in "(1) Patching with hot-mixed type material." In addition, the following matters should be considered.

1. Since the mixture requires a long time to stabilize, measures (e.g., exposing the mixture to the air after spreading and allowing sufficient time for compaction) should be implemented.
2. In small-scale construction, no tack coat may be applied. Since the mixture will be compacted by traveling vehicles, traffic control may be ended after formation and compaction of the patched portions have been completed using only a shovel back, tamper, or similar device. **Photograph-4.2.4** shows construction using packed material.

Photograph-4.2.4: Construction using packed material

(3) Patching with cold-setting material

Cold-setting materials include resin-, asphalt emulsion-, and cement-based materials. All require specific setting times and exhibit high durability. Some can be applied even if construction portions are wet.

1) Patching with resin-based material

Resin-based materials are classified into epoxy-, urethane-, acryl-, and polyester-based materials as well as other types according to resin type. They are also categorized as mortar-based materials, ordinary dense graded materials, and various other types of materials according to grading. Products' characteristics must be sufficiently understood prior to application.

Patching with cold-setting material must basically be implemented in accordance with the procedures (or manual) for each product. The following is an example of patching with a slurry-type cold-setting material.

1. Cut out and remove the damage-affected portions (which consist of the damaged portions and surrounding defective portions). The work area should be masked when using a material necessitating no run-off. For concrete pavement, remove laitance, thin mortar layers, and foreign materials attached to the construction portion by chipping, blasting, or other methods; then, remove dust using compressed air or other means.
2. Carefully clean away any dirt, mud, or other foreign materials from the work area and surrounding environs.
3. When using resin-based material, dry the construction portion (if wet) with a burner or other device.
4. When using resin-based material, confirm the surface to be patched is dry; then, uniformly apply primer to the surface. Adjust the amount of primer that accumulates in the depressed portions on the bottom using a wiper (e.g., a cloth) to remove excess primer. When used on existing asphalt pavement, some modified-asphalt emulsion-based materials and cement-based materials do not permit application of a tack coat. When used on concrete pavement, however, a tack coat must be applied.
5. Fill in the depressed portions with the required amount of material; spread and level off the material with a trowel or similar tool. **Photograph-4.2.5** shows spreading to even a faulting portion.

6. No compaction is generally required. Spread material with a trowel to give a finish.
7. Cure the applied material by considering the material's specifications, and end traffic control after the material has sufficiently cured. Sand and stone dust should be scattered over the material surface before ending traffic control in order to prevent the material or other objects from attaching to vehicle tires or pedestrians' shoe soles as well as to protect the portions upon which no run-off has been implemented. **Photograph-4.2.6** shows a portion after its faulting was repaired.

Photograph-4.2.5: Spreading to even a faulting portion

Photograph-4.2.6: Portion whose faulting has been repaired

2) Patching with cement-based material

Cement-based materials are used to patch concrete pavement. Many are polymer cement-based materials supplied as packed products or packages. Fiber-reinforced materials and fast curing materials are also available. Cement-based materials such as concrete and mortar are often mixed in plants or on-site. In such cases, mortar is used for thin patching, while concrete is used for thick patching; the maximum size of coarse aggregate must be larger than or equal to one-third the patching thickness.

Methods for implementing this type of patching differ depending on which materials are used. The following methods are generally used.

The following is an example procedure for patching with polymer cement-based material.

1. Gouge out the damage-affected portions (the damaged portions) with a breaker, pick, or similar tool and remove dust and other dirt. Keep the construction surface dry to prevent moisture from disturbing the resin's curing.
2. For concrete pavement surfaces, apply the required amount of primer (surface preparation material) to the surface and confirm its curing. Asphalt pavement surfaces do not require application of primer.
3. Pour the required amount of resin into a bag containing aggregate; gently mix the materials in the bag.
4. Quickly complete application of the mixed polymer cement with a trowel or other tool within its working life.
5. After the polymer cement has cured, end traffic control.

The following is an example procedure for patching with cement-based material.

1. Gouge out the damage-affected portions (the damaged portions) with a breaker, pick, or similar tool and chip the jointing concrete surfaces to form normal concrete surfaces. Remove dust and other dirt from the surfaces; then, keep them sufficiently moist. Be careful not to damage the reinforcements and steel when gouging. **Figures-4.2.2** to **4.2.4** illustrate the work areas for gouging and patching an edge defect, pothole, and faulting in concrete pavement. **Photograph-4.2.7** shows the surface after gouging is complete.

Photograph-4.2.7: Surface after completion of gouging

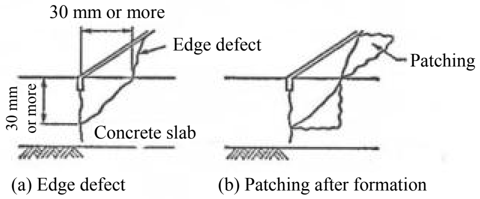


Figure-4.2.2: Work area for an edge defect

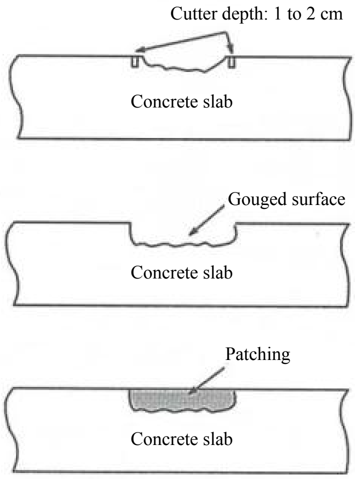


Figure-4.2.3: Pothole

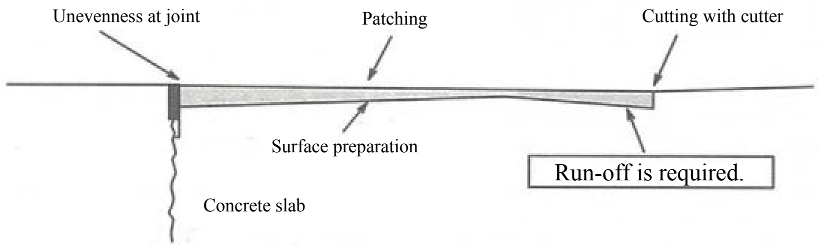


Figure-4.2.4: Work area for evening faulting

2. Sufficiently rub a slight amount of cement paste or mortar on the surface to be patched and remove any excess portion.
3. Before the rubbed cement paste or mortar has cured, remix and place cement-based patching mortar or concrete. Compact the placed material sufficiently by impacting it and then spread it with a trowel.
4. Cure the patched portion after surface finish is complete according to a procedure appropriate for the cement used.

3) Patching with cold-setting all-weather material

Cold-setting all-weather materials enhance water resistance and adhesiveness. They ensure sufficient adhesiveness even if the portions to be patched are wet due to rainy weather or under the desired conditions, and they provide high resistance to material stripping. They are commercially available generally in the form of packed products and are not easily affected by weather conditions such as rain, snow, and temperature. Thus, cold-setting all-weather materials have a wide range of applications.

Patching with cold-setting all-weather material is generally performed in accordance with the following procedure.

1. Remove any oil and dirt in the construction portion. Patching with cold-setting all-weather material requires that no tack coat be applied. **Photograph-4.2.8** shows a construction portion prior to patching.
2. Fill in the depressed portions with the required amount of material; spread the material while giving consideration to extra banking.
3. It is essential to perform sufficient compaction with a blade or similar device. However, in some cases, including emergencies, traffic control may be ended after formation and compaction of the patched portions have been completed using only a shovel back, tamper, or similar device.

Photograph-4.2.9 shows compaction using a shovel back.

4. Scatter sand and stone dust over the material surface before ending traffic control in order to prevent the material or other objects from attaching to vehicle tires or pedestrians' shoe soles. End traffic control to integrate the patched portions with the existing pavement by rolling due to the traffic of traveling vehicles.

Photograph-4.2.8: Construction portion prior to patching

Photograph-4.2.9: Compaction using a shovel back

4-2-2 Sealant injection (sealing)

Sealant injection is used to fill cracks in asphalt pavement surfaces with sealant in order to block rainwater, etc., thereby delaying the advance of pavement damage. In some cases, pretreatment using a cutter or router (ditcher) to form ditches along cracks is performed to ensure sufficient opening widths for reliable sealant filling. When applied to concrete pavement surfaces, this method is called sealing.

Sealants include blown asphalt, hot asphalt-based materials produced using rubber or other materials to modify asphalt, and asphalt emulsion-based and resin-based materials for cold application. **Table-4.2.2** lists major sealing materials and their applications. Sealants applicable to the target crack widths must be selected from among these materials by considering conditions such as crack damage levels, whether road surfaces are dry or moist, temperature, and working life. Durability differs depending on the sealant type, construction method, the damage level due to cracks, and other factors. Some knowledge of these differences in durability has gradually been accumulated and can be consulted as a reference.[1)]

Table-4.2.2: Major types of sealing materials and their applications

Material type		Application		
		Dense graded asphalt pavement	Porous asphalt pavement	Concrete pavement
Hot asphalt-based sealant	Crack seal	○	△*1	○
	Asphalt mortar	○	△*1	△
	Blown asphalt	○	△*1	○
	Joint-sealing compound	○	△*1	○
Asphalt emulsion-based sealant	Special emulsion-based material	○	△*1	○
	Special emulsion cement-based material	○	△*1	○
	Two-liquid mixing material	○	△*1	○
Resin-based sealant	Epoxy resin	○	△*1	○
	MMA resin	○	△*1	○

○: Applicable; △: Applicable under some conditions
*1: The transverse drainage function is lost in sealed portions.

Cracks occurring in concrete pavement are classified into nonprogressive cracks, which have narrow widths, and progressive cracks. It must be noted that these two crack types require different injection methods. For nonprogressive cracks, resin-based sealants are generally used. For progressive cracks, since the sealant provided by resin injection cannot adjust to the expansion and contraction of crack widths, joint-sealing compound or resin-based sealant is injected into U- or V-shaped ditches formed along cracks as shown in **Figure-4.2.5**.[2)]

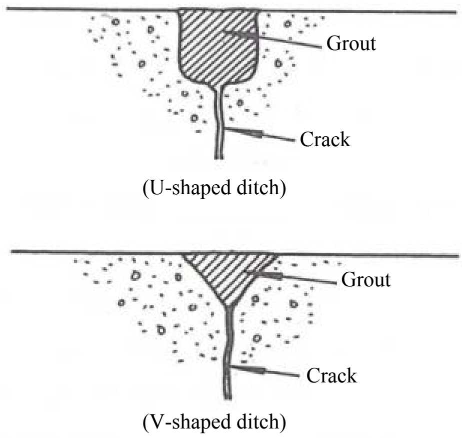


Figure-4.2.5: Ditch shapes for sealing progressive cracks in concrete pavement

It must be noted that when applied to porous asphalt pavement, this injection method may cause degradation or loss of transverse drainage performance.

(1) Injection of hot asphalt-based sealant

Injection of hot asphalt-based sealant employs hot injection sealant made of asphalt-rubber and other materials. Such materials induce neither flow nor outflow at high temperatures and neither brittle fractures nor curing fractures at low temperatures. They exhibit viscosity and high adhesiveness and are excellent in elasticity, adjusting to expansion and contraction appropriately. Since hot asphalt-based sealants are highly viscous compared to resin-based sealants, which will be described later, they can be applied to repair relatively wide cracks (approximately 5 to 10 mm wide) and joints of concrete pavement.

Photograph-4.2.10: Injection of sealant

1. Remove all loosened portions in the cracking portion. Clean away any dust and mud in cracks by blowing with compressed air or other means.
2. Heat and melt the sealant at the specified temperature.
3. Apply a primer appropriate for the material’s characteristics.
4. Pour the sealant into the cracks (**Photograph-4.2.10**). Remove any excess sealant with a chaplet or other tool and form the surface appropriately.
5. Scatter sand or other materials as necessary to prevent the applied sealant from adhering to vehicle tires.
6. After the sealant has sufficiently cured, end traffic control.

Dry the construction surface (if wet) with a burner or other device before injection.

(2) Injection of asphalt emulsion-based sealant

Asphalt emulsion-based sealants include sealants prepared by mixing a special asphalt emulsion-based liquid and cement-based stabilizer, and two-liquid-mixing rubberized-asphalt emulsion sealants. All can be used in cold application. Most are applicable to wet surfaces.

The following is an example procedure for injecting two-liquid-mixing rubberized-asphalt emulsion sealant.

1. Remove all loosened portions in the cracking portion. Clean away any dust and mud in cracks by blowing with compressed air or other means.
2. Add a setting agent in an amount appropriate for the ambient temperature to the main agent in the container; then, mix them uniformly.
3. Inject the mixed sealant into the cracks (**Photograph-4.2.11**[3)]). Remove any excess sealant with a chaplet or other tool and form the surface appropriately.

4. Scatter sand or other materials as necessary to prevent the sealant from adhering to vehicle tires.
5. After the sealant has sufficiently cured, end traffic control.

Injection must be completed quickly within the materials' working lives.

Photograph-4.2.11: Injection of sealant

(3) Injection of resin-based sealant

Injection of resin-based sealant employs cold-setting resin-based sealants, such as epoxy resin and MMA resin. With some exceptions, these sealants generally cure rapidly. They cure even at low temperatures and flexibly follow the behavior of cracks. Cold-setting resin-based sealants, which thus offer excellent workability, enable prompt injection. Thanks to such flexibility, they can be applied to narrow cracks (approximately 5 mm or narrower).

Photograph-4.2.12: Injection of resin-based sealant

The following is an example procedure for injecting epoxy resin-based sealant.

1. Remove all loosened portions in the cracking portion. Clean away any dust and mud in cracks by blowing with compressed air or other means.
2. Add a setting agent to the main agent in the container; then, mix them uniformly.
3. Inject the mixed sealant into the cracks (**Photograph-4.2.12**[4)]). Remove any excess sealant with a chaplet or other tool and form the surface appropriately.
4. After the sealant has sufficiently cured, end traffic control.

Consideration must be given to the following matters when applying this method.

- Depending on the material, dry and moist conditions on construction surfaces differ. Technical data and documents provided by manufacturers should be referred to for information on these conditions.
- Injection must be completed within the materials' specified working lives.

4-2-3 Cutting

Cutting is performed by scraping damaged portions with a machine to restore the roughness and skid resistance of road surfaces (e.g., when continuous or sporadic irregularities have occurred on asphalt pavement surfaces resulting in markedly degraded surface roughness). Cutting is often applied to remove deformations caused by flow occurring in portions where the mixture has been pushed out by rutting or bumps, near intersections, or in other portions. It is also often applied to stripping portions with degraded skid resistance or when performing other repair work.

Cutting is generally performed using a road cutter as shown in **Photograph-4.2.13**.[5)] Recently, a cutting method using a road cutter with a cutting drum having a very small bit pitch has been developed, allowing for a fine surface finish. This method generates only a small amount of noise during construction work and is expected to contribute to reducing tire-road surface noise after the end of traffic control.

Photograph-4.2.13: Cutting with a road cutter

Cutting is applied as a provisional measure. Irregularities may recur during an early stage after performing cutting on road surfaces suffering from flow rutting, corrugation, or other damage caused by asphalt mixture layers. Since irregularities that progress during a short period of time are highly likely to recur after performing cutting, these should be repaired by mill and overlay, replacement, or other methods to remove the causal layers. On road surfaces having degraded pavement, cutting may accelerate stripping damage due to exposure to water. Thus, it is necessary to pay due attention to the progress of damage after performing cutting.

4-2-4 Surface treatment

Surface treatment is employed to form a sealing layer thinner than 3 cm on existing pavement. Different surface treatment methods are used depending on the materials and methods employed to execute the work.

Surface treatment is performed to cope with aging of road surfaces, cracking, abrasion, and other types of damage to road surfaces as well as to perform preventive maintenance. Road surface recovery by surface treatment contributes to recovering and enhancing pavement functions (e.g., water shielding performance and skid resistance).

When applied to slight damage to pavement in the form of preventive maintenance, surface treatment contributes to extending pavement service life.

Surface treatment methods using emulsion-, asphalt mixture-, and resin-based materials are available. Select an appropriate method by considering road surface conditions and traffic volume.

(1) Fog seal

Fog seal is applied to asphalt pavement. Asphalt emulsion diluted with one to three parts of water is sprinkled over asphalt pavement surfaces at 0.5 to 0.9 l/m^2. Small cracks and voids on the surfaces are filled with this diluted emulsion, thereby rejuvenating old pavement surfaces (**Photograph-4.2.14**). Fog seal is sometimes used to settle aggregate and duct after performing other surface treatment. MK-2 and MK-3 are used as the asphalt emulsion for this method. Fog seal is effective for performing repairs in locations with low traffic volume. It allows traffic control to be ended within one or two hours of carrying out the work. When traffic control must be ended quickly, sand should be scattered over the sprinkled emulsion.

A method in which special modified-asphalt emulsion is sprinkled on pavement surfaces at approximately 0.4 l/m^2 has recently been developed to protect and strengthen porous asphalt surfaces.

Photograph-4.2.14: Implementation of fog seal

(2) Chip seal

Chip seal is applied to asphalt pavement. This method is surface treatment using emulsion to form singular or multiple aggregate layers on asphalt pavement. These layers are called seal coats and armor coats, respectively. Seal coats are formed by creating one emulsion layer and one aggregate layer on existing pavement surfaces. Armor coats are formed by superposing two or more seal coats.

Chip seal is implemented for the following purposes.

1. To enhance the water resistance and durability of road surfaces by covering fine cracks and increasing water tightness
2. To prevent the advance of aging of existing pavement
3. To rejuvenate road surfaces
4. To enhance abrasion resistance

Chip seal is generally applied to roads classified as traffic volume N_3 or lower.

Types of emulsion and aggregate for chip seal and amounts thereof must be determined appropriately by considering weather conditions, traffic volume, actual route conditions, the condition of existing pavement surfaces, and other conditions. As emulsion for chip seal, in general PK-1 or PK-2 is used for locations with relatively low traffic volume, PKR-S-1 or PKR-S-2 for locations with relatively high traffic volume, and PK-H for sloped locations or rapid decomposition. Aggregate for chip seal must be a hard material containing a fine-grained fraction and as little duct as possible.

Photograph-4.2.15 shows chip seal work, while **Table-4.2.3** lists standard amounts of materials used for chip seal.

A method using highly concentrated modified-asphalt emulsion and special precoated aggregate that also employs topcoating has recently been developed to handle repairs to roads of traffic volume classes up to N_4. To carry out work, a method using a special machine for simultaneously sprinkling aggregate and emulsion as shown in **Photograph-4.2.16** has been developed.

Table-4.2.3: Standard amounts of materials for chip seal (per 100 m^2)

		Seal coating			Armor coating			
Type of asphalt emulsion		PK-1 PK-2 PKR-S-1, 2	PK-H	Highly concentrated modified-asphalt emulsion	PK-1 PK-2 PKR-S-1, 2		PK-H	
Number of layers		1	1	1	2	3	2	3
Asphalt emulsion	ℓ	–	–	–	–	80～100	–	80～100
Crushed stone No. 5	m^3	–	–	–	–	1.8	–	1.8
Asphalt emulsion	ℓ	–	110～130	110～130	80～100	170～190	80～100	130～150
Crushed stone No. 6	m^3	–	0.9	0.9	1.0	0.8	1.0	0.8
Asphalt emulsion	ℓ	80～100	–	40～60	120～140	120～140	100～120	100～120
Crushed stone No. 7	m^3	0.5	–	–	0.6	0.6	0.6	0.6

Photograph-4.2.15: Chip seal work

Photograph-4.2.16: Chip seal work using a special machine

(3) Slurry seal

Slurry seal is applied to ordinary asphalt pavement and concrete pavement. Slurry prepared by mixing fine aggregate, filler, asphalt emulsion (MK-2 or MK-3), and water is spread as a thin layer (approximately 3 to 10 mm thick) over existing pavement. **Table-4.2.4** lists some examples of aggregate grading values for such slurry mixtures. Slurry mixtures generally contain asphalt emulsion in an amount equivalent to 13 to 20% of the weight of aggregate and filler. The amount of water added is adjusted by considering the amount of surface water of the

Table-4.2.4: Example of aggregate grading for slurry seal

Sieve mesh size		Grading range
Percentage passing (%)	2.36mm	100
	1.18mm	55～85
	600μm	35～60
	300μm	20～45
	150μm	10～30
	75μm	5～15

aggregate; it is generally as much as 10 to 15% of the weight of aggregate and filler.

Slurry seal is generally implemented with a special paver (slurry paver). For pavement with many uneven portions, slurry seal may be manually implemented using rubber rakes or other tools if use of a paver is difficult.

Slurry seal must be implemented in warm weather; it cannot be performed at a temperature of 15°C or lower or in humid, cloudy weather.

(4) Micro surfacing

Micro surfacing, a type of slurry seal, employs a special paver (micro surfacing paver) to form a thin layer by spreading a cold slurry mixture basically consisting of carefully selected aggregate, quick-hardening modified-asphalt emulsion, cement, water, and a decomposition regulator. This is a type of cold surface treatment whose materials and method require no heating, contributing to resource conservation and reduction of CO_2 emissions.[6)]

Slurry seal is applied to ordinary asphalt pavement and concrete asphalt surfaces for the purposes of refreshing old road surfaces, repairing slight rutting, improving road surface textures, and other functional types of recovery and preventive maintenance.

Depending on the thicknesses of the layers to form, either type I or type II mixture is used. Type I mixture uses only screenings as aggregate, while type II mixture uses screenings and crushed stone No. 7 as aggregate. **Table-4.2.5** lists the standard grading range of the mixtures.[7)]

Table-4.2.5: Standard grading range for micro surfacing mixtures

Type of mixture		Type I	Type II
Maximum grading (mm)		2.5	5
Sieve mesh size		Grading range	
Percentage passing (%)	9.50mm	–	100
	4.75mm	100	90～100
	2.36mm	90～100	65～90
	600μm	40～65	30～50
	300μm	25～42	18～30
	150μm	15～30	10～21
	75μm	10～20	5～15

Micro surfacing is generally used to form a single layer with a thickness of 3 to 10 mm by spreading type I or type II mixture. When applied to road surfaces suffering from rutting approximately 15 to 20 mm in depth, two layers may be formed. In such cases, the first layer is generally formed from a type II mixture, while the second layer is formed from a type I or type II mixture.

Mixtures for micro surfacing are prepared and spread using special pavers. Each such paver is equipped with a material storage and supply device, mixing device, and spreading device and has all functions for implementing micro surfacing. While moving forward, they can continuously measure each material and supply it to a continuous pug mill mixer to prepare the mixture; they spread the mixture with the aid of a spreader box.

Mixture preparation and spreading are achieved by special pavers according to the following procedure. **Figure-4.2.6** shows an example of the structure of a special paver.

1. Materials are loaded into a special paver.
2. The materials are continuously measured and supplied to the mixer in the specified mixing ratio.
3. The materials are mixed in the mixer (continuous biaxial pug mill mixer) located in the rear portion of the paver and supplied to the spreader box.

4. The spreader box towed by the paver spreads the mixture over the road surface.
5. The strike-off gives a finish to the road surface.

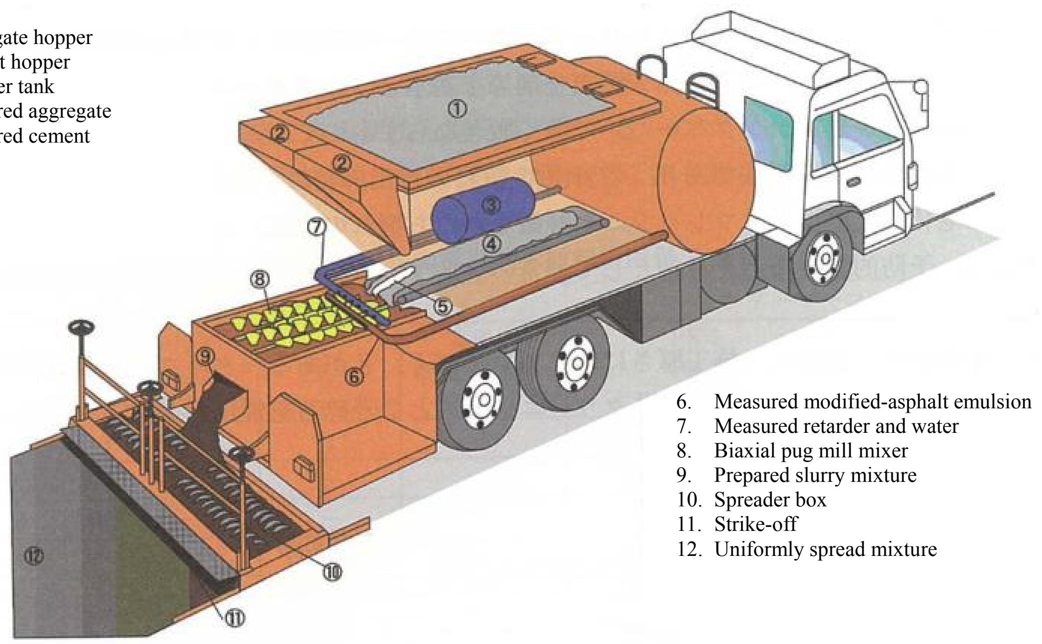


Figure-4.2.6: Example of special paver structure

Photograph-4.2.17: Implementation of micro surfacing

Consideration must be given to the following matters when applying this method.

- For existing pavement suffering from rutting approximately 15 to 20 mm in depth, two layers must be formed.
- This method must not be applied to portions that are frequently affected by torsional effects caused by vehicle tires immediately after the end of traffic control, or to portions that are intersections.
- This method must not be applied to portions with large irregularities or progressive cracks on road surfaces.
- When applying this method, it is desirable to implement it while the atmospheric temperature is in the range of 10 to 25°C during daylight hours. If it is applied in low-temperature, cloudy weather or at night, it is necessary to take measures (e.g., extending curing time by reducing daily work volume or accelerating curing by heating).
- This method must not be implemented immediately before, on, or immediately after days for which rainfall is expected.

(5) Carpet-coat

Carpet-coat is applied to ordinary asphalt pavement and concrete pavement. This method is used to spread and compact hot asphalt mixture to form a thin layer having a thickness of 1.5 to 2.5 cm. This type of surface treatment enables traffic control to be ended relatively soon after paving. Carpet-coat does not offer any substantial advantages in paving over overlay, which is a repair method. However, overlay is generally used to form layers having a thickness of 3 to 5 cm, whereas carpet-coat is used to form thinner layers.

Carpet-coat uses hot mixture made of crushed stone, screenings, sand, stone dust, and bituminous material. The maximum grain size of aggregate should be less than or equal to one-half the pavement thickness, and aggregate with a maximum grain size of 5 mm is generally used for carpet-coat; straight or polymer-modified asphalt is used as bituminous material. **Table-4.2.6** lists examples of the grading range of mixtures for carpet-coat, while **Photograph-4.2.18**[8] depicts carpet-coat work.

Table-4.2.6: Standard mixing ratio for carpet-coat

Sieve mesh size		Grading range
Percentage passing (%)	13.2mm	100
	4.75mm	90～100
	2.36mm	50～80
	300μm	15～35
	75μm	3～12
Asphalt content (%)		6.0～9.5

Photograph-4.2.18: Carpet-coat work

Consideration must be given to the following matters when applying this method.

- Since carpet-coat layers cannot be regarded to be part of the pavement structure, they cannot be deemed to be components that strengthen the pavement structure.
- Carpet-coat requires that pavement have a structurally-sufficient bearing capacity.
- Temperature easily decreases in the thin mixture layers formed by carpet-coat. Thus, initial rolling must be performed as soon as possible unless hair cracks or deformations occur.

Nowadays, crushed stone containing fiber and mastic mixture with a maximum grain size of 5 mm are sometimes used for their high durability, and intermediate temperature setting technologies are sometimes applied to ensure high workability or high quality. When forming thin layers, PKR-T is sometimes used to form tack coats so as to ensure integration with existing pavement. Porous asphalt requires stronger bonding with existing pavement. A method using an asphalt finisher with an emulsion sprinkler to apply special modified-asphalt emulsion as a tack coat at approximately 0.6 l/m^2 has been developed to satisfy the requirements imposed by porous asphalt.

The following surface treatment methods are sometimes applied as maintenance methods and generally applied for preventive purposes. For example, the methods are implemented to add functions immediately after surface course construction as well as to prevent aggregate scattering in the early service-use stage.

(6) Resin surface treatment

Resin surface treatment is applied to ordinary asphalt pavement and concrete pavement. In this method, resin is applied uniformly to pavement surfaces to form a uniform binder layer, and abrasion-resistant hard aggregate is sprinkled on the binder layer to bond the aggregate to the road surface. This surface treatment is sometimes called the neat construction method. **Figure-4.2.7**[9] illustrates a cross-section of a pavement surface formed by this surface treatment, and **Photograph-4.2.19**[10] shows its implementation.

Photograph-4.2.19: Application of resin material

Resin surface treatment, which is implemented particularly to enhance skid resistance under wet conditions, also enhances visibility to draw attention during rainy weather when using colored porcelain or a similar material as the aggregate.

Resin binder, hard aggregate, and primer are employed in this surface treatment. The resin binder consists of a main agent, which is based on an epoxy- or acryl-based resin, and a setting agent, such as a polyamine-based material. The primer is used in treatment of concrete pavement surfaces. Appropriate materials must be selected by considering application conditions, such as temperature and working life.

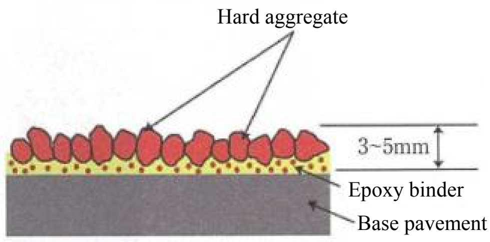


Figure-4.2.7: Cross-section of a pavement surface formed by resin surface treatment

Consideration must be given to the following matters when applying this method.

- Immediately after asphalt paving, light oil components may remain on surface courses and disturb the adhesion of material to road surfaces. Thus, it is desirable to implement this surface treatment after such light oil components and other foreign materials have been eliminated by waiting for three weeks or longer to open up the road to traffic after paving.
- For concrete pavement, this surface treatment must be implemented after concrete placement once three weeks or more in summer or four weeks or more in winter have elapsed. The same applies to pavement using jet concrete and semi-flexible pavement.

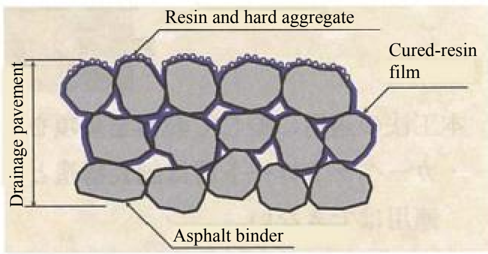


Figure-4.2.8: Cross-section of pavement formed by the drainage topcoat method

(7) Drainage topcoat method

The drainage topcoat method is applied to porous asphalt pavement. In this method, special resin is sprinkled on pavement surfaces to form a strong thin film, thereby enhancing abrasion resistance and durability against aggregate scattering and other damage while retaining the pavement's drainage function (**Figure-4.2.8**[11]). This method, which must generally be implemented within several days after the base mixture has been paved, is performed as preventive maintenance for newly constructed or repaired pavement. It is applied mainly to the following locations, where scattering of porous asphalt mixture aggregate is likely to occur: zones within intersections and vehicle stopping places, service areas of expressways, and ETC (Electronic Toll Collection) entrance lanes.

The following is a typical procedure for this method.

1. Cover curb stones and side gutters outside the construction area, road markings to protect from resin adhesion, and so on with gummed tape, masking tape, or other means.
2. Uniformly apply the required amount of resin (0.5 to 0.7 kg/m^2) with an airless spray or other spraying device suitable for the material. Afterwards, sprinkle the required amount of hard aggregate

(0.25 kg/m^2) before the resin has cured (**Photograph-4.2.20**).

3. Prevent the pavement surface from collecting dust or moisture; leave it untouched for approximately 30 minutes until the resin has cured completely.
4. After the first-layer resin has cured, apply the required amount of second-layer resin (0.3 to 0.5 kg/m^2) and sprinkle the required amount of hard aggregate (0.25 kg/m^2) in the same manner as for the first layer.

Photograph-4.2.20: Implementation of drainage topcoat

Since the presence of moisture on the surface of the base pavement mixture will result in insufficient curing of resin, construction must not be performed during rainy weather. Due attention must be paid to moisture when performing construction even if the weather is not rainy.

The method for applying special modified-asphalt emulsion to porous asphalt pavement surfaces described in "(1) Fog seal" is expected to enhance porous asphalt pavement's resistance to aggregate scattering. Thus, it is classified as a drainage topcoat method.

(8) Permeable resin mortar filling method

The permeable resin mortar filling method is applied to porous asphalt pavement. In this method, gaps in porous asphalt pavement's surface aggregate are filled with permeable resin mortar mixture consisting of resin binder (epoxy resin) and hard ceramic aggregate, thereby reinforcing road surfaces to maintain their functions and extend their service lives (**Figure-4.2.9**[12)]). It is applied mainly to locations where scattering of road surface aggregate is likely to occur, such as intersections, parking lots, and sharply-curved portions, as well as to locations requiring sufficient skid resistance, such as long downward slopes, downward slopes with intersections, and curving portions of expressways.

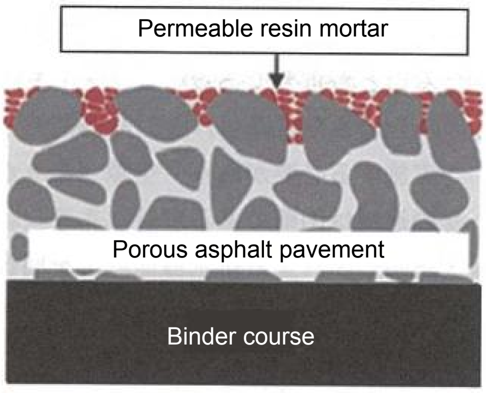


Figure-4.2.9: Cross-section of pavement formed by the permeable resin mortar filling method

The following is a typical procedure for this method.

1. Cover curb stones and side gutters outside the construction area, road markings to protect from resin adhesion, and so on with gummed tape, masking tape, or other means.
2. Uniformly mix the required amounts of materials with a mixer or other device to prepare permeable resin mortar.
3. Uniformly spread the permeable resin mortar over the road surface and rub it into the depressed portions of the porous asphalt mixture's surface with a rubber rake as shown in **Photograph-4.2.21**.[13)] Afterwards, remove any excess resin mortar with an iron rake.
4. Roll the road surface with a pneumatic tire roller to bond the resin mortar to the porous asphalt mixture.
5. Leave the construction portion untouched for curing. After the resin mortar has cured, end traffic control.

Since the time allowed for mixing, filling, and compaction of permeable resin mortar varies depending on the atmospheric temperature and road surface temperature, careful planning is required for this work. In addition, since moisture on road surfaces may result in insufficient bonding or insufficient curing of resin binder, construction is permitted only when road surfaces are dry.

Exposure of resin binder to water before it has cured may result in insufficient curing or poor appearance due to surface

Photograph-4.2.21: Rubbing of permeable resin mortar

whitening. Thus, this type of construction must be avoided when rain is expected.

4-2-5 Washing of void choking

Washing of void choking is applied to porous asphalt pavement. In this method, a drainage function maintenance machine is employed to remove earth, sand, and dust deposited in voids in pavement with the aid of pressurized water or compressed air, thereby recovering the water permeating performance and noise reduction performance provided by the voids. **Photograph-4.2.22** depicts washing of void choking with water.

Photograph-4.2.22: Washing of void choking work

Consideration must be given to the following matters when applying this method

- This method must be implemented periodically to maintain its effectiveness.
- Washing of void choking must be performed before pavement has suffered severe functional degradation; it is ineffective once pavement is suffering from severe void choking.
- The method cannot restore drainage performance once pavement is suffering from void clogging.

4-2-6 Surface roughening

Surface roughening is applied to concrete pavement. This method is used to restore the skid resistance of road surfaces by applying surface texturing to pavement. Surface texturing is realized through means such as shot blasting, water jetting, and diamond grinding.

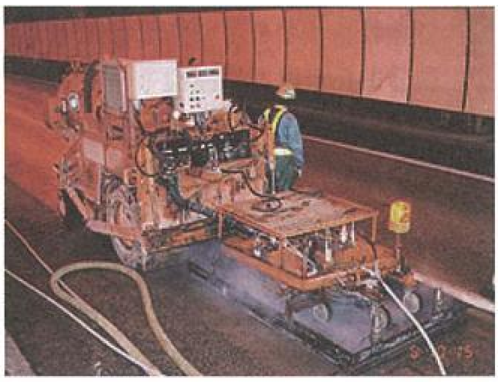
Shot blasting strikes pavement surfaces with tiny steel balls to polish concrete surfaces. Since this process collects and separates striking steel balls and generated dust while polishing, the target road surfaces must be dry. If the surfaces are instead moist, the steel balls and dust will clog up the machine and disturb the work. **Photograph-4.2.23** shows shot-blasting work.

Photograph-4.2.23: Shot-blasting work

In water jetting, ultra-high-pressure water is sprayed over concrete road surfaces to polish them. **Photograph-4.2.24** shows water-jetting work.

In diamond grinding, a thin layer is ground away from concrete pavement surfaces with the aid of a machine having an attached drum with diamond cutters arranged cylindrically on it. Because fine irregularities are formed while coping with faulting at joints and improving surface roughness, this method is said to contribute to noise reduction.[14)] **Photograph-4.2.25** shows diamond grinding work.

All these methods, which grind an ultrathin layer away from concrete surfaces, also contribute to restoring concrete pavement's light color.



Photograph-4.2.24: Water-jetting work

4-2-7 Grooving

Grooving is applied to ordinary dense-graded asphalt pavement and concrete pavement. In this method, shallow grooves having a specific form are cut at regular intervals on pavement surfaces to enhance skid resistance. **Figure-4.2.10** depicts a cross-section of a pavement surface formed by grooving. Grooves are cut in the transverse or longitudinal direction to vehicle traveling directions. Longitudinal grooves are generally formed over portions of roads such as curving portions, slopes, straight portions subject to side winds, and overpasses. Transverse grooves are generally formed in portions of roads near facilities such as intersections, pedestrian crossings, and tollgates. Since grooves formed over road surfaces improve roads' drainage performance in rainy weather, they contribute to increasing road surfaces' skid resistance coefficient, particularly in wet conditions.

Photograph-4.2.25: Road surface after diamond grinding

Grooves also serve to alert drivers by generating different vibrations and sounds while vehicles travel over them and to guide drivers' lines of sight. Grooving is implemented using a special machine equipped with a number of diamond cutters. **Photograph-4.2.26** shows grooving work, while **Photograph-4.2.27** shows a road surface that has undergone grooving.

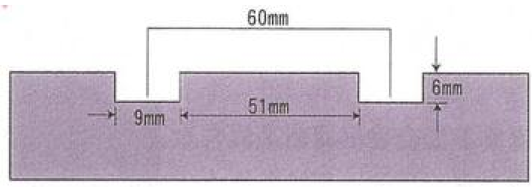


Figure-4.2.10: Cross-section of a road surface that has undergone grooving

Photograph-4.2.26: Grooving work

Photograph-4.2.27: Road surface that has undergone grooving

Consideration must be given to the following matters when applying this method.

- If performing grooving on pavement surfaces immediately after construction, edge defects or flow of pavement may cause grooves to be crushed early. Grooving should therefore be performed on roads that have already been used for a specific period of time after paving.
- Grooving mainly affects the plastic deformation resistance and abrasion resistance of asphalt mixtures forming surface courses. When applying grooving to newly constructed asphalt pavement road surfaces, polymer-modified asphalt mixture should be used.
- It has been reported that longitudinal grooves formed in curving portions affect the traveling performance of two-wheeled vehicles.[15)] To minimize rapid changes in traveling performance, measures may be implemented such as forming narrow grooves in curving portions or performing grooving on the straight portions before and after curving portions for approximately 30 to 50 m.

4-2-8 Thin overlay

Thin overlay paves existing pavement with a hot asphalt mixture layer thinner than 3 cm. Thin overlay using a special mixture consisting of a large amount of fine aggregate is called carpet-coat. The method described in "4-2-10: Road surface maintenance method with in-place surface recycling machines, etc." may also be classified as thin overlay.

For thin overlay, an appropriate crossfall and gradient must be selected so that no faulting occurs at the start or end points, street gutters, utility holes, or other similar portions.

4-2-9 Overlay on rutting

Overlay on rutting is also called the rail-drawing method. It targets only rutting portions of road surfaces (**Photograph-4.2.28**[16]). This method is applied mainly when repairing abrasion ruts in snowy regions; it is unsuitable for repairing flow ruts. It is often performed as leveling, part of the pretreatment for overlay.

Overlay on rutting employs hot asphalt mixture or resin-based mixture. The materials used must be selected by considering purposes, site conditions, and other factors.

Consideration must be given to the following matters when using hot asphalt mixture.

Photograph-4.2.28: Overlay on rutting

- It is desirable to implement measures to prevent exfoliation from pavement edges during service use. For example, asphalt emulsion should be applied as a seal coat to pavement edges and should be covered with sand.
- Overlay thickness is not uniform, and in some portions overlaid layers are very thin. Thus, it is desirable to use emulsified rubberized asphalt (PKR-T) as a tack coat.

4-2-10 Road surface maintenance method with in-place surface recycling machines, etc.[17]

The road surface maintenance method with in-place surface recycling machines, etc. employs a simplified combination of machines compared to the method for in-place surface recycling. The sum of the depth of the scarified portion of existing pavement and the thickness of newly added asphalt mixture is approximately 40 mm or less. Since the combination of machines has been simplified and simple machines are used, the method can be applied to small-scale portions, such as urban and daily service roads. The method cannot be applied under standards requiring structural design of surface course mixture and other portions; it is applied mainly as a preventive maintenance measure to recover road surface performance.

The method is realized by in-place surface recycling achieved by simplified repaving or remixing. **Figure-4.2.11** illustrates the work process for this method and the combination of machines used.

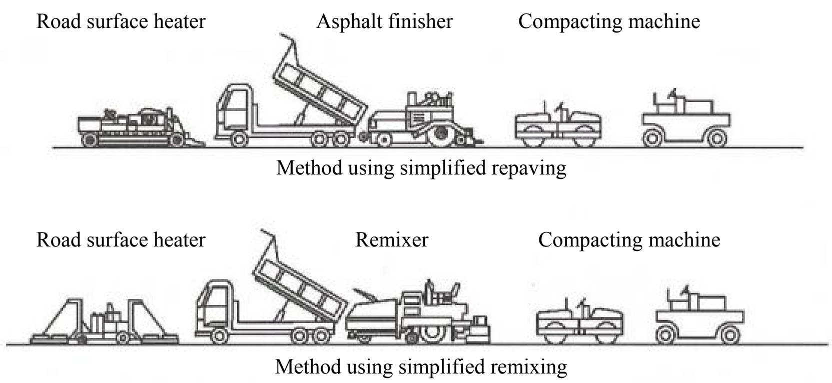


Figure-4.2.11: Work process and the combination of machines

This method is implemented in accordance with the following procedure. First, use a road surface heater that can be placed on urban roads or daily service roads to heat the road surface so that the surface can be scarified. Apply an additive immediately after heating if necessary.

Scarify the existing pavement mixture with cutting bits or other tools installed in the scarifier or remixer in the rear portion of the heater as shown in **Photograph-4.2.29**. Any existing surface course mixture as thick as approximately 10 to 20 mm should be scarified. Use a rake to manually scarify the pavement mixture at the edges and around utility holes, where mechanical scarification is impossible.

Photograph-4.2.29: Scarification of existing pavement

Pave the additional asphalt mixture over the scarified surface course mixture when applying a method using simplified repaving. Such paving can be performed with an ordinary asphalt finisher. Methods using simplified remixing require machines and devices for mixing scarified surface course mixture with additional asphalt mixture.

The thickness of the additional asphalt mixture can be adjusted; however, it has generally been set to approximately 20 mm.

Consideration must be given to the following matters when applying this method.

1) Road surface characteristics

1. The road surface maintenance method with in-place surface recycling machines, etc. cannot be applied when the pavement has a crack ratio or rut depth exceeding the application scope of in-place surface recycling. Since the method scarifies only thin layers of surface course mixture and uses only a small amount of additional asphalt mixture, the method is also difficult to apply when measures for structural repair of cracking, rutting, abrasion, and other types of damage are required. It can be applied as a measure to recover road surface performance or for preventive maintenance in order to improve road appearance and trafficability for vehicles by eliminating cracks near road surfaces, faulting in locations with buried objects, and other types of road damage.
2. Even when the method has been judged to be applicable, prior local replacement or surface roughness improvement (protrusion correction) must sometimes be implemented for portions having concentrated cracking or large rutting.
3. If existing surface courses containing resin-based pavement materials or sealing materials may ignite when heated by a road surface heater, such materials must be removed beforehand by cutting or other means.

2) Route conditions

1. The method generally requires a construction width of approximately 2.5 to 4 m. For locations having a small curvature, it must be checked whether there is space to operate a road surface heater.
2. Whether to protect vegetation and whether to take measures against the odor generated by heating must be examined. Take appropriate actions as necessary.

3) Weather conditions

1. Construction in a cool season, when it is difficult to heat but easy to cool surface course mixture, requires repeated heating with a road surface heater, heat insulation for the additional asphalt mixture, and other heating-related measures.
2. If road surfaces are markedly wet, construction quality may be adversely affected by moisture remaining in the mixture, and construction efficiency may decline due to the extended amount of time required to heat the surface course mixture. In such cases, avoid performing construction.

4-2-11 Injection methods (undersealing methods)[18)]

Injection methods fill voids and cavities formed between concrete slabs and base courses to push up sinking slabs to their normal positions. They are also called undersealing or subsealing methods. These methods can be implemented at relatively low cost and are significantly effective in extending pavement service life.

Injection methods are classified into asphalt- and cement-based injection methods according to the materials used for injection. Asphalt-based injection methods are generally applied in actual construction. Cement asphalt emulsion-based materials, which are advantageous in terms of cold materials, are also used as a trial method.

(1) Asphalt injection method

The asphalt injection method enables traffic control to be ended as soon as the asphalt cools. Blown asphalt (penetration: 10 to 40) is injected in accordance with the following procedure.

1. Bore concrete slabs with a jackhammer or other tool. Bores must be 50 to 60 mm in diameter to allow them to accept an injection nozzle. One bore is generally formed for every area approximately 2 to 8 m^2 in size. It is important to carefully determine the bore arrangement by considering concrete slab size, sinking level, cracking level, injecting machine capacity, bituminous material characteristics, and other conditions. **Figure-4.2.12** illustrates an arrangement of bores for injection.

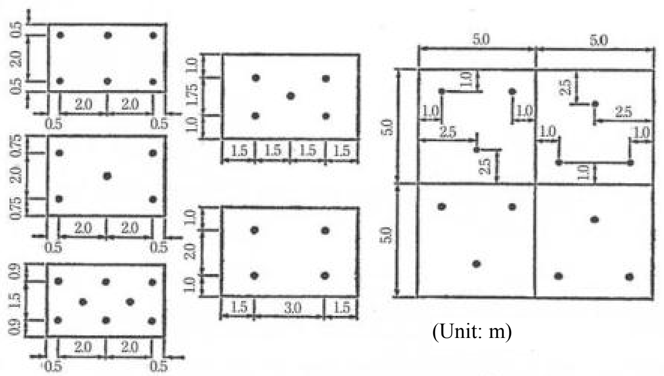


Figure-4.2.12: Arrangement of bores for injection

2. To ensure smooth injection, rake concrete debris and other foreign objects from each bore, or insert a thin pipe into each bore and feed compressed air through the pipe to eject sand, mud, and concrete debris from the portion around the pipe. Also during this process, create a small cavity on the bore bottom. Perform jetting to ensure smooth material movement in the space between the slab bottom and base course by using an injection nozzle to feed compressed air into the bore to remove earth, sand, and moisture that have accumulated at the bottom. A liquid prepared by dissolving stone dust in water should be applied to the concrete slab’s surface so that asphalt escaping from the bores and nozzle can be easily removed.
3. Heat and melt asphalt (at 210°C) and inject the melted asphalt through an injection nozzle at a pressure of 0.2 to 0.4 MPa as illustrated in **Figure-4.2.13** by making use of an asphalt distributor or special machine. The amount of asphalt to inject varies based on the conditions of the concrete slabs and base courses, but it is generally approximately 2 to 6 kg/m^2.
4. Do not remove the nozzle from the bore for 30 seconds after injection is complete. Place a wooden plug in the bore as soon as the nozzle is removed. The wooden plug should be 70 to 100 cm in length.
5. Remove the wooden plug once the asphalt has cooled and cured. Fill the bore with cement or asphalt mortar to close it. Traffic control can be ended generally 30 to 60 minutes after injection is complete.

Since asphalt injection involves handling of heated asphalt, due consideration must be given to the following matters as well as prevention of burns and ignition of combustible objects and asphalt.

- Workers handling nozzles or wooden plugs must wear gloves and protective masks.
- Water in bores becomes steam as soon as material is injected into the bores. Note that asphalt may be ejected by the pressure generated by the steam.
- Also, note that asphalt may be ejected or escape from bores subjected to injection, other bores, cracks, joints, road shoulders, buried objects, and other portions.
- Further, note that asphalt may flow back upon removing the nozzle.

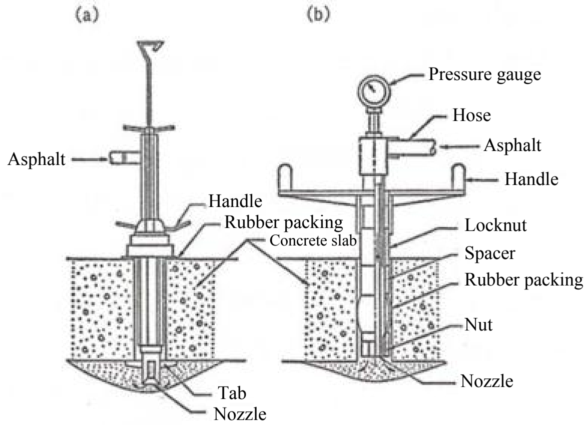


Figure-4.2.13: Asphalt injection nozzle

(2) Cement injection method

The cement injection method is implemented to fill voids between concrete slabs and base courses or to push up sinking slabs. It is used to inject cement grout in accordance with nearly the same procedure as the asphalt injection method.

1. To push up a concrete slab, bore the slab at the points illustrated in **Figure-4.2.14**.
2. Perform jetting in accordance with the same procedure as the asphalt injection method.
3. Use a grout pump or mud-jack to inject material at a pressure of 0.3 to 0.5 MPa. To push up a concrete slab, start with the bore at the location where the sinking of the slab is greatest and inject a small amount of cement grout into each bore in the order illustrated in **Figure-4.2.14**. Repeat this process until the concrete slab has reached the required height.
4. After injection is complete, place wooden plugs 35 to 45 cm in length into the bores.
5. Fill the bores with cement mortar and leave them untouched for curing for the specified period of time. After sufficient strength has developed, end traffic control. Use of very rapid setting cement or similar materials enables service use of the road to commence after two to three hours of curing.

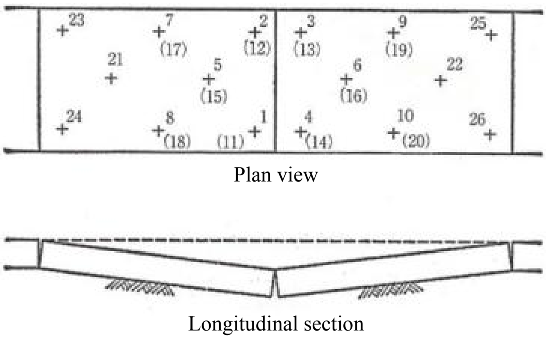


Figure-4.2.14: Pushing up a concrete slab

4-2-12 Bar stitching[18)]

Bar stitching uses reinforcements or similar materials to joint cracked concrete slabs, thereby ensuring load transfer at cracking portions.

Bar stitching is generally implemented in parallel with injection into cracks after applying an injection method to concrete slabs. It can suppress cracking progress and extend pavement service life. Injection into cracks is performed in accordance with “4-2-2: Sealant injection.”

Figure-4.2.15 depicts an example of reinforcement by bar stitching. Bar stitching is also applicable to transverse cracking. Generally, deformed bars are used to joint slabs; however, some bar stitching methods use flat bars, circular steel plates, or reinforcements having other shapes.

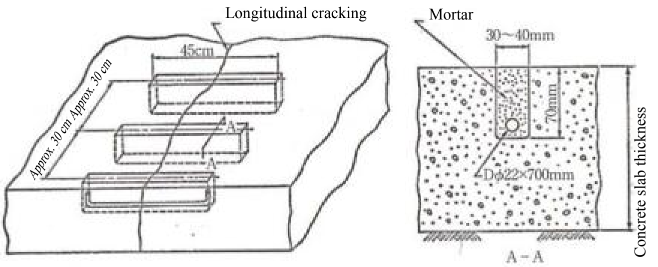


Figure-4.2.15: Example of longitudinal cracking reinforcement

4-3 Repair methods for asphalt pavement

Repair methods are implemented when maintenance is not expected to lead to sufficient recovery of pavement performance. Repair methods include replacement, overlay, and mill and overlay. Since all repair methods are high cost, their adoption and selection of a specific method must be carefully examined by referring to “Chapter 3 Implementation Plans for Maintenance and Repair” and giving consideration to damage causes identified through sufficient surveys.

Repair methods require various types of construction work to be completed in limited work areas within a limited span of time. In addition, traffic control must be ended under conditions by which safe traffic can be ensured. This section describes considerations and related matters for repair work targeting in-service routes.

4-3-1 Replacement

Replacement is used to replace all asphalt mixture layers of existing pavement and part of the base courses or to replace existing pavement in its entirety. In some cases, it is also used to replace subgrade or stabilize subgrade or existing base courses. Methods that replace all layers of existing pavement are called total replacement, while methods that leave part of the existing pavement unchanged are called partial replacement.

(1) Preparation (planning)

In replacement, consideration must particularly be given to the fact that various types of construction work must be completed within a limited span of time for traffic control in order to end such traffic control safely according to schedule. The detailed work schedule and amount of construction to be performed within the limited span of time provided by traffic control must thus be determined by performing a preliminary examination of site conditions, each repair method’s performance, and the procedure for ensuring the method is implemented sufficiently. The amount of construction per day must be determined by also considering permission of public road usage granted by road administrators.

For excavation of base courses and layers underneath, sufficient surveys (particularly of road-occupying facilities, including embedded pipelines) must be performed in the presence of those ordering the construction and owners of road-occupying facilities. These surveys should be implemented by trial boring and other means so that no facilities are damaged by excavation.

To the extent possible, replacement should be implemented on quadrangular road segments that have a side parallel to the road centerline. However, it is difficult to perform compaction with large compacting equipment on road segments having a width of less than 2.5 m. In such cases, base courses, binder courses, and other layers may be insufficiently compacted and are consequently likely to become damaged again. Replacement should therefore be implemented on road segments having a width of 2.5 m or more. Areas to be replaced must be determined also in consideration of the widths of unchanged portions that will be repaired in the future.

Construction plans must be formulated in advance, and appropriate methods must be selected though sufficient consultations.

(2) Demolition and excavation of pavement

1) Cutting of pavement

The boundaries between portions to be replaced and existing pavement must be straight. Cutting locations must be longitudinal to the extent possible.

The road segment to be worked on each day should be cut at the start of work for the day (**Photograph-4.3.1**). For night construction, pavement should be cut with a cutter equipped with noise control equipment (e.g., a sound arrester) or cut beforehand during the daytime. Drainage is generated in pavement cutting work when blade cooling water from cutting equipment captures cutting dust. To prevent water contamination, such drainage must be collected using cutting equipment or other devices having a drainage absorbing function. Collected drainage must be treated appropriately in accordance with the directions and guidance of local public bodies having jurisdiction over the concerned construction sites.

Photograph-4.3.1: Cutting of pavement

2) Demolition of pavement

It must be noted that since noise and vibrations are generated during pavement demolition, in some regions, working hours and other related matters may be regulated by ordinances. In urban areas, road cutters that can perform a large amount of construction per hour and that can cut pavement to a depth of 20 cm or more (**Photograph-4.3.2**) are applied in various ways to suppress the impacts of noise and vibrations. In some cases, pavement is demolished with hydraulic breakers or crushers (**Photograph-4.3.3**), and the demolished pavement is loaded with back hoes onto dump trucks. However, use of hydraulic breakers should be avoided in locations with buried objects. Compared to hydraulic breakers, crushers generate little noise and fewer vibrations while performing a large amount of construction per hour.

Photograph-4.3.2: Demolition of pavement (by road cutter)

Photograph-4.3.3: Demolition of pavement (by crusher)

3) Excavation and loading

Excavation of bottom faces must be performed at the depths specified in drawings. Portions excavated to a level deeper than specified must be backfilled with base course material.

Excavators (**Photograph-4.3.4**) must be selected appropriately for the scale of the areas to be replaced. Excavation must be performed manually in very small areas, portions with a number of utility holes or other objects, and portions with objects buried at shallow depths. For portions with road-occupying facilities, excavation must be carefully implemented under constant supervision in the presence of facility owners.

Photograph-4.3.4: Excavation of pavement

When back hoes must make turns for loading, due attention must be paid so that they do not come into contact with traveling vehicles and so that excavated soil is not scattered over in-service lanes. For small areas subject to control, small-turn back hoes should be considered.

(3) Construction of subgrade and base courses

1) Construction of subgrade

Excavated subgrade surfaces must be as flat as possible. Soft subgrade soil must be replaced in parts with good material or stabilized in parts with a stabilizer (e.g., cement).

After excavation is complete, subgrade must be rolled for compaction with pneumatic tire rollers, macadam rollers, or other devices (**Photograph-4.3.5**). On soft subgrade or under similar conditions, due attention must be paid so that subgrade is not disturbed by over-rolling with rollers. In such cases, compaction must be implemented using bulldozers or similar machines.

Photograph-4.3.5: Construction of subgrade (by rolling)

2) Construction of base courses

1. Construction of granular base courses

Base course material must be spread with motor graders, bulldozers (**Photograph-4.3.6**), or similar machines. In small areas to be replaced where such machines cannot easily be used, material must be spread manually.

Photograph-4.3.6: Construction of base course (by spreading)

Base courses are generally compacted with macadam rollers, vibrating rollers, pneumatic tire rollers, or similar machines (**Photograph-4.3.7**). Compared to use of a singular type of machine, combinational use of machines allows their different characteristic performances to realize high compaction efficiency in a short period of time.

Photograph-4.3.7: Construction of base course (by rolling)

Today, new rolling machines such as vibrating macadam rollers and vibrating pneumatic tire rollers are available. Machines equipped with devices for evaluating compaction levels and other new types of machines are also on the market.

When small bulldozers or similar machines are used to spread base course material, attention must be paid so that the soil around the material is not scarified and mixed into the material.

2. Construction of base courses formed by bituminous stabilization

For base courses formed by bituminous stabilization, material must be spread with asphalt finishers. Hot mixture is often spread as a 10-cm or thicker layer in one pass and then compacted by a method such as the thicklift method. The thicklift method is used to spread mixture into thick layers while keeping their temperatures high, thereby realizing high compaction effectiveness. The method consequently shortens the time required for work and has other advantages as well. However, since bases courses formed by this method take a long time to cool, sufficient curing time must be given before ending traffic control. Ending traffic control while the paved mixture is hot may lead to accelerated development of rutting as well as poor surface roughness. When ordinary asphalt finishers cannot be applied, sometimes motor graders, bulldozers, or similar machines are used. Breakdown rolling is performed with macadam rollers, while second rolling is performed with pneumatic tire rollers.

Photograph-4.3.8: Construction of base course (by compaction at edges)

In some cases, pavement cannot be raised because the areas around road sections are thickly inhabited, there are many buried objects, or other factors, and thus it is difficult to ensure a sufficient overall pavement thickness. However, when subgrade has sufficient bearing capacity (design CBR: 6 or higher), hot mixture is sometimes paved directly over subgrade (using the full-depth asphalt paving method).

Compaction is likely to be insufficient around edges and corners. Small compactors must be used on such portions (**Photograph-4.3.8**).

(4) Construction of asphalt surface and binder courses

Binder courses can be paved using the same methods as used for base course formation by bituminous stabilization. For surface courses, long construction extensions must be taken to ensure surface roughness, and it is desirable to perform work during the daytime. Preliminary cutting performed as deep as the binder courses regardless of section division for replacement can prevent faulting due to sectional divisions for replacement. In such construction, however, since traffic is permitted on cutting surfaces and binder courses before surface course construction, run-off and drainage measures for rainfall must be implemented for faulting at street gutters and utility holes to ensure traffic safety. In addition, scattered crushed stone and asphalt mixture as well as other run-off materials must be sufficiently removed from road surfaces to ensure safety for traveling vehicles and to prevent vehicles from being hit by flicked up stones or other objects.

When under time constraints for traffic control and also sometimes when replacing small interspersed sections, provisional pavement is placed to the level of the surface courses, and surface courses are placed after removal of the provisional pavement another day.

1) Prime coat and tack coat

After damaged portions, dust, mud, and other foreign objects have been eliminated from the cutting surfaces of existing asphalt, a tack coat must be applied with a brush or other tool to the rising portions. In small construction areas, it may be difficult to use a distributor to apply a tack coat or prime coat. In such cases, engine sprayers (**Photograph-4.3.9**) must be used to apply the coat uniformly.

When applying asphalt emulsion with engine sprayers, measures such as using plywood boards to shield against scattering of emulsion must be taken to avoid staining traveling vehicles, roadside structures, and other objects. In addition, ancillary structures must be protected from asphalt emulsion by covering them with vinyl sheets or applying stone dust dissolved in water to them.

After application of asphalt emulsion, sand or other material must be sprinkled uniformly over the prime coat so that the coat does not become separated before curing when work vehicles, etc. move over it. After applying a tack coat, vehicles, etc. must be prohibited from traversing the pavement until the asphalt emulsion has sufficiently decomposed in order to prevent separation of the tack coat. Stone dust or other materials may be sprinkled over portions to which no asphalt emulsion has been applied in order to prevent emulsion that has adhered to the tires, etc. of work vehicles from staining existing pavement. Asphalt emulsion that does not easily adhere to the tires, etc. of work vehicles has been developed and is used to prevent separation of asphalt emulsion as well as adhesion of stains to road surfaces.

Photograph-4.3.9: Application of emulsion (by sprayer)

2) Spreading

For large areas to be replaced, mixture must be spread with asphalt finishers (**Photograph-4.3.10**). For small areas to be replaced, mixture must be spread manually.

Photograph-4.3.10: Paving (by spreading)

When continuously forming two or more layers, tack coating may be omitted. Since different types of asphalt mixtures may be used to form different layers, necessary materials must be shipped at timings appropriate for the progress of site work in consideration of stand-by times and other factors.

3) Compaction work

For large areas to be replaced, asphalt mixture layers should be rolled with large macadam rollers (**Photograph-4.3.11**), pneumatic tire rollers (**Photograph-4.3.12**), or other machines in accordance with the same procedure as new pavement construction.

Photograph-4.3.11: Rolling (by macadam roller)

Photograph-4.3.12: Rolling (by pneumatic tire roller)

Since rolling to binder courses forms finished surfaces lower than the surrounding pavement surfaces, rolling is sometimes insufficient for edges and corners. To prevent insufficient rolling, small vibrating rollers must be used at roll edges and corners. For small areas to be replaced, rolling must be performed with small steel rollers (one to two tons), small vibrating compactors, or similar machines.

4) End of traffic control

After rolling is complete, traffic control must be ended once pavement surfaces have cooled to approximately 50°C or lower.

When construction work is subject to constraints on working hours in the summer, at night, or under other conditions, paving working hours should be determined by considering pavement cooling time, forced cooling with pavement cooling equipment, etc., use of intermediate temperature setting technologies, and other approaches.

4-3-2 Overlay

Overlay is used to form asphalt mixture layers on existing pavement.

In locations with private residences in roadside areas, pavement surfaces raised by overlay may render access to such residences difficult or cause water pooled on road surfaces to intrude upon residential properties. In locations with sidewalks or raceway surfaces, pavement surfaces raised by overlay may render the heights of curb stones relatively low or result in insufficient drainage from road and raceway surfaces. In addition, overlaid pavement inside tunnels may not satisfy tunnel clearances. Due consideration must be given to connecting dimensions with respect to roadside areas, structure heights, and other factors when deciding whether to use overlay.

Overlay of asphalt pavement can roughly be classified into overlay using asphalt mixture and overlay using cement concrete (white topping). Design and construction methods for white topping have yet to be well established, so this section describes only overlay using asphalt mixture. In this type of overlay, tack coats and asphalt mixture layers must be constructed in accordance with the *Pavement Construction Handbook*. Consideration must be given to the following matters when applying overlay.

(1) Preparation

Before implementing overlay, damaged portions of asphalt pavement must be repaired appropriately based on their damage conditions. Damaged drainage facilities (e.g., culverts, drainpipes, and side gutters) must also be repaired to prevent water from permeating into subgrade and base courses. Further, cracks on pavement surfaces must be repaired appropriately based on their conditions.

Local replacement must be implemented on portions suffering from severe damage that appears to be caused by local defects in subgrade or base courses. Sealant injection or measures against reflection cracks must be implemented on road surface portions with cracks as necessary. Note that thin overlay may allow cracks on the pavement to affect surface courses, causing such surface courses to develop reflection cracks.

Construction methods that suppress reflection cracking include methods that form a thin stress-absorbing membrane interlayer (SAMI layer) on pavement and methods using asphalt mixture (e.g., crushed-stone mastic) for binder courses. SAMI layers are formed by sheet methods; sand cushion methods, which alternately sprinkle aggregate and binder (e.g., modified asphalt or modified asphalt emulsion); and other methods. Machines that sprinkle asphalt emulsion and precoated aggregate simultaneously as well as other types of machines have been developed to form SAMI layers. For sheet methods, refer to “4-4-2 (1): Overlay using asphalt mixture.”

Before implementing overlay, dust, mud, and other foreign objects must be removed from road surfaces. Road sweepers (**Photograph-4.3.13**) can efficiently clean road surfaces.

Photograph-4.3.13: Road surface cleaning (by road sweeper)

(2) Tack coat

Asphalt emulsion must be used for tack coating. The amount applied differs depending on road surface roughness and other conditions, but it is generally approximately 0.3 to 0.6 l/m^2.

Photograph-4.3.14: Application of tack coat (by distributor)

For small construction areas, it may be difficult to use a distributor (**Photograph-4.3.14**) to apply a tack coat. In such cases, engine sprayers must be used to implement tack coating uniformly.

It is taxing work to remove emulsion attached to ancillary structures, so such structures must be protected from emulsion by covering them with vinyl sheets or applying stone dust dissolved in water to them. When applying asphalt emulsion with engine sprayers, measures such as using plywood boards to shield against scattering of emulsion must be taken.

(3) Leveling

Forming flat overlay requires pavement road surfaces be corrected in advance; this correction work is called leveling. Leveling is used to fill in depressed portions of road surfaces with asphalt mixture or to form a thin mixture layer to eliminate general unevenness.

Before performing leveling, the actual situation of road surface unevenness must be assessed. Asphalt mixture is used to perform one-layer overlay in order to correct local depressions having a depth of 3 cm or less. When performing overlay to form two or more layers, the first layer is formed as a leveling layer using an asphalt finisher. Defects in the longitudinal or transverse shape of existing pavement must also be corrected by leveling.

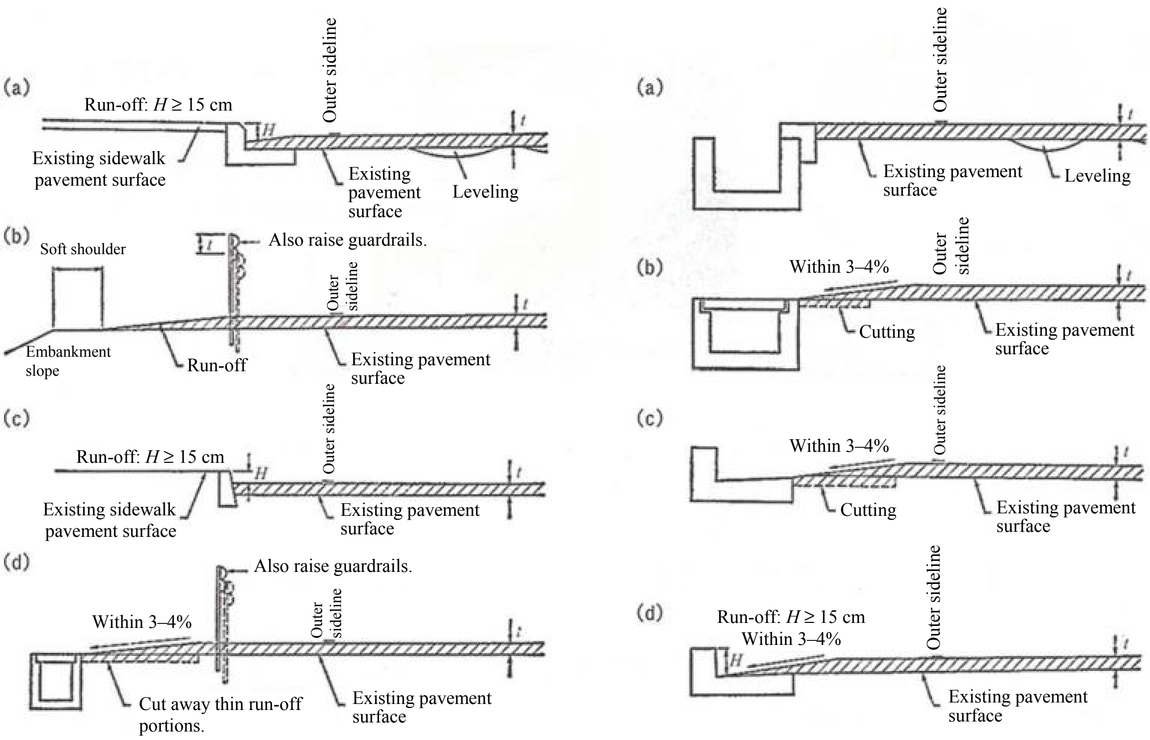
(4) Paving

Photograph-4.3.15 shows spreading, while **Photograph-4.3.16** shows rolling. Before performing overlay, facilities such as side gutters, street gutters, utility holes, and guardrails must be raised if necessary. Utility holes can be raised either before or after paving. If utility holes are raised before paving, they must be firmly secured to prevent their raised portions from moving during paving. If raising utility holes after paving, pavement around the portions to be raised must be drilled and scraped with a special cutter, and run-off using resin-based material must be performed after the portions have been raised. When raising road surface heights by overlay, run-off must be performed to eliminate traffic obstacles in the connecting and similar portions of access roads and pavement.

For run-off to roadsides and structures, refer to **Figure-4.3.1**. For run-off to construction start and end points, refer to **Figure-4.3.2**.

Photograph-4.3.15: Overlay (by spreading)

Photograph-4.3.16: Overlay (by rolling)



1) Road with sidewalk

2) Road without sidewalk

Figure-4.3.1: Examples of run-off near roadside structures[18)]

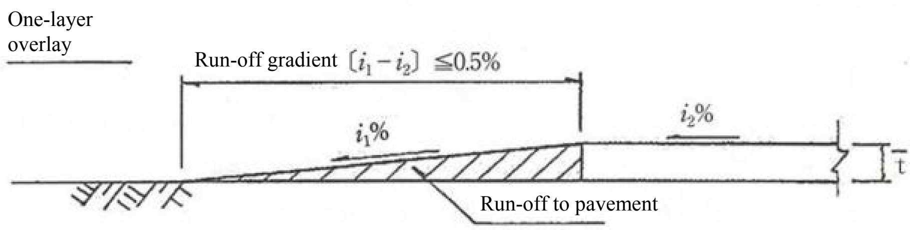


Figure-4.3.2: Example of run-off around the start and end points on the main vehicle lane[19)]

Overlay does not form layers of uniform thickness as seen in newly constructed pavement. Existing pavement generally contains uneven portions, and overlay is implemented to correct such pavement's transverse and longitudinal shapes. Thus, overlay thickness is expressed as an average thickness.

(5) Considerations for applying overlay

Porous asphalt mixture overlaid on existing road surfaces is sometimes damaged when pavement occur stripping by rainwater during at early stage. Thus, it is desirable to overlay the following two layers: asphalt mixture having excellent stripping resistance as the first layer and porous asphalt mixture as the second layer.

The asphalt finisher illustrated in **Figure-4.3.3** has been developed as a piece of equipment for simultaneously overlaying two layers. This asphalt finisher can be used when it is difficult to apply two-layer overlay due to construction constraints, such as limits on overlay thickness or construction time.

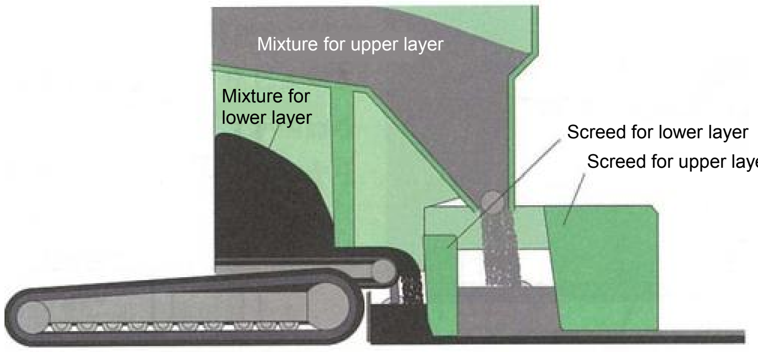


Figure-4.3.3: Structure of the asphalt finisher for simultaneous two-layer overlay

When applying one-layer overlay, lower layers' stripping resistance must be confirmed; then, leveling and cutting must be performed to prevent water from remaining on overlaid layers, after which seepage control treatment should be implemented. Methods for realizing seepage control treatment include the impermeable drainage pavement method (**Figure-4.3.4**), in which an asphalt finisher equipped with an emulsion sprinkler is used to sprinkle special modified-asphalt emulsion at a rate of 1.2 l/m^2 for paving, and another method in which special modified-asphalt compound is sprinkled instead of tack coat material (asphalt emulsion).

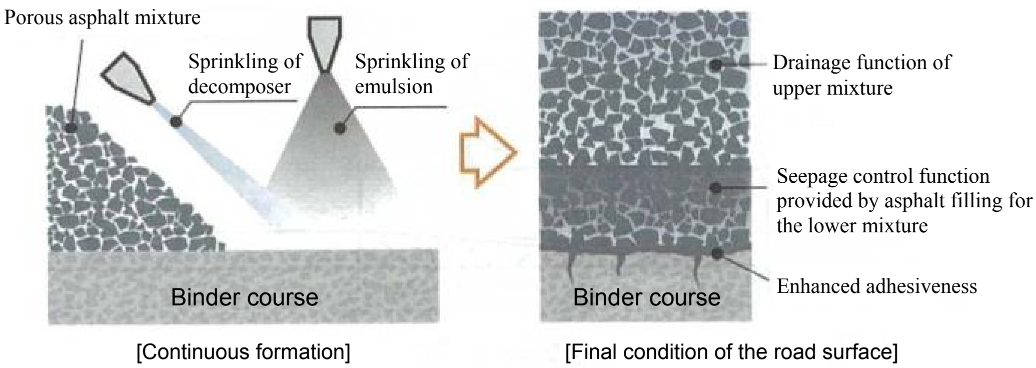


Figure-4.3.4: Construction of impermeable drainage pavement and the final condition thereof

4-3-3 Surface and binder course replacement (mill and overlay)

Surface and binder course replacement is performed to replace existing pavement as deep as the surface or binder course. It is called mill and overlay when removing existing asphalt mixture layers by cutting. For surface and binder course replacement that does not perform cutting when removing existing asphalt mixture layers, refer to "4-3-1 (2): Demolition and excavation of existing pavement."

Mill and overlay cuts part of existing asphalt mixture layers before performing overlay. For surface and binder course replacement that performs cutting to remove all existing asphalt mixture layers, refer to "4-3-1 (4): Construction of asphalt surface and binder courses."

(1) Cutting

During cutting, machines (**Photograph-4.3.17**) must not be tilted transversely and they must not move longitudinally while advancing. Cutting must be performed accurately to realize the planned heights.

A method employing a cutting drum with a very small bit pitch has been developed to give a very fine finish. This method can be used to carry out construction with little noise and few vibrations compared to conventional methods.

Grooves formed by cutting often catch cut chips and other foreign objects; all such objects must be removed.

Photograph-4.3.17: Cutting

(2) Overlay

Refer to "4-3-2: Overlay."

(3) Considerations for applying surface and binder course replacement

1) Application to bridge surface pavement

The same construction method as for general pavement may be applied. For bridge surface pavement, however, due consideration must be given to the following matters.

1. Precautions for cutting

- Note that pavement thickness may not be constant due to the unevenness of concrete decks. Concrete decks must not be scraped when cutting existing pavement.
- Rivet heads, bolt heads, and other similar parts often protrude from steel plate decks. The locations of such protrusions must be identified by preliminary surveys and marked on existing pavement surfaces before cutting in order to prevent such locations from being scraped accidentally. Cutting around such locations must be performed manually. A new method for cutting steel plate decks without using a cutter has been developed. In this method, decks are heated by electromagnetic induction, thereby allowing pavement to be removed without damaging the decks.
- In cutting, whether the targets are concrete decks or steel plate decks, machines must be stopped before reaching expansion devices and bridge anchorages to avoid damaging them, and any remaining portions must be manually scraped away completely. Careful handling is required for rubber joints so as not to damage them with heat.

2. Precautions for paving

- Compaction around expansion devices and bridge anchorages on bridge surfaces is often insufficient. Since such portions may sink, developing faulting during service use, they require appropriate amounts of extra filling. Pavement surfaces around expansion devices should be finished so as to be slightly higher (2 to 3 mm) than the expansion devices.

2) Application to pavement in tunnels

Since subgrade in tunnels is generally bedrock, pavement in tunnels is often designed to be thinner than that of general roads. Tunnel pavement often has nonuniform bearing capacity due to variations in subgrade height brought about by excavation, nonuniform base course thickness due to burial of central drainpipes, and other factors. In addition, tunnels are always affected by water leakage due to spring water after construction. Thus, it is difficult to maintain tunnel pavement base courses in a state identical to that during the construction stage.

Therefore, for maintenance and repair of pavement in tunnels, measures such as cut-off and water conveyance must be sufficiently implemented to cope with water leakage.

3) Application to porous asphalt pavement

When overlaying porous asphalt mixture after cutting, drainpipes and drainage ditches may be constructed at the edges to lead rainwater to drainage facilities, such as side gutters and gullies.

For other considerations, refer to “4-3-2: Overlay, (5): Considerations for applying overlay.”

4-3-4 In-place base course recycling[20)]

In-place base course recycling is used to demolish existing asphalt mixture in situ while simultaneously mixing the demolished mixture with stabilizers (e.g., cement and bituminous material) as well as existing granular base course material. New stabilized base courses are formed by rolling the mixed material. In some cases, all existing asphalt mixture layers are removed, and new stabilized base courses are formed from the material prepared by mixing stabilizers from only existing granular base course material.

In-place base course recycling has the following characteristics.

- In-place base course recycling produces only a small amount of pavement waste compared to total replacement.
- In-place base course recycling can be employed to quickly construct pavement compared to total replacement.
- In-place base course recycling can be performed at a low cost compared to total replacement.
- In-place base course recycling by stabilization using only existing granular base course material strengthens the pavement structure without raising the pavement.
- In-place base course recycling, which requires transport of only a small amount of material (e.g., pavement waste and base course material), is thought to reduce CO_2 emissions due to construction.

For the quality characteristics of in-place recycled base course material and the design of cross-sections of pavement formed from such material, refer to the *Pavement Recovery Handbook*.

(1) Preparation (design)

In-place base course recycling is classified as either in-place recycled-cement stabilization or in-place recycled-cement and bituminous stabilization. In-place recycled-cement and bituminous stabilization includes in-place recycled-cement and asphalt-emulsion stabilization using emulsified petroleum asphalt as bituminous material, and in-place recycled-cement and foamed-asphalt stabilization using foamed asphalt as bituminous material. In addition, in-place recycling and bituminous stabilization includes in-place recycled-foamed-asphalt stabilization using foamed asphalt as bituminous material.

In-place base course recycling is implemented using one of the following three design and construction methods.

1) Stabilization using existing pavement "as is"

This method is used to demolish existing asphalt mixture in situ while simultaneously mixing the demolished mixture with stabilizers (e.g., cement and bituminous material) as well as existing granular base course material. New stabilized base courses are formed by rolling the mixed material. It is applied mainly to portions having a designed daily volume for pavement of less than 1,000 (vehicles/day per direction) (traffic volume class: N_5) and portions with relatively thin asphalt mixture layers. **Figure-4.3.5** gives an example of stabilization using existing pavement "as is."

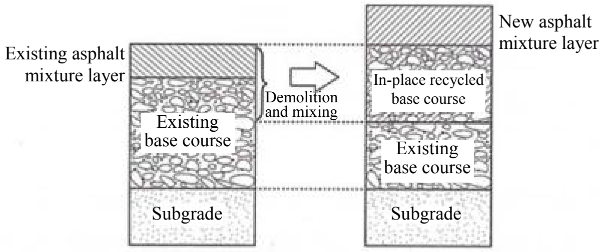


Figure-4.3.5: Example of stabilization using existing pavement "as is"

2) Stabilization after pretreatment when pavement cannot be raised

Pretreatment cuts part of existing asphalt mixture or removes excess portions left after asphalt mixture layers and base courses have been preliminarily demolished by a road stabilizer. It is applied mainly to portions having a designed daily volume for pavement of less than 3,000 (vehicles/day per direction) (traffic volume class: N_6) and portions with relatively thick asphalt mixture layers. **Figure-4.3.6** gives an example of stabilization after pretreatment.

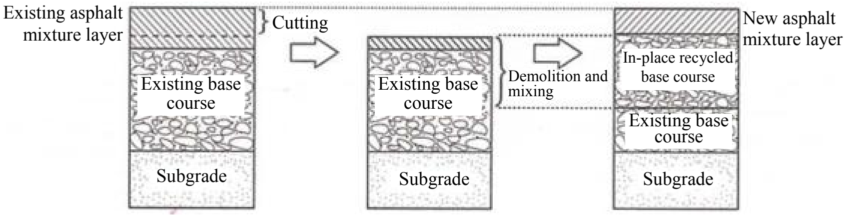


Figure-4.3.6: Example of stabilization after pretreatment (by cutting)

3) Stabilization of only existing base courses

This method is applied to pavement that cannot be raised but has insufficient equivalent thickness. All existing asphalt mixture layers are excavated or removed, after which only the existing granular base course material is stabilized. It is applied to portions with relatively thick asphalt mixture layers regardless of the pavement's designed daily volume. **Figure-4.3.7** gives an example of stabilization of only existing base courses.

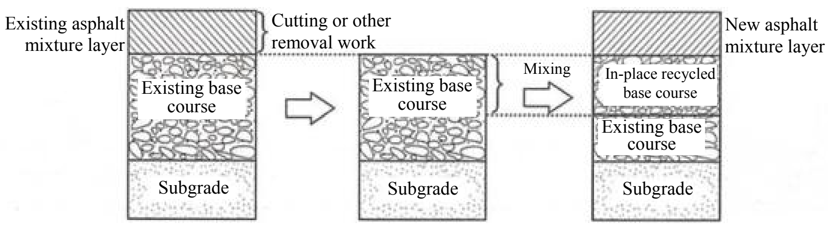


Figure-4.3.7: Example of stabilization of only existing base course

Existing asphalt mixture layers and base course material are demolished and mixed generally with road stabilizers. Demolition and mixing also require machines used for typical base course construction. Stabilizers are sometimes supplied with lorries or similar machines for transport. In some cases, such as construction involving existing asphalt mixture layers thicker than 10 cm, parts of surface courses are cut with road cutters prior to demolition and mixing with road stabilizers. When it is difficult to use road stabilizers near structures, back hoes or similar machines are used instead.

For machines used for typical base course construction, refer to the *Pavement Construction Handbook*.

(2) Procedure

This method forms new asphalt mixture layers approximately 15 to 20% thicker than existing layers. Its construction procedure thus differs depending on stabilizer type, existing asphalt mixture layer thicknesses, constraints on heights of formed pavement surfaces (road surface elevation), and other conditions.

The procedure may include a pretreatment procedure for removing excess material for purposes such as reducing the thicknesses of existing asphalt mixture layers thicker than 10 cm, adjusting the heights of formed pavement surfaces, or adding supplementary material. Excess material produced by pretreatment, when difficult to reuse in situ, is generally transported to recycling plants or similar facilities for reuse. Details of the procedure are as follows, but note that in practice flexible application, not a strict literal interpretation, is required.

1) Procedure without pretreatment

The procedure without pretreatment is applied to demolish existing asphalt mixture layers in situ, to mix the demolished material with stabilizers and existing granular base course material, and to compact the mixed material to form stabilized base courses (**Figure-4.3.5**).

Figure-4.3.8 gives an example of construction according to the procedure without pretreatment.

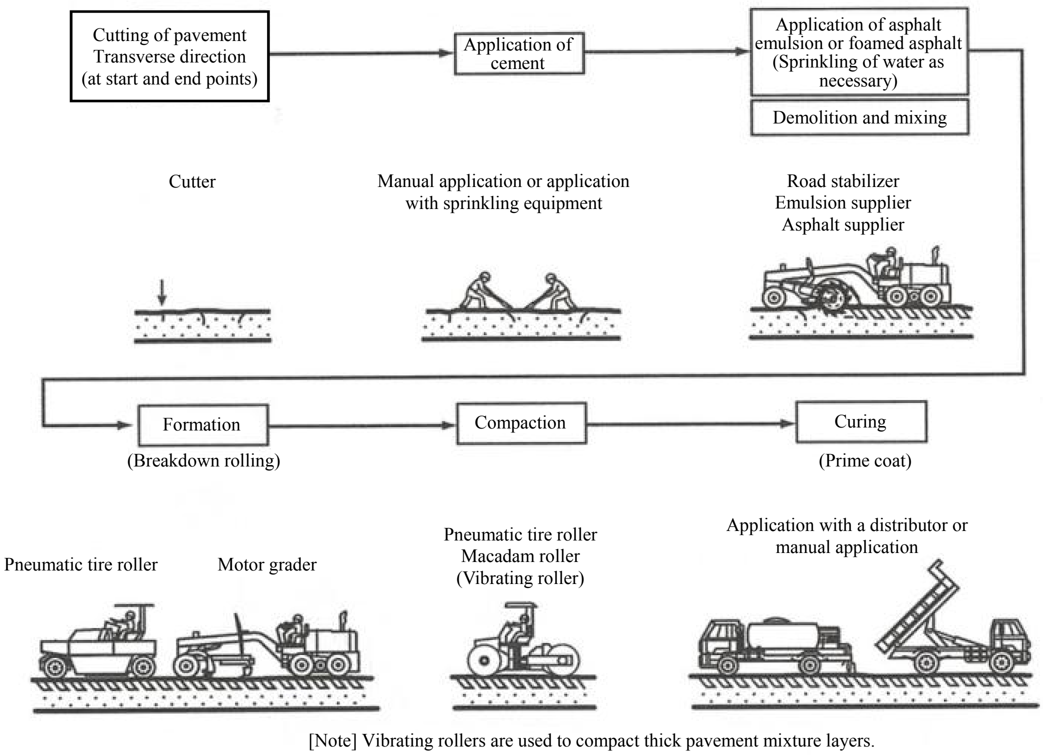


Figure-4.3.8: Procedure without pretreatment (in-place recycled-cement and bituminous stabilization)

2) Procedure with pretreatment

The procedure with pretreatment is applied to adjust the heights of formed pavement surfaces that are difficult to raise, to add supplementary material, to reduce the thickness of existing asphalt mixture layers, or to stabilize pavement using only existing granular base course material (**Figures-4.3.6** and **4.3.7**).

Figure-4.3.9 gives an example of construction according to the procedure with pretreatment.

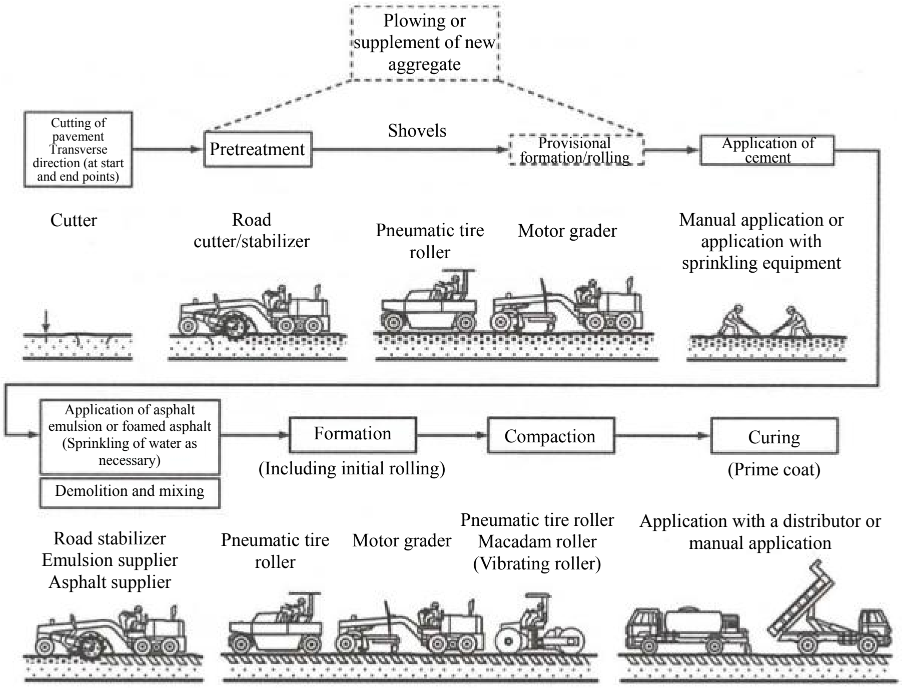


Figure-4.3.9: Procedure with pretreatment
(in-place recycled-cement and bituminous stabilization)

4-3-5 In-place surface recycling[20)]

In-place surface recycling is implemented to improve road surface characteristics and the quality of existing surface course mixture. It recycles existing asphalt mixture layers into new surface courses by consecutively performing in-situ operations (e.g., heating, scarification, mixing (stirring), spreading, and compaction). It offers the following advantages.

- In-place surface recycling, which reuses existing surface course mixture in situ, reduces the amount of pavement waste transported from construction sites.
- In-place surface recycling, which reuses existing surface course mixture, reduces the amounts of new asphalt mixture and other material used.
- In-place surface recycling, which scarifies asphalt while heating it, generates only small vibrations and little noise compared to conventional cutting methods. For the quality of asphalt mixture recycled by in-place surface recycling and design of cross-sections of pavement formed from recycled asphalt mixture, refer to the *Pavement Recovery Handbook*.

In-place surface recycling is achieved by remixing or repaving, the work processes of which are illustrated in **Table-4.3.1**.

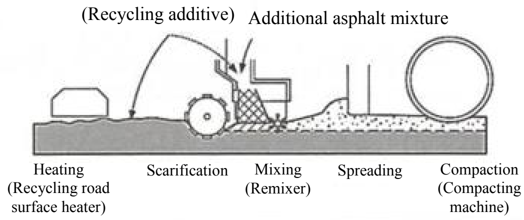
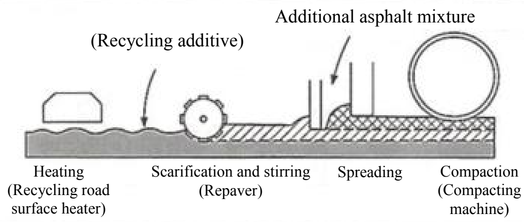
In-place surface recycling employs recycling road surface heaters, recycling additive sprinklers, surface recycling machines, compacting machines, and other machines. Recycling road surface heaters and surface recycling machines are pieces of equipment specialized for in-place surface recycling; in actual construction, equipment having the specified functions must be used.

Surface recycling machines are classified into remixers and repavers. Remixers gather existing surface course mixture in the center of the machine while scarifying the mixture, mix it with additional asphalt mixture or other material, and spread the mixed material. Repavers scarify and stir existing surface course mixture and then spread the stirred material and additional asphalt mixture over the material consecutively.

Compacting machines are used for compaction as is the case with ordinary asphalt pavement. However, since this method compacts mixture at a temperature lower than that for ordinary asphalt pavement, it is desirable to use high-capacity compacting machines. In typical construction, 10-ton or larger road rollers and 15-ton or larger pneumatic tire rollers are used together, or 7-ton or larger vibrating rollers (tandem steel roller type) and 15-ton or larger pneumatic tire rollers are used together.

Recycling additive sprinklers must be able to accurately control the sprinkling rate. When surface recycling machines are equipped with recycling additive sprinkling devices, their traveling speed and sprinkling rate must be adjustable manually or automatically.

Table-4.3.1: In-place surface recycling

Operation type	Overview
Remixing	
Repaving	

(1) Procedure

Read design drawings, specifications, and other design-related documents carefully before beginning construction work to precisely understand the details of construction. Conduct sufficient on-site reconnaissance before starting construction to confirm site conditions and design details. Particularly in the case of consecutive construction, formulate an appropriate implementation plan.

1) Pretreatment

Replace portions in which damage has reached as deep as the binder course or layers underneath or that contain defective surface course mixture. Use a road cutter to remove depressed portions in portions with large rutting so as to reduce their rut depths to 30 mm or less. In the same manner, remove depressed portions around L-shaped side gutters and other roadside structures as a preparation to form smooth run-off. Remove existing pavement or perform other necessary pretreatment around utility holes, handholes, and other road-occupying facilities as well as near bridge joints because such portions are difficult to scarify using this method. Remove pedestrian crossing markings, road marking text, zebra zone markings, and similar markings using a road cutter or other machine. Cover adjacent vegetation zones with protective sheets or other cover materials to protect them from heat as necessary. Take fire prevention measures when combustible objects are present around the construction site.

2) Preparation

In-place surface recycling requires 50- to 100-m road segments in order to deploy construction machines. Determine each work zone in consideration of such deployment. Clean the road surface and remove foreign objects from the work zones. Sand, mud, and other similar materials reduce heating efficiency; it is desirable to wash away such materials with water. When using a recycling additive, divide it into portions of the necessary amount, store them in different containers, and place the containers apart at the required intervals. This need not be done in cases where the additive will be loaded on a surface recycling machine or other such equipment.

The required recycling work is difficult to perform at construction start points; thus, it is desirable to replace the pavement portion extending from the scarifying machine to the end of the spreading machine with additional asphalt mixture.

3) Work process

Figure-4.3.10 illustrates the standard work processes for remixing and repaving as well as gives examples of construction machine deployment. In some cases, machines for supplying additional asphalt are additionally deployed.

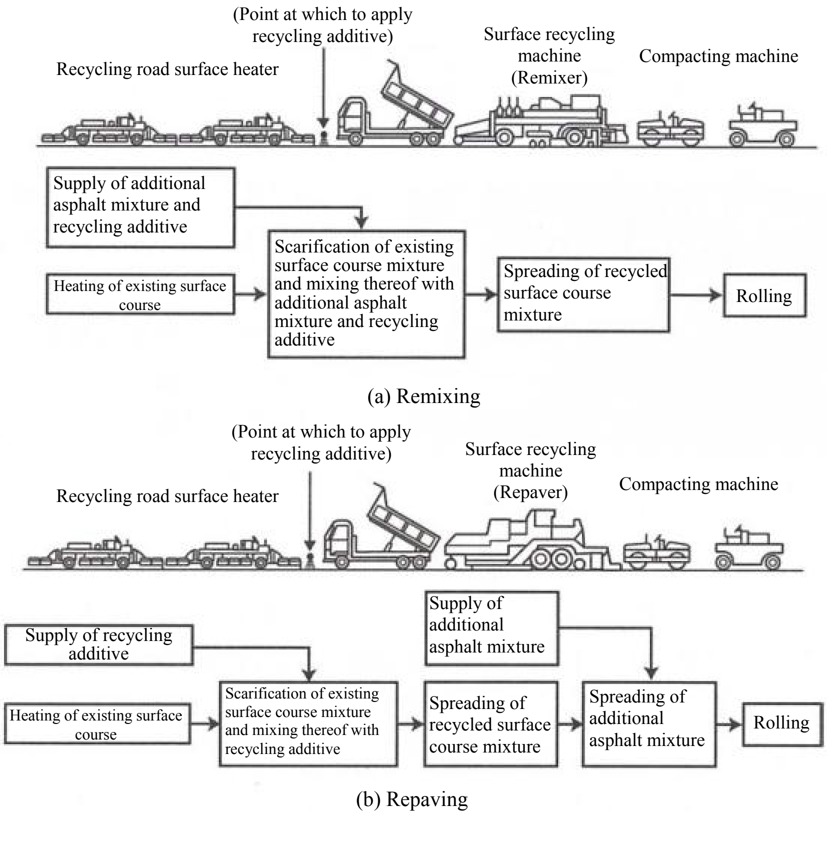


Figure-4.3.10: Work processes and examples of construction machine deployment

(2) Considerations for construction

1) General considerations

- Note that formed pavement surfaces become higher in response to the amount of additional asphalt mixture.
- Even when construction machines have sufficient capacities, insufficient pretreatment or inappropriate arrangement when procuring materials and fuel will inhibit subsequent construction, leading to low quality for the finished work and construction. It is thus necessary to thoroughly formulate a construction plan and to take actions such as reducing construction speed

if materials or fuel cannot be obtained as planned.

- When using a smaller amount of additional asphalt mixture, recycled surface course material is more affected by weather conditions and cools more quickly. In such cases, measures must be taken to prevent cooling of additional asphalt mixture. In addition, existing surface courses must be sufficiently heated, and recycled surface course material must be compacted early on.
- Pavement surface temperature upon ending traffic control should be approximately 50°C or lower. Note that since in-place surface recycling also heats the layers below scarified surfaces, pavement surface temperature may take a long time to fall depending on the atmospheric temperature and weather conditions.

2) Considerations for construction during cool seasons

Since specified construction quality may be difficult to achieve during cool seasons, pavement construction must be avoided at such times. However, when pavement must unavoidably be constructed at an atmospheric temperature of 5 to 10°C, it is essential to take the following measures as well as the measures stipulated for cool seasons in the *Pavement Construction Handbook*.

- Multiple recycling road surface heaters must be used to heat surface courses to a sufficiently high temperature, and vibrating rollers with large compacting capacity must be used for breakdown rolling to realize high compaction efficiency.
- Measures against the cooling of additional asphalt mixture must also be taken. For example, the hoppers of surface recycling machines should be covered with sailcloth.

4-4 Repair methods for concrete pavement

As with asphalt pavement, repair methods for concrete pavement are implemented when maintenance is not expected to lead to sufficient recovery of pavement performance. Repair methods for concrete pavement include replacement and overlay. Since all repair methods are high cost, their adoption and selection of a specific method must be carefully examined by referring to "Chapter 3: Implementation Plans for Maintenance and Repair" and giving consideration to damage causes identified through sufficient surveys.

This section describes considerations and related matters for repair work targeting in-service routes as described in "4-3: Repair methods for asphalt pavement."

4-4-1 Replacement

Replacement is used to replace concrete slabs and all or part of the base courses. In some cases, it is also used to replace subgrade or stabilize subgrade or base courses.

In the replacement process, demolition of pavement as well as construction of subgrade and base courses after excavation and transport must be implemented in accordance with the *Pavement Construction Handbook*. Construction of asphalt and concrete pavement share steps in common with respect to construction of subgrade and base courses. For the common steps, refer to "4-3-1: Replacement."

(1) Preparation (planning)

The thickness of pavement formed by replacement must be designed in accordance with the *Pavement Design Handbook*. In provisional repair, the thickness may be designed by considering that of the adjacent pavement.

In principle, areas to be replaced must be defined by longitudinal joints as borders in the transverse direction of roads and by transverse joints as borders in the longitudinal direction of roads; further, such areas must be quadrangular. Since work with construction machines is easier to perform if areas to be replaced are larger, it is desirable that such areas be at least 20 m in length in the longitudinal direction of roads.

(2) Demolition and excavation of pavement

1) Cutting of pavement

No problems occur when concrete slabs are demolished within areas defined by joints. However, cutters must be used to form clear, straight cut ends.

2) Demolition of pavement

When demolishing concrete slabs, each slab must be demolished separately; the slab is the minimum demolition unit. For other matters, refer to "4-3-1 (2): Demolition and excavation of pavement." However, since concrete slabs contain steel, road cutters must not be used to demolish them.

3) Excavation and loading

Refer to "4-3-1 (2): Demolition and excavation of pavement."

(3) Construction of subgrade and base courses

Refer to "4-3-1 (3): Construction of subgrade and base courses."

(4) Construction of concrete slabs

Concrete pavement is replaced by placing cast-in-place concrete or precast concrete slabs. Cast-in-place concrete includes roller-compacted concrete pavement. This section, however, describes ordinary concrete construction.

1) Construction of concrete slabs (cast-in-place concrete)

Since replacement of concrete pavement (**Photograph-4.4.1**) requires time for concrete curing, it substantially affects road traffic compared to replacement of asphalt pavement. Construction methods, time, processes, and other matters required for replacement of concrete pavement must thus be planned so as to minimize impacts on road traffic above all.

Photograph-4.4.1: Concrete placement

Placed concrete slabs must be left for curing until samples cured on-site have a bending strength of at least 70% of the target strength. Traffic control must not be ended until this curing period has elapsed. When no testing to determine the curing period is performed, the following curing periods must be used as standard: one week for high early strength Portland cement; two weeks for normal Portland cement; and three weeks for blast furnace slag cement.

Tie bars, dowel bars, and similar parts should be used for replacement pavement slabs to prevent damage to pavement, even if such parts were not used in existing pavement slabs. Tie bars, dowel bars, and similar parts that were used in existing pavement slabs can be reused after rustproofing and other necessary treatment if they are removed without damage during demolition. Before reuse, confirm such parts have not suffered rust, thinning, scission, or other types of damage.

Consideration must be given to the following matters when applying this method.

- For work on joints connecting to existing slabs, refer to "4-4-3: Local replacement."

- In principle, the transverse joints in concrete slabs to be replaced must be defined in accordance with the *Pavement Design Handbook*. However, when replacing only one lane, the positions and structural types of transverse joints on the lane must be set to the same as those of the transverse joints on the other lane. At longitudinal joints connecting existing concrete and replaced concrete slabs, tie bars must be installed in principle.
- Edges must be formed between existing roadside structures and replaced concrete slabs using asphalt joint fillers or similar parts.
- Paving by replacement concrete must be implemented in accordance with the *Pavement Construction Handbook*. However, concrete consistent with the paving method to be applied must be selected when large paving machines are difficult to use, when construction areas are small, or in similar cases.

2) Replacement using precast slabs

Replacement using precast slabs, which does not involve curing of cement concrete, allows traffic control to quickly be ended. This method must be carried out in accordance with the *Pavement Construction Handbook*.

Replacement using precast slabs must be implemented in accordance with the following procedure.

1. Cut the target area with a cutter, demolish the cut pavement with a large concrete breaker or similar machine, and transport the demolished pavement. In some cases, an anchor for lifting is attached to existing concrete slabs to transport the slabs without demolishing them.
2. Correct any base course unevenness; sufficiently roll and compact the base course. Add supplementary material as necessary.
3. Place vinyl film to prevent permeation and escape of grout from the voids between precast slabs and the base course.
4. Install steel plates to support height-adjusting bolts.
5. Transport the precast slabs with a lorry, trailer, or other transport vehicle. Lift the slabs with a crane to place them in the required positions (**Photograph-4.4.2**). Appropriate transport vehicles, cranes, and other machines must be selected for this work.
6. Adjust the height of the placed precast slabs to eliminate any faulting between the slabs and surrounding portions. The height of precast slabs is generally adjusted with bolts that have been embedded into them in advance.
7. Placed concrete slabs are sometimes connected to surrounding slabs using dowel or tie bars.
8. Fill the voids between the placed precast slabs and base course with very rapid setting cement-based grout by injecting the grout through grout holes that have been bored in the slabs in advance. When injecting grout, let it flow down spontaneously without applying pressure; inject it sequentially from the lower side of the road gradient while checking that the voids have been securely filled.

Photograph-4.4.2: Placement of precast concrete slabs

4-4-2 Overlay

In overlay, concrete or asphalt mixture layers are paved over existing pavement. This method increases pavement slab thickness, thereby reducing the loads acting on concrete slabs and base courses. Overlay using asphalt mixture covers joints and cracks on concrete slabs to improve trafficability for vehicles, thereby reducing impacts on pavement slabs. However, long-term high service performance requires additional measures against cracking caused by joints of existing concrete pavement slabs. Implementing such measures on existing joints enhances resistance to rainwater.

The following describes overlay using asphalt mixture on concrete pavement and overlay using cement concrete on concrete pavement.

(1) Overlay using asphalt mixture (asphalt overlay)

Tack coats and asphalt mixture layers must be constructed in accordance with the *Pavement Construction Handbook*. The following lists considerations and related matters unique to repair construction.

1) Overlay thickness

The thickness of overlay using asphalt mixture must be designed in the same manner as for overlay of asphalt pavement. Note that it is desirable that the minimum overlay thickness be 8 cm. For overlay thicknesses of 10 cm or more, a crushed-stone mastic layer (5 cm in thickness) will suppress reflection cracking if formed on concrete slabs.

2) Construction methods suppressing reflection cracking

Thin overlay may allow joints and cracks on existing concrete slabs to affect asphalt surface courses. As a result, asphalt surface courses often develop reflection cracking. Some measures must be taken to prevent this from happening; for example, cut joints may be formed on overlaid asphalt surface courses to prevent random cracks. If not forming cut joints, it is desirable to select a construction method that suppresses reflection cracking.

Construction methods that suppress reflection cracking include methods that form a thin stress-absorbing membrane interlayer (SAMI layer) and methods using crushed-stone mastic for binder courses. Bar stitching is sometimes applied to cracking portions on concrete slabs in parallel.

Methods that form a thin SAMI layer include sheet methods; sand cushion methods, which alternately sprinkle aggregate and binder (e.g., modified asphalt or modified asphalt emulsion); and other methods. Note that although such methods delay the onset of reflection cracking, they cannot always completely prevent its occurrence.

The following illustrates a typical procedure for methods using sheets.

When installing sheets, it is essential to bring the sheets into close contact with road surfaces (**Photograph-4.4.3**). Sheets are typically installed in accordance with the following procedure. However, since various types of sheets are commercially available, appropriate ones must be selected by referring to manufacturer-provided specifications.

Photograph-4.4.3: Sheet placement

1. Completely remove any dust, mud, and other foreign objects from joints and cracks.
2. Fill in joints and cracks with asphalt-emulsion-based mortar, injection material, or a similar material. Tap the filled-in portions with a trowel, tamper, or similar tool to sufficiently compact them. When crack widths are 10 mm or larger, use a mixture prepared by adding crushed stone No. 7 to the aforementioned mortar, patching material, or a similar material.
3. Correct portions having large unevenness, local depressions, or similar damage using asphalt mixture, patching material, or a similar material with a maximum grain size equal to one-half their depth. Correct faulting portions in the same manner.

4. Apply asphalt emulsion or other adhesive to the concrete surface portion where sheets will be attached, as illustrated in **Figure-4.4.1**. Place the sheets on this portion and bring them into close contact with it, with approximately 5 to 8cm sheet portions overlapping each other at the sheet edges. When using solvent-based material as an adhesive, allow for sufficient curing time so as to prevent cutback of asphalt mixture.
5. Roll the sheets to bring them into sufficient contact with the concrete surface portion.
6. After the sheets have been brought into sufficient contact with the concrete surface portion, perform overlay. Crawler-type finishers should be used for paving work to prevent sheets from separating from the concrete surfaces. When sheets have been placed across two traffic lanes as illustrated in **Figure-4.4.2**, overlay on their road surfaces must start from the lane in the higher location. This is because doing the work in such an order will prevent rainwater from permeating the layers below the sheets, thereby preventing the sheets from separating from the road surface.

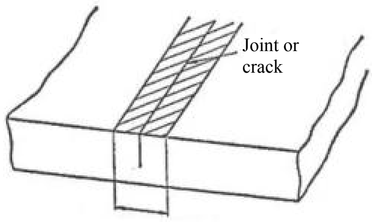


Figure-4.4.1: Sheet placement[18)]

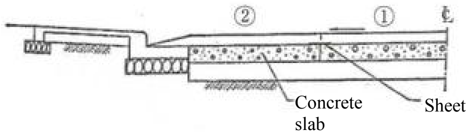


Figure-4.4.2: Order of paving work on sheets placed across two lanes[18)]

3) Implementation of overlay

Before overlay, any severely damaged concrete slabs must be replaced; injection must also be performed on necessary portions in parallel. After that, joints and cracks must be carefully filled in. In overlay, the surfaces of concrete pavement slabs must be cleaned to completely remove dust, mud, and other foreign objects.

Existing asphalt mixture must be removed completely before performing overlay. Asphalt mixture remaining in portions such as those to be patched with asphalt mixture may cause asphalt separation. After cleaning of concrete surfaces is complete, a tack coat must be applied uniformly using as little bituminous material as possible. Asphalt mixture must be paved in accordance with the *Pavement Construction Handbook*. However, irregularities, corrugation, faulting, and other damaged portions of concrete pavement must be corrected locally using asphalt mixture or by forming a leveling layer. When using porous asphalt mixture for overlay, two-layer overlay or seepage control treatment as described in “4-3-2 (5)” must be applied.

Overlay of concrete pavement must be implemented in accordance with the same procedure as overlay of asphalt pavement. Note that consideration must be given to the following matters.

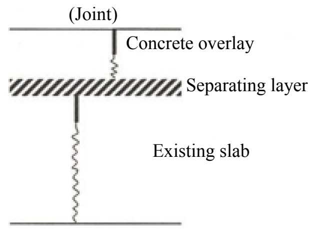
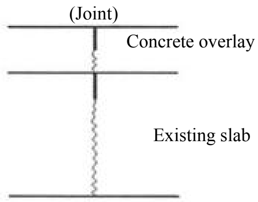
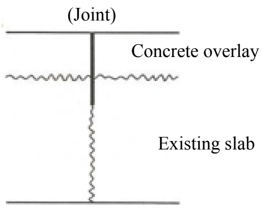
- Ancillary structures (e.g., curbstones and side gutters) must be raised when the overlay is thick.
- Filling in of joints and cracks, run-off of 3cm or larger faulting, correction of 3cm or deeper abrasion and large longitudinal irregularities, and repair of defective portions (e.g., edge defects) must be implemented prior to performing overlay.

(2) Overlay using concrete (concrete overlay)[21)]

Overlay using concrete must be implemented in accordance with the procedure for concrete pavement specified in the *Pavement Construction Handbook.*

Overlay using concrete is classified into the following three types according to the boundary state between existing concrete slabs and overlaid layers: separation overlay (separation raising method), direct overlay (direct raising method), and bonded overlay (bonded raising method) (**Table-4.4.1**). This section describes bonded overlay.

Table-4.4.1: Classification of concrete overlay

Classification	Characteristics	Pavement cross section
Separation (non-bonded) overlay (t: 15 cm or larger) (Separation raising method)	A separating layer is formed between existing concrete slabs and the concrete overlay. Overlay joints can be formed regardless of the positions of existing slab joints. Separation overlay is effective when existing slabs have been severely damaged. However, this method forms very thick overlays compared to other overlay methods.	
Direct (semi-bonded) overlay (t: 13 cm or larger) (Direct raising method)	Overlay concrete can be placed after simple preparation (e.g., cleaning the surfaces of existing concrete slabs). Overlay joints must be formed at the positions of existing slab joints. This method forms relatively thin overlays compared to separation overlay.	
Bonded overlay (t: 5 cm or larger) (Bonded raising method)	Overlay concrete is placed after grinding the surfaces of existing concrete slabs in order to bond the additional and pre-existing concrete portions completely (when existing slabs have suffered severe rutting or other types of severe damage, cutting is implemented after grinding). Overlay joints must be formed at the positions of existing slab joints. In addition, anchor bolts are sometimes attached as deep as the existing slabs. This method forms relatively thin overlays compared to the other two overlay methods.	

Bonded overlay applies bonding treatment to existing slab surfaces and then places an approximately 5- to 10-cm thick concrete overlay atop the surfaces. This method is applied mainly to concrete pavement of roads, bridge decks (deck thickening method), and at airports. It is also called "thin concrete overlay."

Bonded overlay generally uses steel fiber reinforced concrete (SFRC). In some cases, however, plastic fiber reinforced concrete (PFRC) or ordinary concrete, which does not contain fiber for reinforcement, has been used for bonded overlay.

Since bonded overlay forms concrete layers thinner than existing concrete slabs, the formed layers tend to be easily affected by cracks and other damage to existing slabs. Thus, in principle, this method is applied in repair of concrete slabs that have not suffered structural damage. For ordinary roads, it is often applied to repair road surfaces that have developed rutting due to abrasion.

For bonded overlay, it is essential to completely bond existing concrete slabs and overlaid concrete layers. **Figure-4.4.3** illustrates the work process for bonded overlay; the following describes the construction procedure.

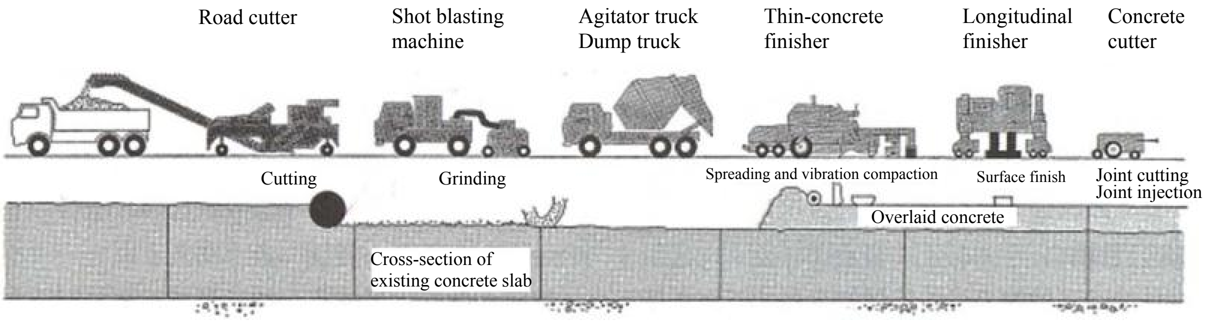


Figure-4.4.3: Construction process[21)]

1) Cutting

On road surfaces with rutting due to abrasion, cutting must first be performed with a road cutter. When existing slabs are wider than the planned construction width, cut lines may be made with a cutter on both ends as illustrated in **Figure-4.4.4** to indicate the construction area.

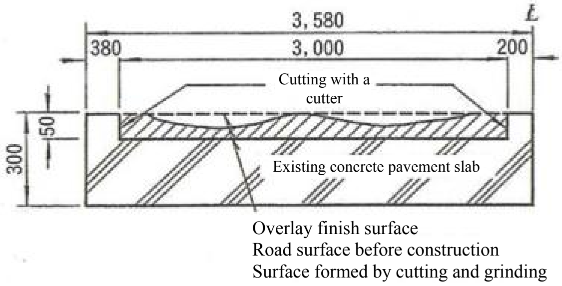


Figure-4.4.4: Construction cross-section in tunnel[21)]

2) Grinding

Defective portions (e.g., stained, loosened, and neutralized portions) must be removed from slab surfaces before grinding the surfaces by shot blasting (**Photograph-4.4.4**) or another method. Resin-based adhesive may be applied to slab surfaces in parallel with grinding to ensure sufficient long-term bonding performance.

Photograph-4.4.4: Shot blasting

3) Mixing of concrete

To mix steel fiber or other fibers into concrete, concrete mixer trucks are generally used to rapidly agitate material near construction sites. In some cases, concrete remixing machines are used as another means of mixing on-site; alternately, mixers in plants are used to agitate material. To apply very rapid setting cement, vehicles equipped with a mobile concrete plant are used to mix material near construction sites.

4) Concrete placement

Before placing concrete, existing slab surfaces are generally maintained in nearly saturated and surface-dried condition. Conventional spreaders, finishers, and longitudinal finishers for concrete pavement can be used for paving. However, since construction generally targets single lanes and forms only thin overlay layers, relatively small concrete finishers dedicated to performing overlay are sometimes used.

5) Curing

When using ordinary or high early strength Portland cement for bonded overlay, wet curing using mats is generally performed. On the other hand, when using very rapid setting cement, curing must be performed for several hours after concrete placement using only sheets; in this case, wet curing is not performed.

6) Joints

Joints must be formed at the same positions as the joints of existing slabs by cutting with a cutter. The cutting depth must extend to the overlay bottom, and the widths of the formed joints must be at least as large as those of the joints of existing slabs.

4-4-3 Local replacement

When load transfer is presumed to be insufficient in portions where concrete slabs have suffered edge cracks, transverse cracks, or other types of cracks extending down to slab bottoms, local replacement is implemented to replace slabs or slabs and base courses locally in such portions. In principle, before performing local replacement, causes of damage must be removed.

(1) Local replacement at edges

Consideration must be given to the following matters when implementing local replacement at edges.

- Make cut lines as deep as 2 to 3 cm outside cracks as illustrated in **Figure-4.4.5**. Round the corners formed at intersecting cut lines to reduce stress concentration.
- Remove concrete portions containing cracks using breakers or similar devices, and grind old concrete jointed surfaces to form longitudinal surfaces. Perform the work carefully so as not to damage reinforcing steels, steel nets, dowel bars, and other components.
- Cut the transverse reinforcements of steel nets and then bend the nets upward. When it is difficult to leave steel nets in place in their entirety, they may be reduced to 20 to 30cm portions.

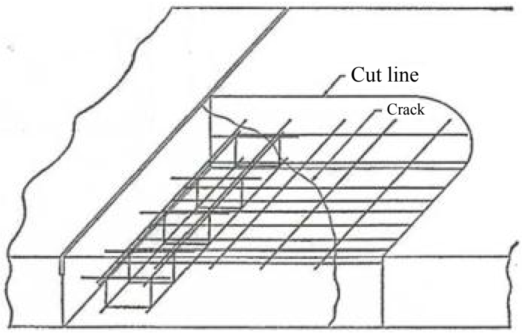


Figure-4.4.5: Local replacement at edges[18)]

- Excavate and replace subgrade and base courses if they are defective.
- Check any dowel bars embedded in existing slabs. Cut and remove defective dowel bars and install new ones. Apply bituminous material to bars protruding on the replacement side.
- When replaced portions are connected to existing slabs via contraction joints, cover the joint surfaces with polyethylene film or apply bituminous or similar material to the surfaces to sever the bond between the new and old concrete portions. When replaced portions are connected to existing slabs via expansion joints, install joint fillers. Place double-ply underlay paper on the surfaces of base courses to reduce their friction resistance to the concrete slabs.
- Follow the *Pavement Construction Handbook* to perform treatment of jointed surfaces and concrete placement.
- Use a cutter to form joint grooves after the concrete has cured, and then inject joint-sealing compound. When edge cracks are present on both sides of a joint, repair the cracks on each side separately in accordance with the aforementioned procedure.

(2) Local replacement on transverse cracks

Transverse cracks extending to concrete slab bottoms must be dealt with appropriately based on their locations and concrete slab structures. The following procedures describe how to deal with cracks in various locations.

1. Cracks less than 10 cm away from joints

   Replace the portion of the concrete slab from the crack to the joint locally after grinding away the portion as deep as the upper parts of dowel bars. Use the crack portion below the dowel bars as transverse contraction joints.

2. Cracks 10 cm or more away from joints but less than 3 m

   Replace the portion of the concrete slab from the crack to the joint locally to a depth as deep as the slab bottom. Use the joint side of the locally replaced portion as a transverse contraction joint without changing its joint structure. Connect the new and old concrete slabs with tie bars on the cracking side of the locally replaced portion. Replacement extensions must be approximately 2 m or longer for tie bar installation or other work. When removing concrete slabs, be careful not to damage dowel bars, reinforcing steel, and other components.

3. Cracks 3 m or more away from joints

For cracks 3 m or more away from joints, replace the cracking portions with contraction joints by performing local replacement. **Figure-4.4.6** illustrates an example of such replacement. Consideration must be given to the following matters when implementing local replacement on portions with cracks 3 m or more away from joints.

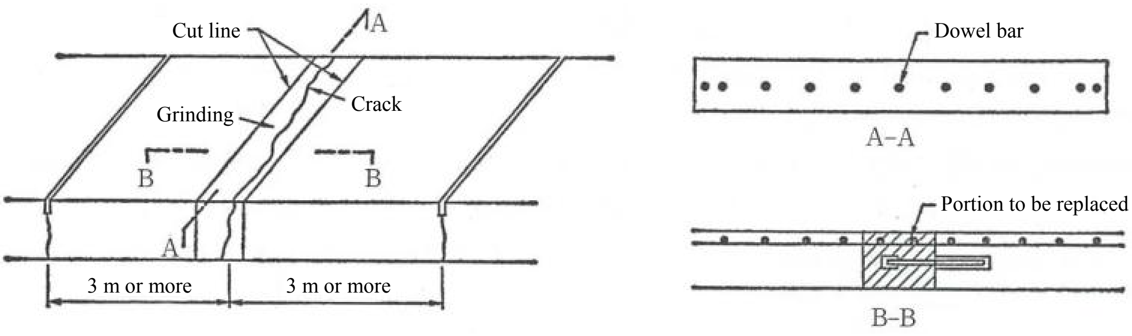


Figure-4.4.6: Local replacement on a portion with transverse cracking[18)]

- Use a cutter to make two cut lines perpendicular to the road centerline, thereby defining a portion that contains the transverse crack and is wide enough for dowel bar installation. One cut line must be as deep as 2 to 3 cm, while the other must be as deep as the bottom of the cross section.
- Remove the concrete between the cut lines. Give a finish to the jointed surfaces in accordance with the same procedure as for local replacement at edges.
- Make holes on slabs' jointed surfaces (contraction joints), inject cement mortar into them, and then place dowel bars (⌀25 × 700 mm) into them so that half the length of the bars is within the holes.
- Apply bituminous material to the protruding portions of the dowel bars and place concrete.
- Form joint grooves using a cutter after the concrete has cured; then, inject joint-sealing compound.
- Repaired portions tend to be easily damaged when slabs are not reinforced with steel nets. The entire slab should be replaced if it has not been reinforced with a steel net.
- Replacement of portions with longitudinal cracks must be implemented in accordance with the same procedure as replacement of portions with transverse cracks.

When damage causes have been eliminated using an injection method or other means, the progress of cracks, even those with large widths, can be stopped by simultaneously performing injection into the cracks and reinforcement, thereby extending the pavement service life.

4-4-4 Thin concrete overlay

Thin concrete overlay is implemented in accordance with the procedure described in "4-4-2: Overlay" (refer to this section for the details of the procedure). For thin layers formed by thin concrete overlay, it is essential to ensure sufficient bonding (integration) with existing concrete slabs, which can be done by implementing surface preparation (grinding, application of adhesive, or water jetting) and secure, uniform compaction using special concrete finishers.

4-5 Maintenance and repair for adding functions and other purposes

In maintenance and repair of pavement, new functions or capabilities may be added or the number of wheel passes causing fatigue failure may be revised in response to changes in needs for pavement and traffic volume. Road construction for recovery after works related to road occupancy, which differ from works for maintenance and repair, may be implemented for the same purpose.

New functions or capabilities are added to some types of pavement during maintenance and repair. This section outlines typical types of such pavement and describes considerations for their implementation as well as the timing for revising the number of wheel passes causing fatigue failure, considerations for recovery after works related to road occupancy, and other related matters.

4-5-1 Pavement to which new functions and capabilities are added

This subsection describes typical types of pavement to which new functions and capabilities are added. It lists their characteristics and considerations when selecting materials for and constructing such pavement.

When new functions and capabilities are added to pavement during maintenance and repair, they are generally added to the layers forming road surfaces (basically, surface courses). Pavement materials, construction methods, and thicknesses are determined during the process of road surface designing. For the details of road surface designing, refer to “3-4-3: Road surface design” and the *Pavement Design Handbook*.

(1) Pavement with a drainage function

1) Overview

Pavement with a drainage function smoothly drains rainwater plus water from other sources away from road surfaces to side strips, road shoulders, or other roadside areas. Such pavement, which allows neither puddles nor water film to form, prevents hydroplaning and reduces water spraying. It is effective for enhancing safety (e.g., by improving visibility in rainy weather) and in reducing water splashing.

2) Types of pavement with a drainage function

Typical types of pavement equipped with a drainage function include drainage pavement and pavement that drains rainwater plus water from other sources away to side strips, road shoulders, or other roadside areas with the aid of shapes formed atop road surfaces. Drainage pavement, whose surface course or surface and binder courses are made of high-void material, drains rainwater by permeating the water quickly into the layers underneath the road surface. The lower layers deliver high water shielding performance to prevent water from permeating into the base course and layers underneath. The drainage layer of drainage pavement is generally made of porous asphalt mixture; research is underway on drainage layers made of porous concrete and other materials. Pavement that drains rainwater with the aid of shapes formed atop road surfaces includes pavement with longitudinal or transverse road-surface grooves formed by grooving as well as concrete pavement that has undergone surface texturing by the aggregate exposure method.

3) Considerations

For considerations on applying and constructing drainage pavement, refer to “4-3-3: Surface and binder course replacement.” Drainage pavement formed by overlaying pavement with a porous asphalt mixture layer after removal of all or part of existing pavement may develop stripping at an early stage if the fundamental layer for constructing the porous asphalt mixture layer has insufficient water resistance performance. The following measures against seepage water must be considered when pavement is likely to develop stripping.

1. Sealant injection into cracks on the fundamental layer
2. Surface treatment for water shielding
3. Two-layer mill and overlay not only on the drainage layer but also on the layer including the water-shielding layer

When sufficient curing time cannot be taken to perform surface treatment for water shielding, the following newly developed method is available. This method uses an asphalt finisher equipped with an emulsion sprinkler to apply modified-asphalt emulsion for tack coating and water-shielding treatment while simultaneously applying porous asphalt mixture.

Porous asphalt mixture is likely to cause aggregate scattering when used in the surface courses of road portions such as intersections, entrances for heavy vehicles, construction joints, and portions subject to traffic of vehicles equipped with tire chains. For such road portions, various measures can be taken against aggregate scattering, including impregnating road surfaces with resin and reinforcing upper portions with voids by filling surface voids with permeable resin mortar as well as using mixture with smaller voids and using binder that suppresses aggregate scattering. For road portions such as intersections with large traffic volume, when measures against aggregate scattering are not expected to prove effective in the long term, other measures are sometimes taken. For example, surface courses may be changed to those made of dense-graded asphalt mixture.

To maintain drainage performance over the long term, periodic maintenance for functional recovery is sometimes implemented. For functional recovery methods, refer to “4-2-5: Washing of void choking.”

For considerations on applying grooving as well as shaping pavement by grooving, refer to “4-2-7: Grooving.”

(2) Pavement with a water-permeating function

1) Overview

Pavement with a water-permeating function is made of water-permeable material that allows rainwater to permeate from surface courses through binder courses to base courses. Such pavement provides the function of suppressing rain runoff into sewers and rivers. Pavement that allows water to permeate into subgrade is also expected to effectively facilitate groundwater recharge.

2) Types of pavement with a water-permeating function

Types of pavement having a water-permeating function include permeable pavement and pavement that imitates natural coverings, such as soil-based pavement and greening pavement. Ordinary pavement prevents rainwater from permeating inside it in order to maintain the durability of subgrade and base courses. In contrast, permeable pavement, whose surface courses, binder courses, base courses, and other portions are made of water-permeable materials, allows rainwater to permeate into its base courses and layers underneath.

Permeable pavement is roughly classified into the following two types according to how it disperses rainwater: pavement that allows water to permeate into subgrade and pavement that stores water provisionally. Pavement that allows water to permeate into subgrade disperses rainwater into natural ground, reducing the peak and total amounts of rain runoff into sewers and rivers compared to ordinary pavement. It is often used for portions of roads such as sidewalks.

Pavement that stores water provisionally delays rain runoff. It is applied to reduce the peak amount of rain runoff into sewers and rivers in locations where rainwater will not be permitted to or naturally permeate into subgrade in order to protect roadside environments.

3) Considerations

1. Whether to apply pavement that allows water to permeate into subgrade must be decided by considering the stability of road structures and roadside structures, impacts on roadside environments, permeation capacities of subgrade and natural ground, and other conditions.
2. Tack coating is not applied except for junctions to ordinary structures. When traffic control is ended before binder courses have been covered, or when surfaces are dirty, asphalt emulsion should be sprinkled at a rate of 0.4 l/m^2 or less to maintain water permeability.
3. Prime coating is not applied in principle. However, high-permeability prime coat should be

applied when erosion or other effects of rainwater in subbase courses may lead to strength degradation.

4. Since permeable pavement delivers the designed permeation performance when constructed from asphalt mixture layers and base courses having sufficient voids, overrolling must be avoided during construction. Note that overrolling may also lead to degradation of permeation performance for pavement that allows water to permeate into subgrade when such pavement is constructed on subgrade made of volcanic cohesive soil or a similar material (e.g., loam).

To maintain permeation performance over the long term, periodic maintenance for functional recovery is sometimes implemented. For functional recovery methods, refer to “4-2-5: Washing of void choking.”

(3) Pavement with a noise reduction function

1) Overview

Pavement with a noise reduction function reduces noise by suppressing air-pumping noise and other types of noise generated by traveling vehicles as well as by absorbing engine and other mechanical noise.

2) Types of pavement with a noise reduction function

Types of pavement having a noise reduction function include pavement made of materials with large voids (e.g., porous asphalt and porous concrete pavement), small-grain aggregate exposure pavement, and elastic pavement for higher noise reduction performance. Such pavement reduces noise with the aid of voids by absorbing air-pumping noise generated when air is compressed between the tread surfaces of traveling vehicles and road surfaces, vibration noise generated when tires vibrate due to irregularities or other shapes on road surfaces, engine noise, and other noise.

Porous asphalt pavement, which is generally used for noise reduction, is called low-noise pavement. Types of elastic pavement include pavement made of asphalt mixtures containing rubber powder or a similar material and pavement with a thin rubber-particle layer attached to its surface.

When formed from small-grain porous asphalt mixture to enhance noise reduction performance, surface courses may consist of two layers; in such cases, the upper portion is comprised of small-grain porous asphalt mixture, while the lower portion is comprised of ordinary porous asphalt mixture or a similar material. Special polymer-modified asphalt is sometimes used as small-grain porous asphalt mixture for surface courses.

3) Considerations

For considerations on application and construction, refer to “4-5-1 (1): Pavement with a drainage function.”

(4) Pavement with a light-coloration function

1) Overview

Pavement with a light-coloration function enhances road surface brightness and light reflectivity in order to improve lighting effects and nighttime visibility. It is often used in tunnels; it is also used for intersections, road junctions, road shoulders, side strips, bridge surfaces, and other road portions.

Pavement with a light-coloration function produces high road surface brightness, improving the lighting effects of road surfaces in tunnels and at night as well as reducing lighting costs. In addition, such pavement reduces the rate of increase in road surface temperature during summer, suppressing rutting due to flow. Light-colored aggregate excellent in terms of light reflectivity improves road surface visibility at night, contributing to highly safe trafficability.

2) Types of pavement with a light-coloration function

Pavement with a light-coloration function includes concrete pavement; mixture pavement comprised of asphalt mixture whose coarse aggregate is partially or entirely replaced with light-colored aggregate; and pavement formed by sprinkling on road surfaces, which is rolled asphalt pavement formed by squeezing light-colored aggregate precoated with resin-based binder or a similar material in the form of crushed stone onto the pavement. Asphalt mixture-based pavement is generally called light-colored pavement.

3) Considerations

1. Since mixture pavement starts providing its light-coloration effects once its asphalt film has been separated from its surface after ending traffic control, it takes a certain amount of time to produce the effects. To produce the effects earlier, the asphalt film should be removed by blasting or other means.
2. To allow road-sprinkling pavement to provide sufficient light-coloration effects and durability, it is essential to uniformly spread precoated crushed stone.

To recover degraded light-coloration performance, surface roughening is sometimes implemented. For functional recovery methods, refer to “4-2-6: Surface roughening.”

(5) Pavement with a color function

1) Overview

Pavement with a color function gives various colors to road surfaces to improve road appearance, distinguishability, and other characteristics related to road visibility. It offers the following advantages.

1. Various colors and design patterns on road surfaces improve the street landscape.
2. Different colorings for school zones, intersections, bus lanes, sidewalks, bicycle lanes, and other road portions contribute to safe, smooth traffic flows.

2) Types of pavement with a color function

Typical asphalt-mixture pavement with a color function includes pavement made of hot asphalt mixture colored by pigments, pavement made of hot asphalt mixture comprised of colored aggregate, and pavement using resin-based binder. It also includes pavement formed by impregnating semi-flexible pavement with colored cement milk and pavement colored by pigments.

Pavement colored by pigments or other coloring material in order to give it a color function is called colored pavement.

3) Considerations

1. Pavement made of colored aggregate provides color effects after its asphalt film has been separated from its surface. To produce the effects earlier, the asphalt film should be removed by blasting or other means.
2. Pavement is colored using inorganic pigments or organic pigments. Since some organic pigments may become discolored, check their weather resistance before application.
3. Tools and construction machines for paving must be washed well.
4. When constructing pavement using resin-based binder, the antiadhesive agents applied to prevent aggregate from adhering to tire rollers and other portions may affect color development and mixture properties. Such characteristics should be checked in advance.
5. The aggregate of mixture subjected to hot mixing is put through different heating and other processes depending on whether it is mixed at factories or asphalt plants. Consequently, pavement constructed on-site may develop colors different from those developed when mixing at factories. When pavement texture and quality are important factors, check such characteristics in

advance.

(6) Pavement with an anti-skid function

1) Overview

Pavement with an anti-skid function enhances road surface skid resistance to improve trafficability for vehicles. It is used for road portions that require particularly high skid resistance (e.g., steep slopes, curved portions, portions adjacent to railroad crossings, and portions near pedestrian crossings with large pedestrian traffic at intersections). Road surface slipperiness depends mainly on the skid resistance between the aggregate and vehicle tires. Since wet road surfaces generally suffer from degraded skid resistance, it is also essential to ensure appropriate road surface drainage.

Construction methods implemented to enhance asphalt mixture skid resistance include a method employing open- or gap-graded asphalt mixture. In addition to enhancing skid resistance, it is thought to suppress water accumulation on road surfaces from drainage pavement and other types of pavement. Construction methods in which asphalt mixture aggregate is replaced with hard aggregate and methods for constructing rolled asphalt pavement are also applied to enhance skid resistance.

2) Types of pavement with an anti-skid function

Pavement with an anti-skid function includes pavement comprised of mixtures having enhanced skid resistance, pavement formed using resin-based binder to bond hard aggregate to road surfaces, and pavement that has undergone surface texturing by grooving, blasting, or other means. For details of the construction method using resin-based binder to bond hard aggregate to road surfaces, refer to "4-2-4 (6): Resin surface treatment."

3) Considerations

1. The construction method using resin-based binder may lead to asphalt stripping when applied to asphalt pavement immediately after construction. This method should thus be applied approximately three weeks after the road is opened to traffic.
2. The curing time required for the construction method using resin-based binder varies based on the atmospheric temperature. When applied for construction performed at an atmospheric temperature of less than 5°C, the method may require measures for heat insulation and heating.
3. To maintain excellent skid resistance over the long term when applying a method for bonding hard aggregate or other material to road surfaces, it is essential to select aggregate that is not easily susceptible to abrasion or breaking due to traffic loads.
4. Since grooving may lead to edge defects and early flow if performed on paved road surfaces immediately after pavement construction, it should be implemented after the roads have been opened to traffic for a certain period of time.

(7) Pavement with high surface roughness

1) Overview

Pavement having high surface roughness is realized by ingenious construction methods or other means. High surface roughness is thus expected to facilitate high trafficability for vehicles and to reduce vibrations and other discomforts caused by road surface irregularities. It is used for high-speed route portions and portions that tend to generate vibrations due to surface roughness degradation when such portions especially require high surface roughness.

2) Construction of pavement with high surface roughness

To construct pavement with high surface roughness, it is essential to estimate the optimal planned road-surface heights. Such optimal planned heights must be determined based on the results of thorough surveys of paved road surfaces and structures so as to minimize variations in road heights that may affect surface roughness.

To minimize irregularities due to construction, it is also necessary to carry out thorough management for each process, from material supply to spreading and rolling. For example, appropriate construction machines must be used to stably perform spreading.

3) Considerations

1. Planned road-surface heights determined during the design process sometimes become inconsistent with the heights of utility holes and other structures to be integrated with pavement. In such cases, construct heights may be changed to achieve the required surface roughness.
2. Asphalt mixture must be supplied smoothly to asphalt finishers in order to spread the mixture at a stable rate.
3. Direct supply of asphalt mixture from dump trucks to asphalt finishers may result in fluctuations in the loads exerted on the asphalt finishers, affecting spreading. To prevent this from happening, conveyers are sometimes used to receive asphalt mixture from dump trucks first and then the received mixture is supplied to asphalt finishers to prevent load fluctuations.
4. To achieve high surface roughness, construction machines (e.g., graders and asphalt finishers) are sometimes controlled by an information construction technology system combining 3D design data, GNSS, a laser surveying technique, and other data and techniques.
5. For some road portions, high surface roughness cannot be achieved even if construction work is carried out perfectly, such as portions in which the gradient and crossfall of road surfaces change from place to place as well as portions for which road-surface heights must be planned under constraints due to road junctions. In such cases, planned road-surface heights must be determined carefully.
6. To achieve high surface roughness for road portions having severe surface irregularities, in some cases road-surface heights must be changed substantially. For national expressways and other roads, IRI (International Roughness Index) is sometimes used as a performance index for road surface irregularities. However, since IRI reflects long-term irregularities more than surface roughness, substantial changes to road-surface heights may be required to improve IRI values. In such cases, the maintenance and repair methods to apply must also be carefully selected.

In addition to the pavement types described in this section, various other types of pavement can be implemented to provide additional functions and capabilities. For their details, refer to the *Pavement Design Handbook*, *Pavement Construction Handbook*, *Handbook on Environmentally-friendly Pavement Technologies*, and other sources.

4-5-2 Pavement for changing the number of wheel passes causing fatigue failure

In some cases, the number of wheel passes causing fatigue failure in pavement is revised, such as when the traffic volume of an in-service road substantially changes. The number of wheel passes causing fatigue failure is increased in response to increases in traffic volume, etc., and decreased in response to decreases in traffic volume due to construction of alternative routes, etc. In both cases, the materials and thicknesses of each pavement layer must be determined in consideration of various pavement requirements so that the pavement can securely offer additional functions and satisfy the requirement for the number of wheel passes causing fatigue failure.

To increase the number of wheel passes causing fatigue failure, pavement structures must be substantially revised. In such cases, generally some improvement measures are taken to satisfy the requirement for the number of wheel passes causing fatigue failure. For example, part of overlay layers or existing base courses may be improved to enhance pavement bearing capacity. Pavement is reconstructed when the requirement for the number of wheel passes causing fatigue failure cannot be achieved by improving part of the existing pavement, or when pavement reconstruction is economical from the perspective of life cycle costs and other factors.

When improving part of the existing pavement, structural design and construction method selection are implemented in accordance with the same procedure as for maintenance and repair of pavement. For the details, refer to “Chapter 3 Implementation Plans for Maintenance and Repair.”

Consideration must be given to the following matters when changing the number of wheel passes causing fatigue failure.

(1) Surveys on the number of wheel passes causing fatigue failure

The number of wheel passes causing fatigue failure must be determined based on the results of surveys of actual traffic volumes. Wheel load surveys are sometimes performed on routes or road portions having heavy large-vehicle traffic volume with high ratios of large vehicles carrying heavy loads in order to determine the number of 49-kN equivalent wheel loads.

(2) Surveys on bedrock conditions

The design CBR, elastic modulus, design bearing capacity factor, and other subgrade factors are used as bedrock conditions for design methods. When changing the number of wheel passes causing fatigue failure, surveys on these bedrock conditions must be carried out at sufficient intervals. When data on past repairs or other available data suggests that bedrock conditions vary substantially from place to place, deflection and other surveys are sometimes implemented to grasp the distributions of bedrock condition values. Locations for surveys for determining design values are selected in consideration of these distributions.

(3) Surveys on the current condition of pavement

To change the number of wheel passes causing fatigue failure, measures must be taken to prevent pavement from easily suffering damage during the specified design period. When improving part of the pavement in order to increase the number of wheel passes causing fatigue failure, structural design must be implemented based on the results of surveys on the pavement in its entirety, including subgrade. When decreasing the number of wheel passes causing fatigue failure, it is also desirable to implement such surveys and appropriate measures if factors that may affect durability are detected.

Surveys of the current condition of pavement are implemented in accordance with the same procedure as for maintenance and repair of pavement. For the details, refer to “3-2: Surveys” and “3-3: Evaluation.”

4-5-3 Paving for recovery after works related to road occupancy[18)]

Works related to road occupancy include work to construct electric poles and road signs along roads and work to embed pipelines for electricity, phone service, gas, water supply and sewage, and other purposes. Road construction is implemented for such works.

The road excavation required to embed pipelines or perform recovery and other related work generates discontinuous portions of pavement. Inappropriate recovery work thus causes road surfaces to suffer from sinking, cracking, and other problems, thereby accelerating road degradation. In addition, frequent construction work on in-service roads, when accompanying excavation, not only substantially affects traffic and roadside areas but also degrades pavement’s structural strength. Thus, after sufficient coordination with owners of road-occupying facilities and road administrators, it is essential to perform construction according to plans that have been formulated by considering the types and locations of buried objects, construction periods, construction methods, and other related conditions.

Excavation for works related to road occupancy and recovery after such works is implemented in accordance with instructions, specifications, and other related documents issued by road administrators. Consideration must be given to the following basic matters.

(1) Prior confirmation

Before excavation, the locations of buried objects must be confirmed by referring to documents and data. When locations cannot accurately be identified from such documents or data, or when there are multiple buried objects, trial boring and other surveys must be additionally performed to identify the locations prior to the start of construction. Probing with devices is also effective for identifying the locations of buried objects.

(2) Excavation

Consideration must be given to the following matters in road excavation to embed objects or repair buried objects.

1. The pavement excavation width must be minimized.
2. Excavation must be implemented by trenching, shaft sinking, the jacking method, or similar methods. Reaming must not be applied.
3. In pavement demolition, pavement slabs must be carefully cut with a concrete cutter or other tool.
4. Demolished pavement slabs, earth and sand produced during excavation, and other unnecessary materials must be immediately transported away from construction sites; they must not be stacked on top of roads.
5. In construction on soft soil or in leaky road portions, appropriate cut-off methods, etc. must be taken against the escaping of earth and sand, loosened foundations, etc.
6. For provisional storage of buried objects that appear during construction, sufficiently safe protective measures decided upon by consultation with the owners of said objects must be taken.
7. To prevent damaging buried objects and surrounding structures during excavation, manual excavation must be performed, and personnel for monitoring cutting blades must be deployed, as necessary,.

(3) Earth retaining and lining

Consideration must be given to the following matters in earth retaining and lining.

1. Before installation of sheet piles, etc., surveys must be implemented to identify the locations of buried objects, after which such sheet piles, etc. must be installed consecutively.
2. Piles, girders, covering plates, and other provisional structures must have structures that are sufficiently safe to support their expected loads.
3. In principle, lining must be implemented with steel or PC-concrete covering plates having high surface skid resistance.
4. Covering plates must be securely placed so that they do not wobble. Longitudinal run-off to existing paved road surfaces must be implemented so as to facilitate safe and smooth traffic flows, preserve roadside environments, and ensure an appropriate gradient.

(4) Backfilling

Consideration must be given to the following matters in backfilling.

1. Backfilling must be implemented with sand, pit-run gravel, high-quality soil, or similar material. Material containing matter such as mud or organic impurities must not be used.
2. Each layer formed by backfilling must be 20 cm or thinner and must be compacted thoroughly with rammers or similar machines.
3. Sheet piles, etc. must be gradually pulled out during removal so that foundations are not damaged.

(5) Recovery of road surfaces

Consideration must be given to the following matters when recovering road surfaces.

1. In principle, road surfaces must be recovered to their original conditions.
2. Provisional recovery of pavement must be implemented immediately after backfilling is complete.
3. In provisional recovery, structures must be built that can withstand short-term traffic loads. In principle, hot asphalt mixture must be used for paving. However, cold mixture may be used for small recovery areas having small traffic volumes if full-scale recovery is to be implemented shortly thereafter.
4. Periodic patrols must be conducted on provisionally recovered road sections until full-scale recovery. If road surfaces show signs of suffering from sinking, irregularities, faulting, or other problems, mending must be performed immediately to ensure safe and smooth traffic flows as well as to preserve roadside environments.
5. Full-scale pavement recovery must target subgrade and base courses of surrounding portions affected by loosened soil, etc. caused by excavation. The target area for full-scale recovery should also be determined in consideration of the workability of construction machines and other factors.
6. Excavation depths, backfilling methods, and other related factors may cause road surfaces to sink substantially under rolling due to traffic loads that are exerted starting immediately after provisional

recovery. In such cases, full-scale pavement recovery should be postponed until the road surface sinking has been sufficiently reduced.

7. At joints connected to existing pavement and structures, compaction tends to be performed insufficiently, resulting in early damage. To prevent this from happening, tack coating must be applied to well-cleaned junctions, and compaction must be carefully performed to bond the spread mixture together. Seal coating may be applied to enhance sealing at joints.

(6) Others

Road ancillary objects that are damaged or moved provisionally in construction work involving buried objects must be restored to their original conditions.

Column: Maintenance and repair of pavement for sidewalks, bicycle lanes, etc.

Unevenness and puddles that occur due to damage to pavement for sidewalks and bicycle lanes, etc. hinder comfortable traffic flows for pedestrians and cyclists. To prevent such inconvenience from leading to accidents, it is desirable to carry out maintenance and repair at an appropriate timing. Pavement for sidewalks and bicycle lanes, etc. is comprised of various surface course materials. Except in emergency cases, the same materials as existing pavement are generally used in maintenance and repair.



(1) Damage causes

1) External damage-inducing factors include heavy work as well as loading and unloading of heavy articles atop pavement, entry and parking of vehicles, and the impacts of roadside construction. Trash, mud, and other dirt on pavement not only spoil its appearance but also result in insufficient surface drainage, sometimes indirectly damaging the pavement.
2) Internal damage-inducing factors include nonuniform bearing capacities of subgrade and base courses, insufficient backfilling for underground objects, damage (leading to water leakage, etc.) to underground objects, and unevenness of sidewalk surfaces due to roots from trees lining the street and roadside.

(2) Considerations for maintenance and repair

1) Damage only affecting surface courses can generally be eliminated by replacing the surface courses. However, damage caused by structural factors (e.g., nonuniform bearing capacity) must be handled by further implementing maintenance and repair on subgrade and base courses.
2) Damage to existing surface courses comprised of flat plates, blocks, tiles, or similar materials is sometimes handled using cold mixture or similar material in emergencies. However, since such approaches may permit damage to recur and spoil the road’s appearance, repair must be performed quickly using the same material as the existing surface courses.
3) Since maintenance and repair of pavement for sidewalks and bicycle lanes, etc. is often implemented with small machines or manually, sufficient compaction must be performed without fail. For such work, which is generally performed in very small areas, appropriate safety measures must be taken to protect pedestrians and structures.
4) Void choking in permeable pavement degrades its permeation performance. Periodic washing with high-pressure water, etc. should be performed to recover performance.

[References]

1) Watanabe, et al.: Result of a Durability Test on Crack Seal Material, 28th Collection of Papers of the Japan Road Association, Japan Road Association (3)-2 32077, October 2009
2) Sato, et al.: Kensetsutosyo, “Maintenance and Repair of Pavement,” p. 127, May 1992
3) Website of AOI Chemical Inc., July 2012
4) Website of NIPPO Corporation, July 2012
5) Road Management Technology Center, Road Structure Management Study Group: Road Management Technology Handbook, p. 75, Kajima Institute Publishing Co., Ltd., February 2010
6) Japan Emulsified Asphalt Association: Basics and Applied Technologies for Asphalt Emulsion, p. 26
7) Japan Road Association: Pavement Construction Handbook (2006 edition), p. 229, February 2006
8) Road Management Technology Center, Road Structure Management Study Group: Road Management Technology Handbook, p. 65, Kajima Institute Publishing Co., Ltd., February 2010
9) Technical Association of Resin Pavement: Instructions for Resin-based Anti-skid Pavement (2004 edition), July 2007
10) Road Management Technology Center, Road Structure Management Study Group: Road Management Technology Handbook, p. 73, Kajima Institute Publishing Co., Ltd., February 2010
11) Society for the Study of the Drainage Topcoat Method: Technical Materials for the Drainage Topcoat Method, January 2008
12) Council on the Permeable Resin Mortar System Method: Second Edition of Technical Materials for the Permeable Resin Mortar System Method, May 2008
13) Website of Obayashi Road Corporation, July 2012
14) Japan Road Association: Technical Materials for Concrete Pavement, p. 57, August 2009
15) Hayasaka, et al.: Effectiveness of Grooving in Snowy Regions and Optimal Grooving Patterns, the Civil Engineering Research Institute for Cold Region (Hokkaido), Monthly Report No. 590, p. 26, July 2002
16) Road Management Technology Center, Road Structure Management Study Group: Road Management Technology Handbook, p. 79, Kajima Institute Publishing Co., Ltd., February 2010
17) Japan Road Association: Pavement Recovery Handbook (2010 edition), pp. 112–115, November 2010
18) Japan Road Association: Guidelines for Road Maintenance and Repair, July 1978
19) Chubu Regional Bureau: Instructions for Road Design (Design), Chapter 14 Maintenance and Repair, December 2008
20) Japan Road Association: Pavement Recovery Handbook (2010 edition), November 2010
21) Fukuda: Concrete Pavement 5, Lecture on Maintenance and Repair of Pavement 13, Pavement, May 1991

Chapter 5: Confirmation and Inspections of Performance

5-1 Overview

According to the *Technical Standards for Pavement Structures and Their Descriptions*, the values of pavement performance indices must be checked immediately after completing construction. The standards also stipulate that the values must be checked at specified points in time (if specified) after the pavement is put into service use. However, note that the *Technical Standards for Pavement Structures and Their Descriptions* target new pavement construction, pavement reconstruction, and large-scale pavement repair, though this same concept may also apply in other cases, such as when those ordering construction have specified performance index values for maintenance and repair works.

Pavement performance is inspected by checking performance index values or by checking finished work and construction quality against specifications for pavement having demonstrated performance.

When those ordering construction have specified values for performance indices and methods for checking such values, values are checked in either of the following manners: 1. contractors design and construct pavement, and after completing completion, those ordering construction check the values; 2. those ordering construction design the pavement, and after contractors construct it according to the required performance specifications under an agreement reached between two parties, those ordering construction check the finished work and construction quality.

When contractors construct pavement that has been designed by those ordering construction in accordance with specifications for pavement having demonstrated performance, those ordering construction will inspect pavement performance by checking finished work and construction quality against the specifications. Thus, this guidebook has been compiled so as to apply to conventional orders based on the specifications described in “1-3: Performance Specification and Ordering” of *Guidelines for Pavement Design and Construction* (2006 edition).

Multiple performance indices are often used in various combinations to specify pavement performance. In such cases, pavement performance is inspected by combining checks of performance index values with checks of finished work and construction quality.

In contracts, post-construction checks of pavement performance are implemented as inspections; thus, judgment is made based on the results, as is done with checks of finished work and construction quality in conventional orders based on specifications.

Performance check items, checking methods, criteria for performance index values, and other related matters are generally contained in design drawings and documents. In bidding based on comprehensive judgment, blanket ordering for design and construction, or other ordering procedures, contractors often make proposals, and those ordering construction decide on the proposals by consulting with the contractors. This guidebook gives some examples of performance confirmation; however, those ordering construction must act flexibly for each construction order.

After being used to judge performance, pavement performance index values measured during the performance checking stage must be stored in the road administrator’s database as data for future maintenance and repair of pavement.

5-2 Methods for checking and inspecting performance

5-2-1 Method for checking performance index values

When performance indices and methods for measuring their values are specified in design drawings and documents, performance must be judged based on criteria specified by those ordering construction.

Pavement performance indices are classified into “essential performance indices,” “performance indices of rainwater permeation," and "performance indices defined on an as-needed basis."

Performance index values are determined by measurement of on-site pavement or pavement samples, or by other methods. In each approach, values are measured directly or indirectly. To determine performance index values, it is desirable to perform direct measurement of pavement on-site. When applying indirect measurement, the values of indices related to the target performance indices of on-site pavement must be measured, and the values of the target indices must be estimated from the measured values.

5-2-2 Method for checking finished work and construction quality

When the finished work and construction quality of pavement has been specified in design based on specifications for pavement whose performance has been demonstrated, its performance immediately after construction must be inspected by checking finished work and construction quality against the specifications.

This method requires contractors to implement voluntary management of finished work and construction quality at trial batch tests and each construction stage. In addition, those ordering construction must perform performance checks and inspections at construction stages and completion of construction, on an as-needed basis. For the details of methods for checks and inspections at construction stages, see "5-4-1: Methods for inspecting finished work and construction quality."

5-3 Methods for checking performance index values[2), 3)]

5-3-1 Methods for checking performance index values

For the details of methods for checking performance index values, refer to *Pavement Performance Evaluation Methods —Methods for Evaluating Essential and Principal Performance Indices—* and *Pavement Performance Evaluation Methods —Methods for Evaluating Performance Indices Defined as Needed—*. The decision on whether to use other methods must be made by those ordering construction. When proposing additional pavement performance evaluation methods, they should also be referenced.

When applying maintenance methods using construction methods such as patching and sealant injection, the performance index values measured by the methods described in *Pavement Performance Evaluation Methods* often do not sufficiently reflect the actual pavement performance. In such cases, the method for inspecting finished work and construction quality described in "5-4-2: Method for inspecting finished work and construction quality achieved by maintenance methods" must be used to collect data for establishing a new pavement performance evaluation method applicable to the maintenance method. When proposing new pavement performance evaluation methods applicable to maintenance methods, they should also be referenced.

Performance indices and methods for measuring their values are defined as follows.

(1) Essential performance indices

The follow three indices are the essential performance indices: the number of wheel passes causing fatigue failure, the number of wheel passes causing plastic deformation, and surface roughness. **Table-5.3.1** lists the definitions of essential performance indices and methods for measuring their values.

Table-5.3.1: Definitions of essential performance indices and methods for measuring their values

Performance index	Definition	Classification of measuring method	Measuring method
Number of wheel passes causing fatigue failure	The number of 49-kN wheel loads that are repeatedly applied to a paved road surface until cracking caused by fatigue damage occurs; it is specified for each paved section formed by a number of identical layers, in which each layer has uniform thickness and is made of the same material.	Indirect measurement	• Deflection measurement method using FWD to determine the number of wheel passes causing fatigue failure (asphalt pavement) • Method by verifying design and checking design values after construction to determine the number of wheel passes causing fatigue failure (asphalt pavement and concrete pavement)
Number of wheel passes causing plastic deformation	The number of 49-kN wheel loads that are repeatedly applied to a paved road surface at a surface course temperature of 60°C until the paved road surface develops 1-mm downward displacement; it is specified for each paved section having a surface course of uniform thickness and made of the same material.	Indirect measurement	• Dynamic stability measurement with a wheel tracking tester to determine the number of wheel passes causing plastic deformation (asphalt pavement)
Surface roughness	The standard deviation of the difference in elevation between the paved road surface and the ideal flat paved road surface at any one point on each 1.5-m segment of either of two parallel straight lines 1 m away from the center line of the roadway; it is specified for each paved section having a surface course of uniform thickness and made of the same material.	Direct measurement	• Measurement of surface roughness using a 3-meter profilometer • Measurement of surface roughness using a surface characteristics survey vehicle

(2) Performance indices of rainwater permeation

The amount of seepage water is the performance index of rainwater permeation. **Table-5.3.2** shows the definition of this index and the method for measuring its value.

Table-5.3.2: Definition of the performance index of rainwater permeation and method for measuring its value

Performance index	Definition	Classification of measuring method	Measuring method
Amount of seepage water	The amount of water that permeates through a circular area 15 cm in diameter from the road surface into the lower layers over 15 seconds; it is specified for each paved section having a surface course of uniform thickness and made of the same material.	Direct measurement	• On-site measurement of the amount of seepage water using a permeameter

(3) Performance indices defined on an as-needed basis

Performance indices defined on an as-needed basis consist of 11 "performance indices for pavement of roadways and marginal strips" and five "performance indices for pavement of sidewalks." **Table-5.3.3** lists the definitions of performance indices defined on an as-needed basis and methods for measuring their values.

Table-5.3.3: Definitions of performance indices defined on an as-needed basis and methods for measuring their values

Performance index	Definition	Classification of measuring method	Measuring method
Noise value	The value obtained when rounding to the nearest whole number the equivalent noise level; before rounding, the equivalent noise level undergoes velocity correction on an as-needed basis when measured by “tire-road surface noise measurement with a paved road surface measuring vehicle,” or it undergoes velocity correction and temperature correction on an as-needed basis and then is converted to a tire-road surface noise value by the person in charge of measurement when measured by “tire-road surface noise measurement with an ordinary passenger car for measurement.”	Direct measurement	• Tire-road surface noise measurement of noise values with a paved road surface noise measuring vehicle • Tire-road surface noise measurement with an ordinary passenger car for measurement
Skid resistance value	The skid resistance value measured using a skid resistance measuring vehicle of the Public Works Research Center or a skid resistance measuring vehicle whose performance has been verified to be equivalent to that of a measuring vehicle of the Public Works Research Center	Direct measurement	• Skid friction coefficient measurement with a skid resistance measuring vehicle • Dynamic friction coefficient measurement with a DF tester
Abrasion loss	The level of abrasion loss in surface courses caused by tire chains, etc. in snowy regions, etc.	Direct measurement	• Measurement of abrasion loss by using a raveling tester (chain-rotating tire and reciprocating sample type)
Impact aggregate scattering value	The level of aggregate scattering occurring when vehicles, etc. equipped with tire chains travel over pavement made with a porous asphalt mixture in snowy regions, etc.	Indirect measurement	• Cantabro test for measuring impact aggregate scattering values
Torsional aggregate scattering value	The level of aggregate scattering occurring when pavement having a surface course made of porous asphalt mixture is distorted by tires	Direct measurement	• Measurement of torsional aggregate scattering values with a torsional aggregate scattering tester
Road surface lightness	Degree of brightness of the road surface color	Direct measurement	• Road surface lightness measurement with a colorimeter
Adfreezing tensile strength	Degree of ease of separating ice sheets from road surfaces in winter	Direct measurement	• Measurement of adfreezing tensile strength with a tensile tester
Road surface temperature reduction value	Difference in road surface temperature between reference pavement and pavement for which road surface temperature increases are suppressed	Direct measurement	• On-site measurement of road surface temperature with a thermometer to determine road surface temperature reduction values as well as measurement of sample surface temperatures under lamp irradiation to determine road surface temperature reduction values
Vibration level reduction value	Road traffic vibration reduction realized through repair works	Direct measurement	• Road traffic vibration measurement for vibration level reduction values

Performance index	Definition	Classification of measuring method	Measuring method
Maximum runoff ratio	Ratio of the maximum amount of runoff into drainage facilities, etc. to the amount of rainfall	Indirect measurement	• Permeability measurement for determining water retention rates and storage rates • Density measurement by the sand compaction method to determine the density of subgrade and subbase courses • Permeability test for determining the coefficient of permeability of subgrade as well as borehole measurement for determining the coefficient of permeability of saturated subgrade
CO_2 emissions reduction value	Level of CO_2 emissions reduction compared to pavement made of ordinary material or constructed by ordinary methods	Others	• Measurement using CO_2 unit consumption to determine CO_2 emissions reduction
Sidewalk skid resistance value	Performance that must be delivered by sidewalk pavement for easy walking and barrier-free environments	Direct measurement	• Measurement with a pendulum skid resistance tester to determine sidewalk skid resistance
Sidewalk surface roughness	Performance that must be delivered by sidewalk pavement for easy walking and barrier-free environments		• Measurement with a profiler to determine sidewalk surface roughness
Sidewalk surface faulting	Performance that must be delivered by sidewalk pavement for easy walking and barrier-free environments		• Measurement with rulers and gap gauges, etc. to determine sidewalk faulting
Sidewalk hardness	Performance that must be delivered by sidewalk pavement for easy walking and barrier-free environments		• Elasticity measurement with golf balls and steel balls to determine sidewalk hardness
Amount of seepage water permeating into sidewalks	Performance that must be delivered by sidewalk pavement for easy walking and barrier-free environments		• On-site measurement of the amount of seepage water to determine the amount of seepage water permeating into sidewalks

5-3-2 Inspection of performance index values and their criteria

In contracts, checks of pavement performance are implemented as inspections; thus, judgment is made based on the results, as is done with checks of finished work and construction quality. For methods for judging performance index values, refer to those in “5-3-1: Methods for checking performance index values” as references. Those ordering construction must specify the criteria for performance index values by considering the conditions of target sites, regional conditions, and other factors as well as by using statistical approaches to ensure safety, such as giving consideration to data variation.

5-4 Inspection of finished work and construction quality

5-4-1 Methods for inspecting finished work and construction quality

The following describes methods for inspecting finished work and construction quality for pavement as well as judgment criteria.

(1) Lot size and sampling

The unit of samples required to judge construction is called an inspection lot. In large-scale construction, etc., each construction lot is divided into multiple inspection lots of appropriate sizes; inspection for judgment is generally conducted on each inspection lot so divided. In principle, random sampling is performed with the aid of a random number table or other means on an as-needed basis.

(2) Selection of inspection items

Inspection items must be selected in consideration of various factors, such as conditions relating to those ordering construction, regional conditions, site conditions, and the economic benefit and efficiency of inspection. The criteria for finished work and construction quality of pavement are used to inspect pavement to judge whether it delivers the designed performance. In principle, the same criteria must be applied to construction of different scales and roads of different types.

(3) Inspection during each stage

1) Checking by trial batch tests

Tests for checking material quality—including mixture design, tests for determining standard densities and other reference values, and test construction performed to establish work standards—are classified as pre-construction trial batch tests. When such tests are specified in design drawings and documents, contractors must perform them, and those ordering construction must inspect and judge the test results.

Material test reports prepared by material manufacturers, mixture specifications of asphalt mixture accepted by preliminary review, and mixture specifications of standard cement concrete shipped by JIS-certified plants may be used for inspection instead of the results of trial batch tests.

2) Inspection timing

1. Portions that are difficult to inspect after completing construction, such as portions covered with other material during the course of construction, must be inspected during each relevant construction stage.
2. Inspectors other than supervisors must perform construction inspections upon completion of construction.

3) Inspection procedures

1. “5-4-3: Items and methods for finished work quality inspection” and “5-4-4: Items and methods for construction quality inspection” describe inspection methods as references. If applicable inspection methods equivalent to or better than the described methods are developed, such newly established methods may be used under an agreement between those ordering construction and contractors.
2. “5-4-5: Criteria for finished work and construction quality” lists judgment criteria as references. When applying inspection methods equivalent to or better than the described methods, appropriate criteria must be newly determined by consultation between those ordering construction and contractors.

4) Sampling and witness inspections

In principle, the sampling inspection must be employed to examine construction. Quality management data prepared by contractors must not be accepted as inspection results without first checking such data. In the following cases, however, construction may be examined by witness inspection checking materials and construction conditions in the presence of contractor personnel, such as supervisors and personnel qualified as first-grade pavement construction management engineers.

1. When judging sampling inspection to be inappropriate based on construction types (e.g., bridge pavement), construction scale, construction conditions (night or emergency repair construction), or other construction-related conditions, or external conditions such as traffic
2. When judging sampling inspection to be inappropriate based on the fact that the portions were covered with other material during the course of construction
3. The quality of concrete slabs must be judged based on their bending strength, split tensile

strength, or compressive strength. Such strength inspections must generally be performed using management data from samples formed by the standard curing method; it is not to be performed on cores or prismatic samples extracted from the concrete slabs.

5-4-2 Method for inspecting finished work and construction quality realized by maintenance methods

In maintenance construction, finished work and construction quality management is generally not very effective in on-site work if performed in the same manner as for large-scale construction. The following steps should be taken, particularly for quality management: implementation of trial batch tests of materials to check whether they satisfy specifications, establishment of work standards for construction, and implementation of construction management using check sheets to check compliance with work standards. In this process, construction must be sufficiently observed to detect defects.

The following are examples of inspections of finished work and construction quality realized by patching, sealant injection, and surface treatment, which are methods typically used for maintenance construction.

(1) Patching

Patching is often performed as part of repairs in emergencies or similar cases. In such cases, inspection must be performed quickly.

1) Finished work quality inspection

Finished work quality inspection must focus on the following two items.

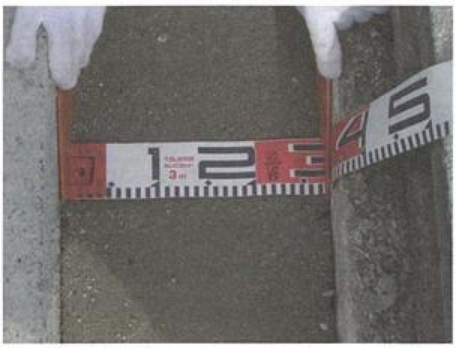
1. Construction area
2. Construction thickness

Finished work quality inspection of construction areas takes measurements of widths, extensions, diameters, and other properties prior to construction (**Photograph-5.4.1**) or construction areas after construction (patched area in **Photograph-5.4.2**).

Finished work quality inspection of construction thicknesses must be implemented by a method other than core sampling (**Photograph-5.4.3**). For wide areas, construction thicknesses must be measured using leveling cords or other tools.

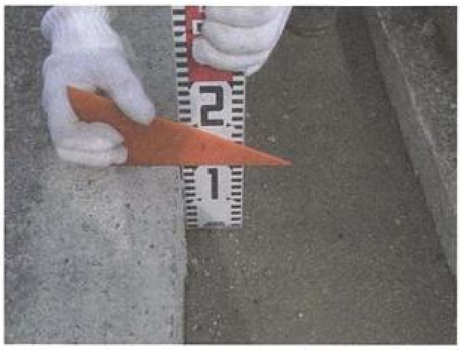
When the amount of patching material used cannot be estimated from the construction area and thickness, estimate it from the number of empty material bags.

Personnel must confirm that finished surfaces exhibit neither large faulting nor large irregularities.



Photograph-5.4.1: Measurement of width

Photograph-5.4.2: Patching[5)]



Photograph-5.4.3: Measurement of thickness

2) Construction quality inspection

Materials that have been checked and approved by those ordering construction must be used for patching.

Contractors must carry out inspection using photographs and witness inspection to verify that pavement has been patched at appropriate temperatures by appropriate methods in order to demonstrate that patched portions will not be damaged immediately after start of service use.

(2) Sealant injection

Sealant injection is applied to cracks to prevent water from permeating into pavement. Above all else, intrusion of water must be prevented.

Photograph-5.4.4: Sealant injection[5)]

1) Finished work quality inspection

It is generally difficult to measure crack depths. Thus, finished work quality inspection must focus on the following two items.

1. Construction extension
2. Amount of material used (empty bags, etc.)

Construction extensions must be measured in order to judge whether cracks have been sealed securely. Cracks in complex shapes (**Photograph-5.4.4**) can be measured with a rolling measurer (**Photgraph-5.4.5**).

Empty bag inspection must be conducted to judge whether cracks have been filled with sealant. Average crack depths can be estimated based on construction extensions and the amount of material used.

Photograph-5.4.6 shows an example measurement of injection depth. A heated needle is pushed into sealant and then pulled out quickly; the asphalt that has attached to the needle is measured as the injection depth. In this measurement, however, injection depth must be determined in consideration of the fact that asphalt attaches to the needle even if there is a cavity below the asphalt.

Photograph-5.4.5: Rolling measurer

Photograph-5.4.6: Measurement of injection depth

2) Construction quality inspection

Materials that have been checked and approved by those ordering construction must be used for sealant injection.

Contractors must carry out inspection using photographs and witness inspection to verify that sealant has been injected at appropriate temperatures by appropriate methods in order to demonstrate that injected sealant will not separate or protrude immediately after start of service use.

(3) Surface treatment

Surface treatment is employed to form 2.5-cm or thinner sealing layers on road surfaces by chip sealing or carpet coating. In surface treatment, various types of material are used to recover the performance of road surfaces that are suffering from degraded performance. Appropriate inspection items should thus be selected in accordance with the purpose of each inspection.

1) Finished work quality inspection

Finished work quality inspection must focus on the following two items.

1. Construction area
2. Construction thickness (on an as-needed basis)

Finished work quality inspection of construction areas takes measurements of widths, extensions, and other properties prior to construction or construction areas after construction.

When it is required to conduct finished work quality inspection of construction thicknesses, construction thicknesses must be measured using leveling cords or other tools.

When the amount of material used cannot be estimated from the construction area and thickness, estimate it from the number of empty material bags.

Personnel must confirm that finished surfaces exhibit neither large faulting nor large irregularities.

2) Construction quality inspection

Materials that have been checked and approved by those ordering construction must be used.

Contractors must carry out inspection using photographs and witness inspection to verify that surface treatment has been implemented at appropriate temperatures by appropriate methods in order to demonstrate that treated portions will not be damaged immediately after start of service use.

5-4-3 Items and methods for finished work quality inspection

Items for finished work quality inspection must be selected by referring to the inspection items listed in **Table-5.4.1**. Regarding which inspection items to implement and their inspection intervals, those ordering construction must comprehensively consider construction details and other conditions to make the final decision as to whether each inspection item can be omitted.

The inspection items listed in **Table-5.4.1** must basically be inspected by the corresponding methods listed in **Table-5.4.2**. When applicable inspection methods equivalent to or better than the methods listed in **Table-5.4.2** have been developed, such newly established methods may be used under an agreement between those ordering construction and contractors.

Table-5.4.1: Examples of items and intervals of finished work quality inspection[1), 4)]

Construction type		Item	Interval
Constructed subgrade		Improvement thickness	On an as-needed basis
		Reference height	40 m
		Width	40 m
Subbase course		Reference height	20 m
		Width	40 m
		Thickness	20 m
Base course	Mechanical stabilization, cement (line soil) stabilization, cement and bituminous stabilization, and bituminous stabilization	Width	100 m
		Thickness	20 m
	Asphalt cushion course	Width	100 m
		Thickness	1,000 m^2
Binder course	Asphalt mixture layer	Width	100 m
		Thickness	1,000 m^2
Surface course	Asphalt mixture layer	Width	100 m
		Thickness	1,000 m^2
	Cement concrete slab	Width	40 m
		Thickness	100 m
	Roller compacted concrete slab	Width	40 m
		Thickness	40 m

Table-5.4.2: Standard methods for inspecting finished work quality[1)]

Item	Construction type	Inspection method
Reference height	Constructed subgrade and subbase course	*Handbook of Pavement Survey and Test Methods*: G001 Method for measuring the reference height of subgrade surface
Width	Constructed subgrade, subbase course, base course formed by mechanical stabilization, base course formed by cement (lime soil) stabilization, base course formed by cement and bituminous stabilization, and base course formed by bituminous stabilization	*Handbook of Pavement Survey and Test Methods*: G002 Method for measuring the width of granular base course
	Asphalt cushion course, binder course, surface course, cement concrete slabs, and roller compacted concrete slabs	*Handbook of Pavement Survey and Test Methods*: G004 Method for measuring pavement width
Thickness	Subbase course	*Handbook of Pavement Survey and Test Methods*: G003 Method for measuring the thickness of granular base course (Sampling inspection: direct measurement; other types of inspection: leveling cords or levels)
	Base course formed by mechanical stabilization, base course formed by cement (lime soil) stabilization, base course formed by cement and bituminous stabilization, and base course formed by bituminous stabilization	*Handbook of Pavement Survey and Test Methods*: G003 Method for measuring the thickness of granular base course (Witness inspection: leveling cords or levels; other types of inspection: direct measurement)
	Asphalt cushion course and binder course	(Core sampling) *Handbook of Pavement Survey and Test Methods*: G006 Method for measuring pavement thickness (Other than core sampling) *Handbook of Pavement Survey and Test Methods*: G003 Method for measuring the thickness of granular base course (Leveling cords or levels)
	Surface course (asphalt mixture layer, cement concrete slab, and roller compacted concrete slab)	(Core sampling from the surface course) *Handbook of Pavement Survey and Test Methods*: G006 Method for measuring pavement thickness (Other than core sampling) Forms or *Handbook of Pavement Survey and Test Methods*: G003 Method for measuring the thickness of granular base course (Leveling cords or levels)

5-4-4 Items and methods for construction quality inspection

(1) Items for construction quality inspection

As references for construction quality inspection, **Table-5.4.3** lists some examples of quality inspection items and intervals corresponding to the examples of criteria shown in the *Guidelines for Pavement Design and Construction* (2006 edition). This table also specifies construction scales. For example, medium- or larger-scale construction refers to construction with a paving area of 10,000 m^2 or larger or construction using a total amount of binder- and surface-course material of at least 3,000 t (1,000 m^3 when using concrete). Small-scale construction refers to construction carried out over a period of several consecutive days realized by work of the same type and falls under either of the following two categories.

1. Construction with a construction area of at least 2,000 m^2 but less than 10,000 m^2
2. Construction using a total amount of binder- and surface-course material of at least 500 t but less than 3,000 t (at least 400 m^3 but less than 1,000 m^3 when using concrete)

Table-5.4.3: Examples of items and intervals of construction quality inspection[4)]

Construction type				Medium- or larger-scale construction	Small-scale construction	Examples of inspection intervals
Subbase course		Water content (percent of dry weight), PI, Grading		△	-	When a defect is detected
		Degree of compaction		○	△	One piece per 1,000 m^2
		Proof rolling		○	-	As required
Base course	Mechanical stabilization	Water content (percent of dry weight), PI		△	△	When a defect is detected
		Grading	2.36 mm	○	-	Once or twice per day
			75 µm	△	-	Once or twice per day
		Degree of compaction		○	△	One piece per 1,000 m^2
	Cement and lime soil stabilization	Grading	2.36 mm	○	-	Once or twice per day
			75 µm	△	-	Once or twice per day
		Cement content Lime content	Quantitative test	△	-	Once or twice per day
			Amount of material used	○	○	As required
		Degree of compaction		○	△	One piece per 1,000 m^2
		Water content (percent of dry weight)		△	△	When a defect is detected
	Cement and bituminous stabilization	Cement content		○	○	Once or twice per day
		Asphalt emulsion content		○	○	Once or twice per day
		Degree of compaction		○	△	One piece per 1,000 m^2
		Water content		○	△	Once or twice per day
	Bituminous stabilization	Grading		○	-	Printed records: for everything, or Extraction test or sieve analysis: once or twice per day
		Asphalt content		○	△	
		Degree of compaction		○	△	One piece per 1,000 m^2
Concrete slabs		Grading, Unit weight		○	△	Once every 300 m^3 for fine aggregate and once every 500 m^3 for coarse aggregate, or once per day
		Percentage of fine aggregate surface moisture		○	△	Twice per day
		Consistency		○	○	Twice per day
		Air content		○	○	Twice per day
		Concrete temperature		○	○	During consistency measurement
		Concrete strength		○	○	Twice per day
		Chloride content		○	○	Twice per day
Roller compacted concrete slabs		Grading, Unit weight		○	△	Once every 300 m^3 for fine aggregate and once every 500 m^3 for coarse aggregate, or once per day
		Percentage of fine aggregate surface moisture		○	△	Twice per day
		Consistency		○	○	Twice per day
		Concrete temperature		○	○	Twice per day
		Concrete strength		○	○	Twice per day
		Degree of compaction		○	○	40 m/time (at three points in the transverse direction)
Surface and binder courses	Hot asphalt mixture	Appearance		○	○	As required
		Temperature		○	○	As required
		Grading		○	△	Printed records: for everything, or Extraction test or sieve analysis: once or twice per day
		Asphalt content		○	△	
		Degree of compaction		○	△	

Legend ○ : Inspection item implemented periodically or as needed
△ : Inspection item that must be implemented when a defect is detected or as necessary
\- : Inspection item that may be omitted

Regarding the items and intervals of construction quality inspection, those ordering construction must comprehensively consider construction details and other conditions to make the final decision as to whether each inspection item can be omitted. When the quality of asphalt mixture has been certified by preliminary review or another examination, those ordering construction must comprehensively consider construction details and other conditions to make the final decision as to whether each inspection item can be omitted and whether inspection intervals should be reduced.

(2) Method for inspecting construction quality

When applicable inspection methods equivalent to or better than the standard methods for inspecting construction quality listed in **Table-5.4.4** have been developed, such newly established methods may be used under an agreement between those ordering construction and contractors.

Values corresponding to construction quality inspection must be calculated from values measured as variable values of specific inspection items through sample tests. Judgments on each lot are made by comparing the calculated values with the predetermined judgment criteria. Note that witness inspection can only be implemented in those cases described in “5-4-1 (3) 4): Sampling inspection and witness inspection 1. to 3.”

Table-5.4.4: Standard methods for inspecting construction quality[1)]

Item	Construction type	Inspection method
Degree of compaction	Replacing subbase course; base course formed by mechanical stabilization; cement (lime soil) stabilization (constructed subgrade and base course); cement and bituminous stabilization	*Handbook of Pavement Survey and Test Methods*: G021 Method for measuring the density of subgrade by the sand replacement method *Handbook of Pavement Survey and Test Methods*: G022 Method for density measurement using RI
	Base course formed by bituminous stabilization; asphalt cushion course; binder course; surface course	(Core sampling) *Handbook of Pavement Survey and Test Methods*: B008 Method for specific gravity test of asphalt mixture (Other than core sampling) In accordance with the work standards; determine in advance the type of compacting equipment, number of rolling coverage items, temperature, etc.
	Roller compacted concrete slabs	*Handbook of Pavement Survey and Test Methods*: B072 Test method for roller compacted concrete pavement
Grading	Subbase course; base course formed by mechanical stabilization; base course formed by cement (lime soil) stabilization; cement and bituminous stabilization	*Handbook of Pavement Survey and Test Methods*: A003 Method for sieving analysis of aggregate
Grading and asphalt content	Base course formed by bituminous stabilization; asphalt cushion course; binder course; surface course	(Core sampling) *Handbook of Pavement Survey and Test Methods*: G028 Method for asphalt extraction tests (Other than core sampling) Inspection by asphalt extraction test on samples collected at mixing installations or immediately after spreading with finishers in accordance with the *Handbook of Pavement Survey and Test Methods*: G028 Method for asphalt extraction tests, or inspection using printed records stored in mixing installations
Cement/lime/asphalt emulsion/asphalt content	Cement (lime soil) stabilization (constructed subgrade and base course); cement and bituminous stabilization	Measurement of amounts of materials used
Bending strength	Cement concrete slabs; roller compacted concrete slabs	*Handbook of Pavement Survey and Test Methods*: B062 Method for bending strength test of concrete

5-4-5 Criteria for finished work and construction quality

Those ordering construction must appropriately specify the criteria for finished work quality by considering regional conditions, site conditions, and other factors.

The following are some examples of criteria applied to structural pavement design implemented in accordance with “Appendix 4: Asphalt concrete pavement in conformity with the standards for the number of wheel passes causing fatigue failure” and “Appendix 5: Cement concrete pavement conforming with the standards for the number of wheel passes causing fatigue failure” in the *Guidelines for Pavement Design and Construction* (2006 edition).

(1) Criteria for finished work quality

Table-5.4.5 lists some examples of standard criteria applied in sampling inspection of finished work quality.

Table-5.4.5: Examples of criteria for finished work quality[1)]

Construction type		Item	Criterion for each measured value	$\overline{X}_{10}$
Constructed subgrade		Reference height (cm)	Within ±5	-
		Width (cm)	-10 or more	-
Subbase course		Reference height (cm)	Within ±4	-
		Width (cm)	-5 or more	-
		Thickness (cm)	-4.5 or more	-1.5 or more
Base course	Mechanical stabilization	Width (cm)	-5 or more	-
		Thickness (cm)	-2.5 or more	-0.8 or more
	Cement (lime soil) stabilization Cement and bituminous stabilization	Width (cm)	-5 or more	-
		Thickness (cm)	-2.5 or more	-0.5 or more
	Bituminous stabilization	Width (cm)	-5 or more	-
		Thickness (cm)	-1.5 or more	-0.8 or more
	Asphalt cushion course	Width (cm)	-2.5 or more	-
		Thickness (cm)	-0.9 or more	-0.3 or more
Binder course		Width (cm)	-2.5 or more	-
		Thickness (cm)	-0.9 or more	-0.3 or more
Surface course		Width (cm)	-2.5 or more	-
		Thickness (cm)	-0.7 or more	-0.2 or more
Concrete slabs		Width (cm)	-2.5 or more	-
		Thickness (cm)	-1.0 or more	-0.35 or more
Roller compacted concrete slabs		Width (cm)	-3.5 or more	-
		Thickness (cm)	-1.5 or more	-0.45 or more

[Note 1] The reference heights of one-layer base courses for concrete slabs and roller compacted concrete slabs must be within ±3.0 cm for each measured value.

Judgment of the finished work quality must be made in accordance with the following procedure.

1. For heights and widths, each measured value must be within the criterion range.
2. For thicknesses, at least nine of the ten measured values must be within the criterion range, and the average value ($\overline{X}_{10}$) of the 10 measured values must also be within the criterion range.
3. Finished work quality can be examined by witness inspection in the presence of supervisors or other inspectors during night, emergency, or other types of construction that involve small-scale construction ranging from base course to binder course carried out under time constraints to allow for quick ending of traffic control.
4. When inspection cannot be implemented before ending traffic control due to factors related to traffic control, inspection must be carried out as soon as possible thereafter.

(2) Criteria for construction quality

Table-5.4.6 lists some examples of standard criteria applied to sampling inspection of construction quality.

Table-5.4.6: Examples of construction quality criteria[1)]

Construction type		Item		$\overline{X}_{10}$	$\overline{X}_{6}$	$\overline{X}_{3}$
Constructed subgrade		Degree of compaction (%)		92.5 or more	93 or more	93.5 or more
Subbase course		Degree of compaction (%)		95 or more	96 or more	97 or more
Base course	Mechanical stabilization	Degree of compaction (%)		95 or more	95.5 or more	96.5 or more
		Grading (%)	2.36 mm	Within ±10	Within ±9.5	Within ±8.5
			75 µm	Within ±4.0	Within ±4.0	Within ±3.5
	Cement stabilization Lime soil stabilization Cement and bituminous stabilization	Degree of compaction (%)		95 or more	95.5 or more	96.5 or more
		Grading (%)	2.36 mm	Within ±10	Within ±9.5	Within ±8.5
			75 µm	Within ±4.0	Within ±4.0	Within ±3.5
		Cement/lime content (%)		-0.8 or more	-0.8 or more	-0.7 or more
	Bituminous stabilization	Degree of compaction (%)		95 or more	95.5 or more	96.5 or more
		Grading (%)	2.36 mm	Within ±10	Within ±9.5	Within ±8.5
			75 µm	Within ±4.0	Within ±4.0	Within ±3.5
		Asphalt content (%)		-0.8 or more	-0.8 or more	-0.7 or more
	Asphalt cushion course	Degree of compaction (%)		96 or more	96 or more	96.5 or more
		Grading (%)	2.36 mm	Within ±8.0	Within ±7.5	Within ±7.0
			75 µm	Within ±3.5	Within ±3.5	Within ±3.0
		Asphalt content (%)		Within ±0.55	Within ±0.50	Within ±0.50
Binder course		Degree of compaction (%)		96 or more	96 or more	96.5 or more
		Grading (%)	2.36 mm	Within ±8.0	Within ±7.5	Within ±7.0
			75 µm	Within ±3.5	Within ±3.5	Within ±3.0
		Asphalt content (%)		Within ±0.55	Within ±0.50	Within ±0.50
Surface course		Degree of compaction (%)		96 or more	96 or more	96.5 or more
		Grading (%)	2.36 mm	Within ±8.0	Within ±7.5	Within ±7.0
			75 µm	Within ±3.5	Within ±3.5	Within ±3.0
		Asphalt content (%)		Within ±0.55	Within ±0.50	Within ±0.50
Roller compacted concrete slabs		Degree of compaction (%)		97.5 or more	97.5 or more	98 or more

Judgment of construction quality must be made in accordance with the following procedure.

1. For each lot with an area of 10,000 m^2 or less, the average of 10 measured values extracted at random must be within the criterion range for $\overline{X}_{10}$.
2. When it is difficult to obtain 10 values, the average of three measured values extracted at random may be used for judgment. In this case, the average must be within the criterion range for $\overline{X}_3$.
3. If the average of the three values deviates from the criterion range for $\overline{X}_3$, an additional judgment must be made on average $\overline{X}_6$ of six measured values (consisting of the previous three values and three additional measured values). If this average also deviates from the criterion range, an additional judgment must be made on average $\overline{X}_{10}$ (consisting of the previous six values and four additional measured values). In this case, the criterion range for $\overline{X}_{10}$ must be applied in judgment.
4. Large lots are sometimes rejected due to local inconformity. In such cases, the number of areas to be dealt with after rejection can be reduced by dividing each rejected lot into several smaller lots and reinspecting the smaller lots.
5. The quality of concrete slabs must be judged from their bending strength or split tensile strength. Such strength inspections must be performed using management data from samples formed by the standard curing method; it is not to be performed on cut cores or other samples. Judgment of construction quality must be made in accordance with the criteria specified in *JIS A 5308 Ready-mixed concrete*.

Nominal strength refers to the design standard strength.

i) The value obtained from each test must be at least 85% of the specified nominal strength.

ii) The average of the values obtained from three tests must be at least equal to the specified nominal strength.

[References]

1) Japan Road Association: Guidelines for Pavement Design and Construction (2006 edition), February 2006

2) Japan Road Association: Pavement Performance Evaluation Methods —Methods for Evaluating Essential and Principal Performance Indices— (2013 edition), April 2013

3) Japan Road Association: Pavement Performance Evaluation Methods: Separate Volume —Methods for Evaluating Performance Indices Defined as Needed—, March 2008

4) Japan Road Association: Pavement Construction Handbook (2006 edition), February 2006

5) Japan Road Contractors Association website (as of August 5, 2013)
http://www.dohkenkyo.net/pavement/meisyo/joon.html
http://www.dohkenkyo.net/pavement/meisyo/siruko.html

Chapter 6: Accumulation of Construction Records

6-1 Overview

Performing efficient, rational maintenance and repair within limited budgets requires that timing, target portions, and methods of maintenance and repair be selected so as to minimize lifecycle costs based on objective data. This objective data is accumulated by collecting records from daily, periodic, and other inspections as well as construction records for maintenance and repair. Maintenance and repair plans must be formulated based on such accumulated objective data.

It is also desirable to collect and accumulate records of pavement construction for recovery after works related to road occupancy and apply these when formulating maintenance and repair plans.

This chapter outlines how to collect, accumulate, and apply construction records.

6-2 Construction records

6-2-1 Purposes of collecting construction records

Construction records can be used as fundamental data to decide the timing of maintenance and repair, to select maintenance and repair methods, to examine the possibility of material recycling, and for various other purposes. Such fundamental data must be reflected in maintenance and repair plans and thus must be collected and accumulated in an appropriate manner.

When new materials, new construction methods, or other new technologies are adopted to increase construction efficiency, reduce costs, or for other purposes, collected and accumulated records of surveys of construction management, etc. related to such new technologies will become common knowledge among related parties. New technologies can be widely applied as common technologies once their effectiveness has been demonstrated through repeated use. Widespread use will ultimately contribute to the advancement of pavement technologies in Japan.

6-2-2 Method for collecting construction records

Construction records must be collected in appropriate formats after construction is complete.

Table-6.2.1 lists some examples of data to collect from maintenance and repair construction.

Table-6.2.1: Examples of data to collect from maintenance and repair construction

Classification	Items
Location	Route No., distance marking or coordinate system, lane No., and place name
Road structure	Lane structure, road width, bridges/other structures, and intersections
Roadside environment	Classification of snowy regions and use of roadside areas
Traffic conditions	Results of traffic volume surveys (incl. classification of large vehicles) and travel speed
Pavement conditions	Designed daily volume for pavement (design class), design CBR, status of performance specifications, T_A, pavement structure, materials, year and month of paving, contractor name, and plant name
Pavement design	Designed daily volume for pavement (design class), design CBR, status of performance specifications, T_A, residual T_A, pavement structure, materials, reason for maintenance and repair, and pavement survey results (e.g., deflection measured with FWD)
Pavement construction	Construction project name, contractor name, plant name, ordering system, construction method, construction period, pavement structure, materials, results of performance checks, and construction management data
Road surface characteristics	Crack ratio, rut depth, surface roughness, and other items (skid resistance, etc.)
Other surveys	Deflection measured with FWD and environmental noise
Reference info.	Notified data, complaint data, etc.

6-2-3 Formats for recording construction information

Table-6.2.2 shows an example of a format for recording the results of construction for maintenance and repair. **Tables-6.2.3** and **6.2.4** show examples for recording the results of trial batch tests of materials. **Table-6.2.5** shows an example for recording the results of construction quality management, while **Table-6.2.6** shows an example for recording the results of finished work quality management.

Table-6.2.2: Example of a format for recording the results of construction for maintenance and repair

Location	Route No.		Distance marking	~ (Up / down)
	Lane No.		Place name	
Road structure	Lane structure		Road width	
	Earthwork / bridge / tunnel sections		Intersection / road section having uninterrupted flow	
Roadside environment	Ordinary region / snowy region		DID / urban area / level terrain / mountainous area	
Traffic conditions	Total traffic volume		Large vehicle traffic volume	
	Travel speed			
Pavement conditions	Designed daily volume for pavement		Design CBR	
	T_A		Year and month of paving	
	Contractor name		Plant name	
	Pavement structure			
	Materials			
	Status of performance specifications			
Pavement design	Designed daily volume for pavement		Design CBR	
	T_A		Residual T_A	
	Reason for maintenance and repair			
	Results of pavement surveys			
	Pavement structure			
	Materials			
	Status of performance specifications			
Pavement construction	Construction project name		Contractor name	
	Plant name		Ordering system	
	Pavement structure			
	Materials			
	Construction method			
	Construction period			
	Results of performance checks			
Road surface characteristics	Crack ratio			
	Rut depth			
	Surface roughness			
	Others			
Other surveys	Deflection measured with FWD			
	Environmental noise			
Reference info.	Notified data			
	Complaint data			

Table-6.2.3: Example of a format for recording the results of trial batch tests of materials

Surface course	Hot asphalt mixture	Mixture type		
		Asphalt type		
		Grading	2.36-mm sieving pass (%)	
			75-µm sieving pass (%)	
		Asphalt content (%)		
		Stability (kN)		
		Flow value (1/100 cm)		
		Percentage of air voids (%)		
		Degree of saturation (%)		
		Residual stability (%)		
		Dynamic stability (times/mm)		
		Coefficient of permeability (cm/sec)		
Binder course		Mixture type		
		Asphalt type		
		Grading	2.36-mm sieving pass (%)	
			75-µm sieving pass (%)	
		Asphalt content (%)		
		Stability (kN)		
		Flow value (1/100 cm)		
		Percentage of air voids (%)		
		Degree of saturation (%)		
		Residual stability (%)		
		Dynamic stability (times/mm)		
Concrete slabs	Concrete type			
	Cement type			
	Maximum size of coarse aggregate (mm)			
	Unit content of cement (kg/m^3)			
	Water cement ratio (%)			
	Quantity of coarse aggregate per unit vol. of cement (Or sand ratio (%))			
	Slump (cm)			
	Air content (%)			
	Bending strength (MPa)			
	Chloride content (kg/m^3)			

Table-6.2.4: Example of a format for recording the results of trial batch tests of materials

Base course	Type of base course material		
	Maximum grain size (mm)		
	Grading	4.75-mm sieving pass (%)	
		2.36-mm sieving pass (%)	
		75-μm sieving pass (%)	
	Crushed stone for mechanical stabilization Recycled crushed stone for mechanical stabilization	Modified CBR (%)	
		PI	
	Mechanically stabilized steel slag	Unit weight (kg/l)	
		Modified CBR (%)	
		Immersion expansion ratio (%)	
	Hydraulic mechanically stabilized steel slag	Unit weight (kg/l)	
		Modified CBR (%)	
		Immersion expansion ratio (%)	
		Unconfined compression strength [14 days] (MPa)	
	Cement stabilization Recycled cement stabilization	Cement content (%)	
		Unconfined compression strength [7 days] (MPa)	
	Lime soil stabilization Recycled lime soil stabilization	Lime content (%)	
		Unconfined compression strength [10 days] (MPa)	
	Bituminous stabilization Recycled bitumen stabilization	Asphalt content (%)	
		Stability (kN)	
		Flow value (1/100 cm)	
		Percentage of air voids (%)	
	Cement and bituminous stabilization Recycled cement and bituminous stabilization	Cement content (%)	
		Asphalt emulsion content (%)	
		Foamed asphalt content (%)	
		Unconfined compression strength (MPa)	
		Primary displacement magnitude (1/100 cm)	
		Residual strength rate (%)	
Subbase course	Type of subbase course material		
	Maximum grain size (mm)		
	Grading	4.75-mm sieving pass (%)	
		2.36-mm sieving pass (%)	
	Crusher-run Recycled crusher-run	Modified CBR (%)	
		PI	
	Crusher-run steel slag	Modified CBR (%)	
		Immersion expansion ratio (%)	
	Cement stabilization Recycled cement stabilization	Cement content (%)	
		Unconfined compression strength [7 days] (MPa)	
	Lime soil stabilization Recycled lime soil stabilization	Lime content (%)	
		Unconfined compression strength [10 days] (MPa)	

Table-6.2.5: Example of a format for recording the results of construction quality management

Item				Set value	Measured value		
					Range	Average	Standard deviation
Surface course	Hot asphalt mixture	Grading	2.36-mm sieving pass (%)				
			75-µm sieving pass (%)				
			Asphalt content (%)				
			Degree of compaction (%)	-			
Binder course		Grading	2.36-mm sieving pass (%)				
			75-µm sieving pass (%)				
			Asphalt content (%)				
			Degree of compaction (%)	-			
Concrete slabs			Slump (cm)				
			Air content (%)				
			Concrete strength (MPa)				
			Chloride content (kg/m^3)				
Base course	Mechanical stabilization		Water content (%)				
		Grading	2.36-mm sieving pass (%)				
			75-µm sieving pass (%)				
	Lime soil stabilization Cement stabilization	Grading	2.36-mm sieving pass (%)				
			75-µm sieving pass (%)				
			Cement content (%)				
			Lime content (%)				
			Water content (%)				
	Cement and bituminous stabilization		Cement content (%)				
			Asphalt emulsion content (%)				
			Foamed asphalt content (%)				
			Water content (%)				
	Bituminous stabilization	Grading	2.36-mm sieving pass (%)				
			75-µm sieving pass (%)				
			Asphalt content (%)				
			Degree of compaction (%)	-			
Subbase course			Water content (%)				
	Grading		2.36-mm sieving pass (%)				
			Degree of compaction (%)	-			

Table-6.2.6: Example of a format for recording the results of finished work quality management

Item			Design value	Range of measured values	Average of measured values
Surface course	Hot asphalt mixture	Thickness (cm)			
		Width (cm)			
		Surface roughness (mm)	-	-	Note)
		Amount of seepage water (ml/15 s)	-		
Binder course		Thickness (cm)			
		Width (cm)			
		Amount of seepage water (ml/15 s)	-		
Concrete slabs		Thickness (cm)			
		Width (cm)			
		Surface roughness (mm)	-	-	Note)
Base course	Mechanical stabilization	Thickness (cm)			
		Width (cm)			
	Cement stabilization Lime soil stabilization	Thickness (cm)			
		Width (cm)			
	Cement and bituminous stabilization	Thickness (cm)			
		Width (cm)			
	Bituminous stabilization	Thickness (cm)			
		Width (cm)			
Subbase course		Thickness (cm)			
		Width (cm)			

Note) Fill in the field marked by σ.

6-3 Accumulation of construction records

6-3-1 Purposes of accumulating construction records

Even when pavement has the same structure, performance degradation occurs in different ways depending on traffic conditions, climate conditions, roadside environments, and other conditions. Thus, road administrators should accumulate and analyze collected construction records together with records of daily, periodic, and other types of inspections and consider the results of such analysis when deciding upon the timing of maintenance and repair, selecting maintenance and repair methods, and formulating maintenance and repair plans. When adopting new materials, new construction methods, or other new technologies, these accumulated records of construction using such new technologies will contribute to demonstrating the technologies' effectiveness. Road administrators should thus accumulate records of construction for maintenance and repair both periodically and continuously.

6-3-2 Method for accumulating construction records

For the details of formats for recording the results of construction for maintenance and repair, refer to "6-2-3: Formats for recording construction information." Construction records can be accumulated in various forms, including handwritten record books, electronic data files, and computer databases.

Appropriate management of data accumulated in the forms of handwritten record books or electronic data files is possible when data volumes are small. However, management of stored data and documents becomes more complicated as the volume of data increases as well as when data must be corrected or updated. When accumulating construction records via such media, it is thus essential to formulate rules for data management to maintain the data's soundness even when multiple data administrators carry out operations.

Data accumulation using computer databases requires work to establish systems and enter data. However, doing so offers various advantages, such as integrated data management, simple procedures for deleting and retrieving documents, and ease of sharing, updating, and providing information. As shown in "6-2-3: Formats for recording construction information," pavement construction records contain various types of information, and the volume of data to be placed under management becomes enormous as data is accumulated. It is therefore desirable to use computer databases to accumulate such data. **Figure-6.3.1** illustrates the structure of a database of records of construction for maintenance and repair.

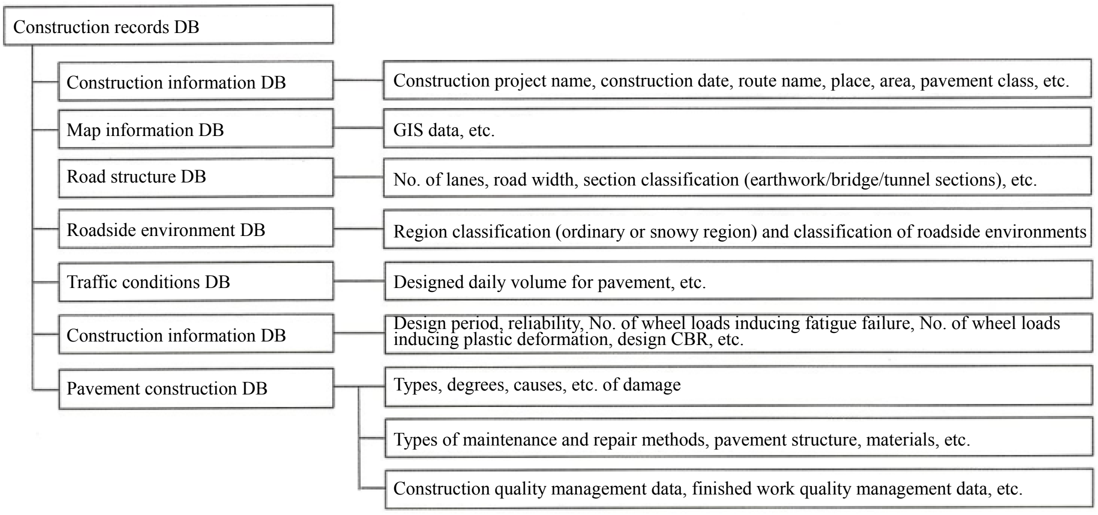


Figure-6.3.1: Example of a database of records of construction for maintenance and repair

6-4 Applications of construction records

6-4-1 Purposes of applying construction records

Accumulated records of construction for maintenance and repair can be used together with inspection records and other information to grasp the actual conditions of paved road surfaces, to estimate their soundness, and to predict their degradation.

For pavement under similar conditions, accumulated construction records enable setting of similar target administrative values, formulation of similar maintenance and repair plans, and selection of similar maintenance and repair methods, including application of new materials and new technologies. Data obtained from this process plays a valuable role in establishing reliable, rational methods for designing road surfaces and in increasing the sophistication of structural design methods. It is therefore important to use and disclose construction records as well as other accumulated data voluntarily.

6-4-2 Examples of applications of construction records

Table-6.4.1 lists some examples of applications of records of construction for maintenance and repair together with inspection records and other information.

Table-6.4.1: Examples of applications of construction records

Application example	Data applied
Pavement soundness	Damage conditions (e.g., cracking, rutting, and surface roughness degradation)
Analysis of pavement degradation factors	Data on pavement damage
Prediction of pavement degradation	Data on pavement damage, on roadside environments, and degradation factors
Demonstration of effectiveness of new materials/technologies	Data on pavement construction (methods and materials) and on pavement damage
LCC calculation	Degradation prediction equations, target administrative values, and budget data
Formulation of maintenance and repair plans	LCC data and medium- and long-term budget data
Setting of target administrative values	Degradation prediction equations, LCC data, and medium- and long-term budget data

Appendices

Appendix 1: Concepts for Setting and Amending Target Administrative Values

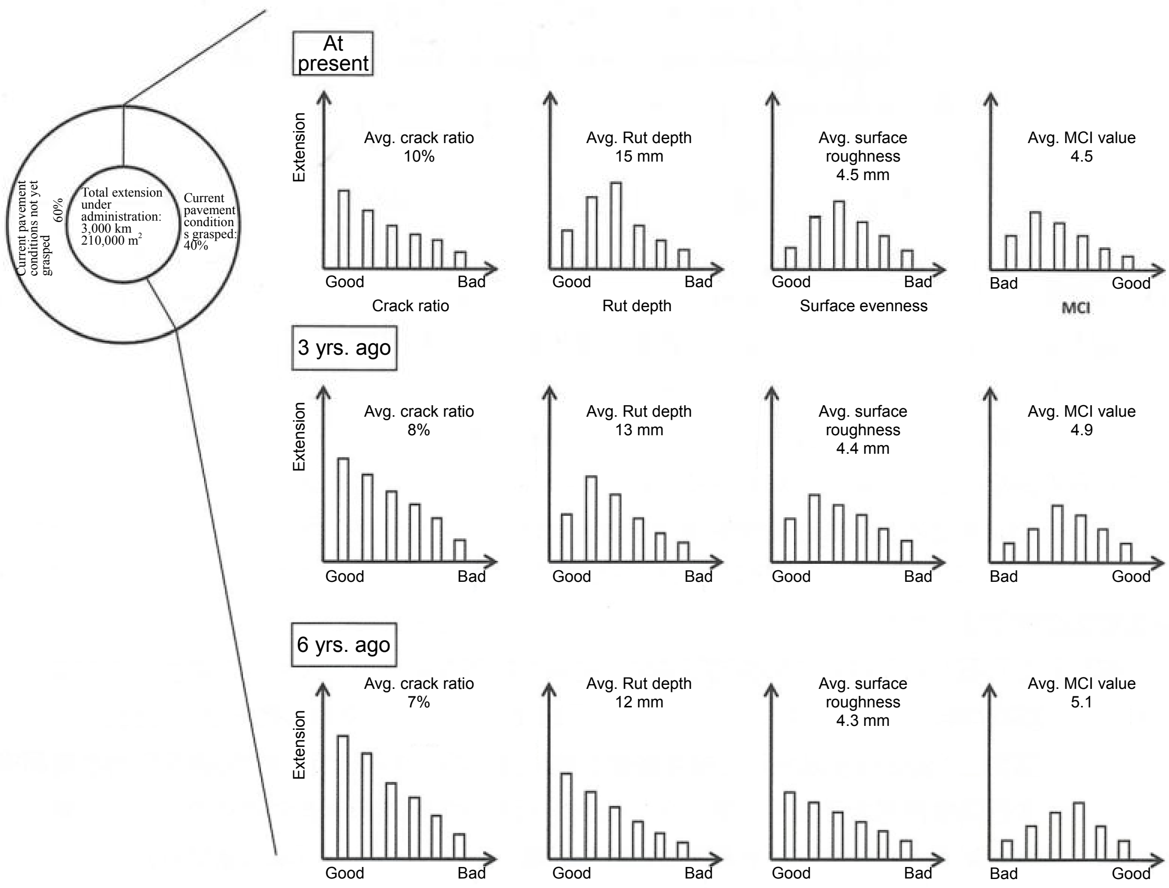
Procedures for implementing pavement management include those for setting target administrative values. Different target administrative values affect different road-related matters, such as the level of service for road users and the budget required for pavement administration.

Target administrative values can be set or amended through various approaches. The following is an example of applying such approaches to trunk roads.

1 Data on past pavement administration

(1) Data on current pavement conditions

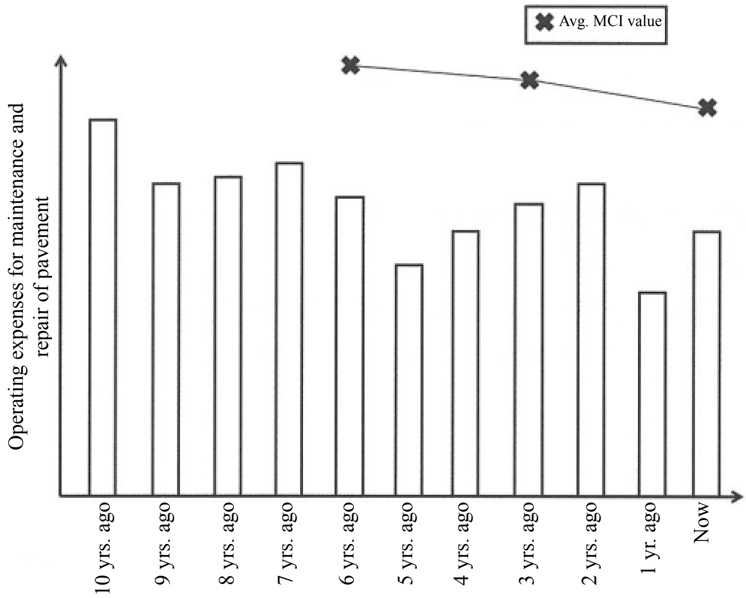
Data on the pavement conditions of roads under the administration of each road administrator must be organized. Historical changes in pavement conditions must also be organized if possible (**Appendix Figure-1.1.1**).



Appendix Figure-1.1.1: Example of organized data on past changes in pavement conditions

(2) Past operating expenses for maintenance and repair of pavement

Data on operating expenses for maintenance and repair of pavement for approximately the past decade must be organized. However, when replacing pavement of lanes, for example, in one-lane expansion construction, operating expenses for maintenance and repair of pavement cannot be identified from the perspective of budget categories. Such types of operating expenses must also be covered by organizing data in order to grasp the relationship between the changes in pavement conditions and operating expenses (**Appendix Figure-1.1.2**).



Appendix Figure-1.1.2: Example of organized data on the relationship between changes in pavement conditions and operating expenses

2 Collection and organization of information about target administrative value levels from the perspectives of service indices and administrative indices

(1) Organization of knowledge about the relationship between target administrative value levels and service levels

Ride quality and other satisfaction levels are the most important service indices for pavement. Satisfaction levels are affected by matters related to pavement performance such as safety, roughness, comfort, and the environment. Available information about how pavement conditions affect these matters must be organized. However, the relationship between pavement conditions and matters related to pavement performance as well as the impacts of pavement conditions on socioeconomic activities are not clearly understood. It is thus necessary to continue collecting and organizing relevant information. Complaints, requests, and other information from road users and roadside residents are also useful.

Example)

Influence of water splashing due to rutting
(Information example)
Ministry of Construction: Comprehensive Research on Pavement Administration Levels and Maintenance and Repair Methods, *Collection of Reports on Specified Subjects in the Road Category at the 40th Technical Research Meeting of the Ministry of Construction*, 3, pp. 134–149, October 1986

Evaluation Test on Impaired Visibility for Traveling Vehicles due to Water Splashing
(Information example)
Ministry of Construction: Comprehensive Research on Pavement Administration Levels and Maintenance and Repair Methods, *Collection of Reports on Specified Subjects in the Road Category at the 40th Technical Research Meeting of the Ministry of Construction*, 3, pp. 134–149, October 1986

Rutting and Sense of Security, etc.
(Information example)
Watanabe and Ishida: A Discussion on Target Administrative Values for Pavement, *Collection of Technical Reports of the 11th Hokuriku Road Pavement Conference*, D-11, August 2009

IRI and Sense of Security, etc.
(Information example)
Watanabe and Ishida: A Discussion on Target Administrative Values for Pavement, *Collection of Technical Reports of the 11th Hokuriku Road Pavement Conference*, D-11, August 2009

(2) Organization of data on past maintenance and repair implemented based on target administrative value levels from the perspectives of administrative indices

Administrative indices for pavement are defined from the perspectives of road administrators to facilitate appropriate administration of pavement, including grasping pavement’s structural soundness. Specific examples of administrative indices are the crack ratio and deflection measured with FWD. Maintenance and repair appropriate for the level of the administrative index corresponding to each pavement condition must be defined by considering historical records.

Example) Damage due to cracking
When the crack ratio of pavement reaches a specific value, the pavement must be replaced.

3 Setting of administrative indices appropriate for road characteristics

Administrative indices appropriate for road characteristics, roadside environments, and other related conditions must be defined by considering the information organized in 2. The feasibility of future monitoring must also be considered in order to define the indices.

Example)
1. The cracking index and rut depth must be used as administrative indices for all roads.
2. Surface roughness must be included in the administrative indices for roads for XX.

4 Target administrative values

(1) Provisional setting of target administrative values

Target administrative values must be set provisionally to ensure pavement provides services appropriate for the pavement conditions identified in 1 and the road characteristics and travel speed based on the information organized in 2.

Example)
1. The following target administrative values must be applied to all roads.
   Crack ratio: 30% or less
   Rut depth: 30 mm or less

2. The following conditions must be included as target administrative values for roads for XX.
   Rut depth: 20 mm or less
   Surface roughness: 5 mm or less

(2) Formulation of maintenance and repair patterns satisfying the target administrative values and degradation prediction model

A maintenance and repair pattern satisfying the target administrative values set provisionally in (1) and a model for predicting future pavement degradation must be formulated by considering data on past pavement administration.

Example) 1. Roads other than those for XX

[Crack ratio]
New construction or replacement → Surface treatment at a crack ratio of 20% → (30% reduction of the cracking progress rate) → Mill and overlay at a crack ratio of 30% → (Return to the initial cracking progress rate) → Surface treatment at a crack ratio of 20% → (30% reduction of the cracking progress rate) → Replacement …

[Rut depth]
New construction, replacement, or mill and overlay → Cutting at a rut depth of 30 mm → (Reduction of the rut depth to 15 mm without changing the rutting progress rate) → Mill and overlay …

Example) 1. Roads for XX

[Crack ratio]
New construction or replacement → Surface treatment at a crack ratio of 20% → (30% reduction of the cracking progress rate) → Mill and overlay at a crack ratio of 30% → (Return to the initial cracking progress rate) → Surface treatment at a crack ratio of 20% → (30% reduction of the cracking progress rate) → Replacement ...

[Rut depth]
New construction, replacement, or mill and overlay → Mill and overlay at a rut depth of 20 mm ...

[Surface roughness]
New construction, replacement, or mill and overlay → Mill and overlay at a surface roughness of 5 mm ...

(3) Estimation of future operating expenses for maintenance and repair of pavement

Future operating expenses for maintenance and repair of pavement must be estimated for the maintenance and repair pattern formulated in (2) based on unit prices determined from past records for each construction method and other factors.

The estimated operating expenses must be examined realistically from the perspective of accountability to road users and taxpayers. When expenses are not satisfactory, administrative indices and the levels of target administrative values must be redefined in accordance with the procedures described in 3 or 4 (1).

5 Disclosure of target administrative values and operating expenses required for the future

After target administrative values have been determined from the perspective of accountability to road users and taxpayers as described in 4, the values and operating expenses required for the future must be disclosed. Before putting the planned management into practice, public involvement should be solicited on an as-needed basis; when necessary, reexamination must be carried out in accordance with the procedures described in 3 or 4 (1).

Example) Content of disclosure

"For roads in the XX area, we will implement road administration to maintain this level in accordance with the maintenance and repair pattern. Such road administration requires future operating expenses of approximately XX hundred million yen, which is approximately XX yen per citizen in the prefecture and a unit extension price of approximately XX yen/km. We will adopt optimal maintenance and repair methods for each case from the perspective of LCC by considering pavement damage conditions on-site."

6 Evaluation of pavement management, examination of the adequacy of target administrative values, and modification thereof

After performing the disclosure described in 5, planned pavement management is put into practice. Such management must be evaluated after being performed for a specific period of time. Actual maintenance and repair requires appropriate diagnosis of pavement and other independent decisions at each site in accordance with the descriptions in Chapter 3 and the following chapters.

Evaluation after performing management for a specific period of time must be implemented from various perspectives, such as: the relationship between the amount of operating expenses and the degree of accomplishment of target administrative values; the adequacy of the formulated maintenance and repair pattern; the latest construction methods, etc., results of on-site follow-up surveys, and availability of other maintenance and repair patterns based on the latest knowledge for realizing longer-life pavement (advantageous from the perspective of LCC) that satisfies the target administrative values; and new information about the target administrative values.

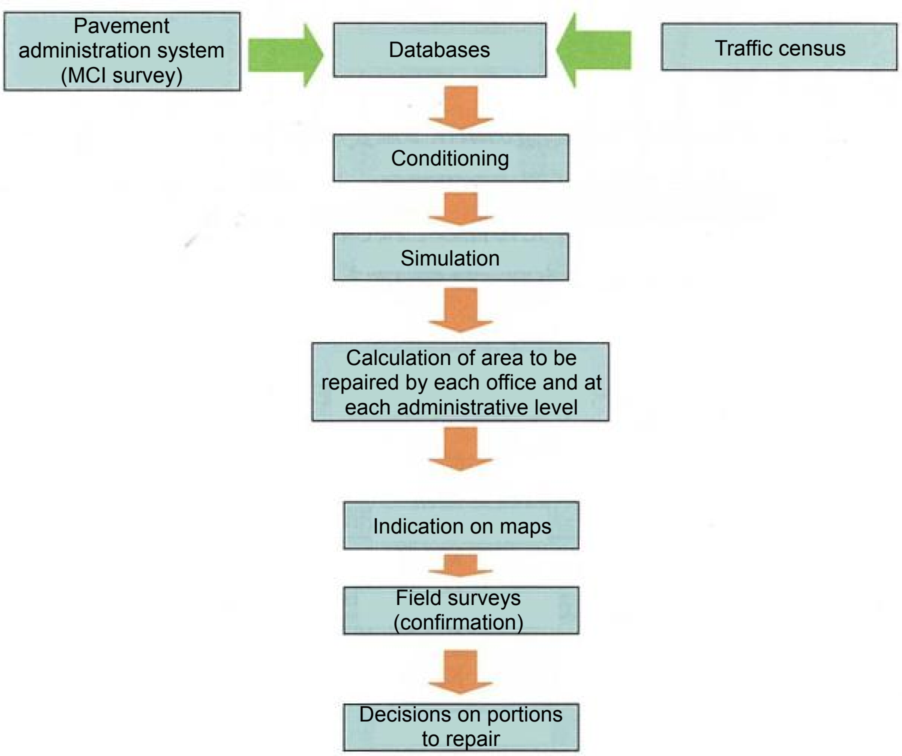
Evaluation results must be reported to road users and taxpayers, and target administrative values must be reviewed in accordance with the procedure described in 3 through activities to enable communication between road administrators and road users as well as between road administrators and taxpayers.

Appendix 2: Concrete Examples of Pavement Administration for Trunk Roads

1 Case study of Prefecture M

1-1 Framework

In prefecture M, the prefectural government administers a total of 3,504 km of roads (national roads: 805 km; principal local roads: 1,115 km; ordinary local roads: 1,584 km). 3,357 km of this road traffic is paved. Pavement administration and maintenance must be efficiently implemented on such an enormous road traffic despite severe financial circumstances. Against this backdrop, the prefectural government has been addressing trial pavement management in accordance with a basic plan that specifies appropriate administrative levels for each route. **Appendix Figure-2.1.1.1** illustrates the pavement management framework.



Appendix Figure-2.1.1.1: Pavement management framework

1-2 Survey and evaluation of pavement conditions

The prefectural government has accumulated surface characteristics data (crack ratios, rut depths, and surface roughness) using surface characteristics survey vehicles to measure all national roads since FY 1986 and all prefectural roads since FY 1998. The prefecture was divided into blocks, and in the past surveys were implemented to cover all blocks within three-year cycles. At present, however, the surveys are implemented to cover all blocks within five-year cycles based on evidence, such as degradation prediction equations established independently from past records. Surveys are implemented on 100-m evaluation units for each route, and measurement is performed on representative lanes (down lanes of two-lane roads or second down lanes of multilane roads). The evaluation index is the pavement's maintenance control index (MCI).

1-3 Setting of target administrative values

The following three classes are defined as administrative classes for roads according to their importance. Road sections are classified into one of these administrative classes based on traffic volume and regional characteristics, and target administrative values are set to levels appropriate to roads' required service levels (**Appendix Table-2.1.3.1**).

Appendix Table-2.1.3.1: Administrative classes and target administrative values

Classification	Definition	Administrative level (target administrative value)
Administrative Class I (Sections that must provide high-level services)	Sections with a large vehicle traffic volume of 250 or more or an ordinary vehicle traffic volume of 1,600 or more, or sections in DID areas	MCI value of 4 or higher
Administrative Class II (Sections that must provide standard-level services)	Sections with a large vehicle traffic volume of less than 250 or an ordinary vehicle traffic volume of less than 1,600, except for Administrative Class III sections	MCI value of 3 or higher
Administrative Class III (Sections for which serviceability must be ensured)	Sections in mountainous regions with only low traffic volume but not daily service roads	MCI value of 2 or higher

Note) Traffic volumes are for 24 hours on weekdays in one direction.

1-4 Prediction of soundness

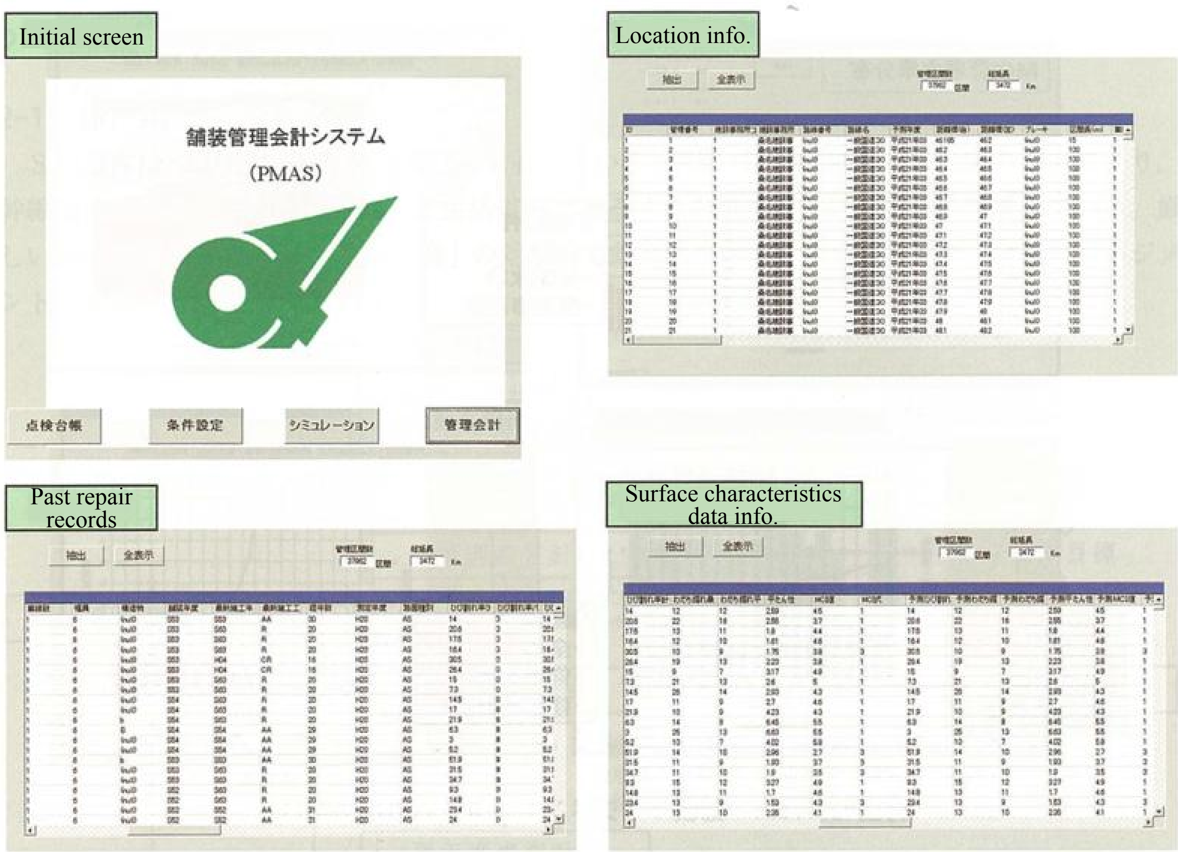
Prefecture M's government, which initially used a degradation prediction equation simplified on the premise of a decrease in MCI of 0.2 per year, established original degradation prediction equations based on accumulated surface characteristics data (aging changes in average soundness). Prediction accuracy was improved by formulating an independent degradation prediction equation with respect to traffic volume separately for each index of cracking, rutting, and surface roughness. **Appendix Table-2.1.4.1** lists the degradation prediction equations established by Prefecture M's government.

Appendix Table-2.1.4.1: Degradation prediction equations established by Prefecture M's government

Item	Prediction class	Prediction equation
Cracking (%)	$N_1 \sim N_4$ (Former LA) traffic	$C_i=C_0+1.72+0.36i$
	$N_5 \sim N_7$ (Former BCD) traffic	$C_i=C_0+1.62+0.54i$
Rutting (mm)	$N_1 \sim N_4$ (Former LA) traffic	$D_i=D_0+1.08+0.24i$
	$N_5 \sim N_7$ (Former BCD) traffic	$D_i=D_0+0.39+0.27i$
Surface evenness (mm)	$N_1 \sim N_4$ (Former LA) traffic	$\sigma_i=\sigma_0+0.14+0124i$
	$N_5 \sim N_7$ (Former BCD) traffic	$\sigma_i=\sigma_0+0.25+0.11i$

1-5 Accumulation and updating of data

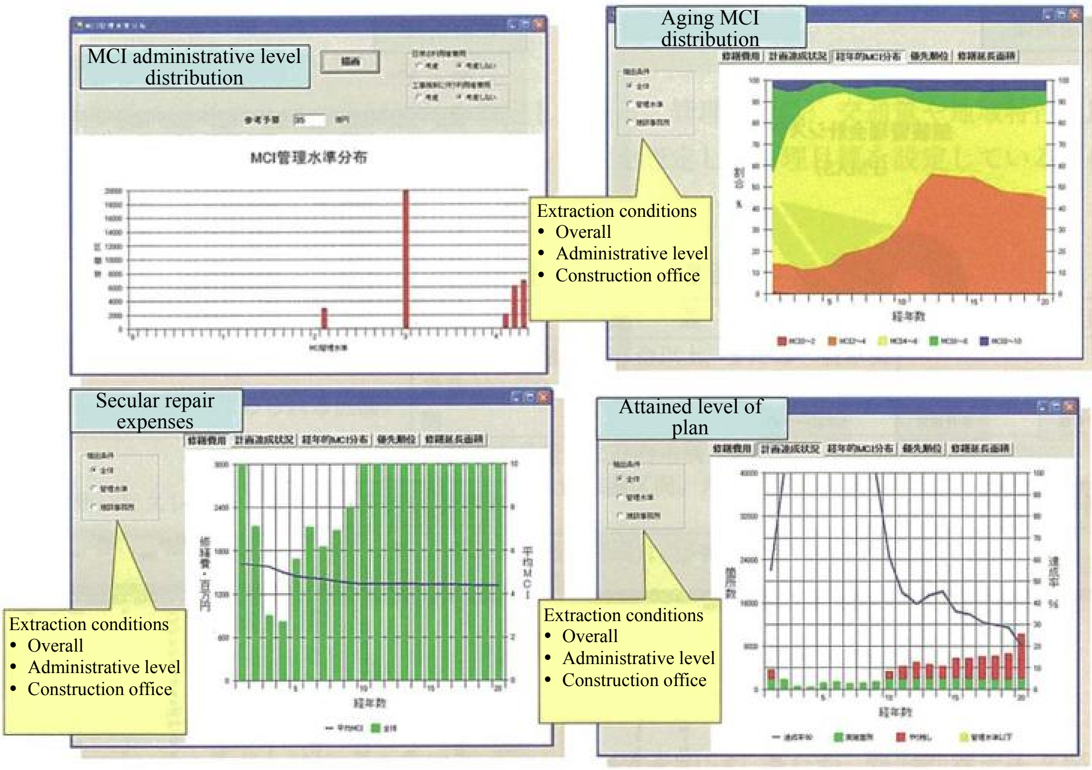
The prefectural government established a database for centralized management of the data necessary for pavement administration as well as surface characteristics data. This database stores information (e.g., past repair records) as attribute data for each section. **Appendix Figure-2.1.5.1** shows some screenshots of the database.



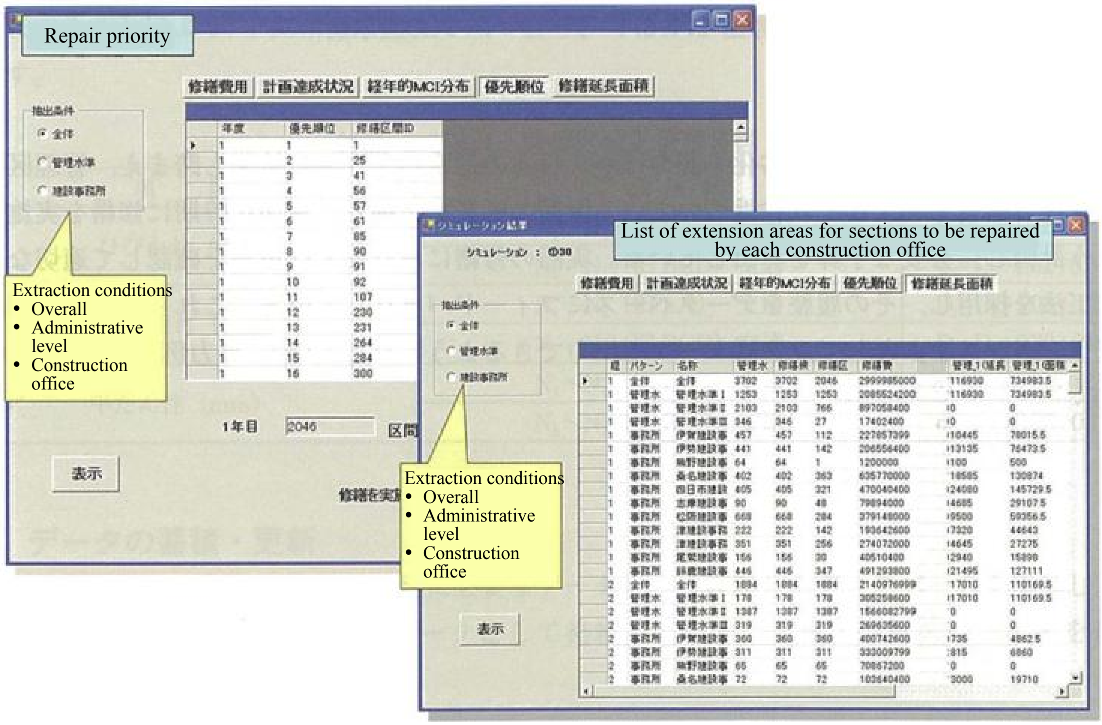
Appendix Figure-2.1.5.1: Database screenshots

1-6 Formulation of maintenance and repair plans

The prefectural government grasps the extension of sections satisfying their target administrative values and that of sections about to exceed their target administrative values for each administrative class based on the results of the aforementioned surface characteristics surveys, degradation predictions, and ordinary patrols. In this way, it formulates appropriate plans so that each section can be repaired at the desired timing as well as estimates the necessary budget for the plans. Before actual repair work, the prefectural government surveys construction sites to ensure appropriate maintenance and repair methods are adopted. Repair records are then reflected in Prefecture M's pavement management system database; this data can be browsed on computers. **Appendix Figures-2.1.6.1** and **2.1.6.2** show some screenshots of the pavement management system.



Appendix Figure-2.1.6.1: Pavement management system screenshots (1)



Appendix Figure-2.1.6.2: Pavement management system screenshots (2)

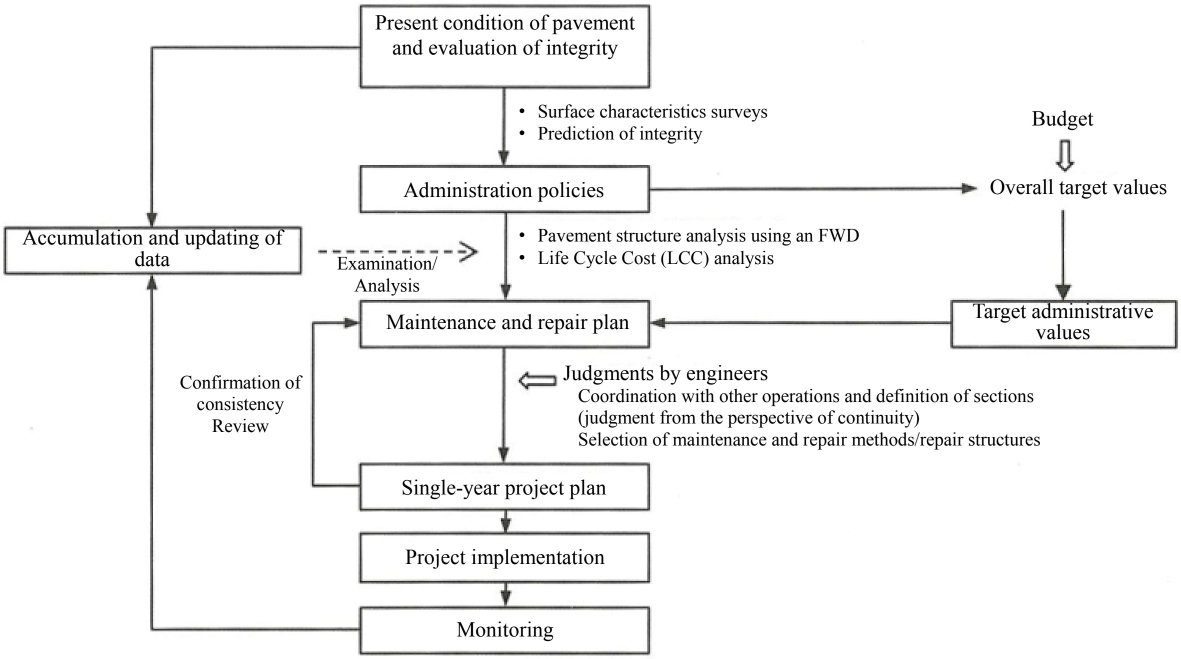
[Reference]

1) Japan Road Association website: http://www.road.or.jp/technique/090210.html

2 Case study of Municipality S

2-1 Framework

Municipality S administers more than 1,100 km of roads; these are classified into "Class-1 and -2 routes" and "other routes" according to road and pavement structures and their modes of use. "Class-1 and -2 routes" are trunk roads, while "other routes" are daily service roads. Municipality S aimed to implement effective, efficient pavement administration of Class-1 and -2 routes despite severe financial circumstances. **Appendix Figure-2.2.1.1** illustrates Municipality S's pavement management framework.



Appendix Figure-2.2.1.1: Pavement management framework

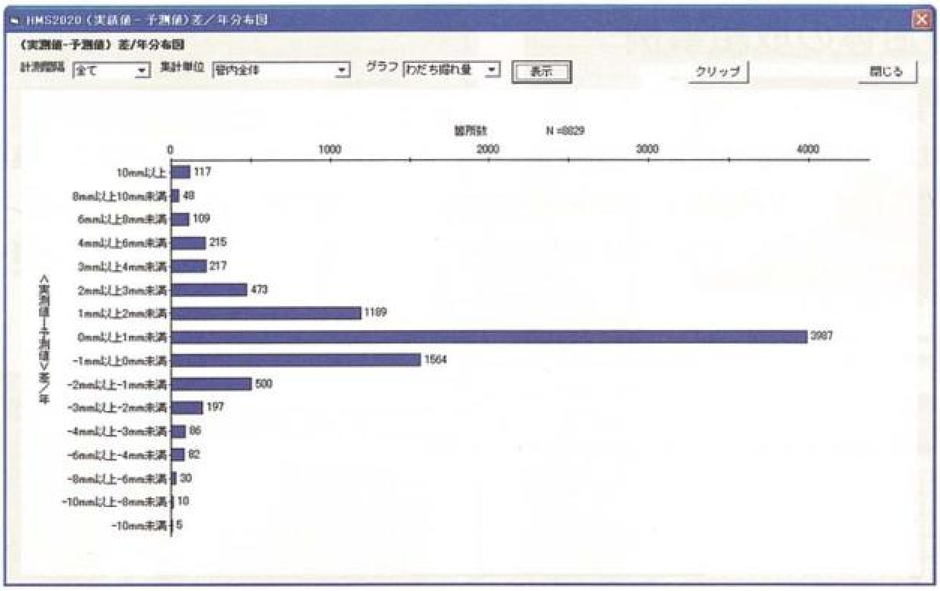
2-2 Present condition of pavement and evaluation of soundness

(1) Present condition of pavement and evaluation of soundness

Surface characteristics data (crack ratios, rut depths, and surface roughness) were measured with surface characteristics survey vehicles. Surface characteristics surveys were implemented on all Class-1 and -2 routes, and the soundness of pavement was evaluated based on the maintenance control index (MCI) value calculated from an evaluation formula expressed by the three factors (crack ratio, rut depth, and surface roughness). Evaluation was implemented on 20-m road units to grasp the situation of partial damage, and obtained data was accumulated and updated together with road register data (e.g., extension, road width, traffic volume class, regional class, and pavement type) as well as past maintenance and repair records.

(2) Prediction of soundness

Since only surface characteristics data measured in the preceding fiscal year was available, the conventional prediction equation was applied to perform prediction. Sections that had developed damage continuously to some degree were extracted from among the Class-1 and -2 routes (approximately 10% of all routes), and surface characteristics surveys were implemented on the extracted sections using surface characteristics survey vehicles. For verification, these measured surface characteristics values were compared with the surface characteristics values calculated by substituting surface characteristics data measured in the previous fiscal year into the conventional prediction equation (**Appendix Figure-2.2.2.1**).



Appendix Figure-2.2.2.1: Example of prediction equation verification

2-3 Administration policies

(1) Soundness of pavement structures

Deflection surveys with FWD were implemented on several selected sections for which pavement was judged to be “lightly damaged,” “moderately damaged,” or “severely damaged”[1)] in order to grasp the relationship between pavement damage levels and pavement soundness (pavement bodies consisting of base courses and layers above the base courses) measured by FWD deflection surveys.[2)]

Pavement damage level

Lightly damaged pavement:	Delivering almost complete serviceability and requiring no repair at present (Pavement with a crack ratio of approximately 15% or less)
Moderately damaged pavement:	Delivering almost complete serviceability but requiring partial or functional repair (Pavement with a crack ratio of approximately 15% to 35%)
Severely damaged pavement:	Requiring repair by overlay or larger-scale method (Pavement with a crack ratio of approximately 35% or more)

This analysis revealed the following relationship between pavement damage levels and pavement soundness.

Lightly or moderately damaged pavement:	The pavement structure and asphalt mixture layers are both “in a state of soundness.”
Severely damaged pavement:	The pavement structure and asphalt mixture layers are both “not in states of soundness.”

(2) Life cycle cost analysis

Life cycle cost (hereafter, LCC) analyses were implemented on all Class-1 and -2 routes. LCCs were calculated for the three maintenance and repair patterns listed in **Appendix Table-2.2.3.2** on the premise of use of the maintenance and repair methods listed in **Appendix Table-2.2.3.1** in order to determine the most economically efficient maintenance and repair plan. LCCs were calculated for a 40-year period using the following formula: LCC = Road administrator expenses (Construction costs + Repair costs + Maintenance costs − Remained value) + Road user expenses (Vehicle traveling costs + Time loss costs) (**Appendix Figure-2.2.3.1**).

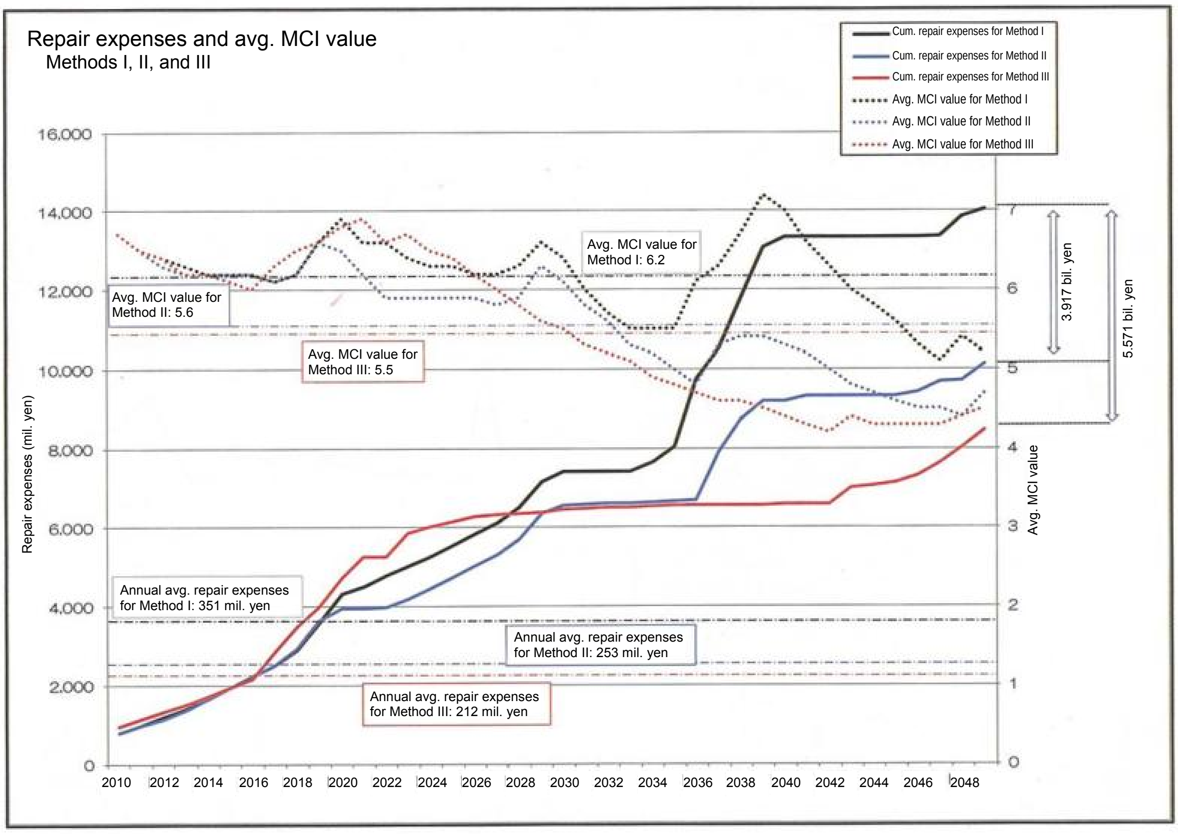
Appendix Table-2.2.3.1: Maintenance and repair methods

Type of method	Reference MCI value	
	Method I	Methods II and III
Replacement	Less than 3.5	Less than 3.5
Mill and overlay	3.5 or more but less than 5.0	3.5 or more but less than 5.0
Crack sealing	-	Whenever the value becomes less than 5.5

Appendix Table-2.2.3.2: Maintenance and repair patterns

Method	Maintenance and repair pattern
Method I	Construction → OL → OL → OL → Replacement ...
Method II	Construction → Crack sealing → OL → Crack sealing → OL → Replacement ...
Method III	Construction → Crack sealing → OL → Crack sealing → OL → Replacement ...

* Method III is based on Method II; under this method, a supplementary construction method is implemented to suppress reflection cracking in parallel with OL in Method II.
OL refers to mill and overlay.



Appendix Figure-2.2.3.1: LCC analysis results

The annual average repair expenses for Method I were 351 million yen, while the annual average repair expenses for Method II, which was based on preventive maintenance using crack sealing, were 253 million yen. The annual average repair expenses for Method III, which forms sand cushions to extend the service lives of paved road surfaces (supplementary construction method for suppressing reflection cracking), were 212 million yen.

Method II reduced annual average repair expenses by 98 million yen (28%) compared to Method I, a conventional method. Method III reduced annual average repair expenses by 139 million yen (40%) compared to Method I.

(3) Administration policies

It is essential to use knowledge about the soundness of pavement structures and the results of LCC analysis effectively to implement administration to prevent pavement from developing severe damage. Costs must be reduced by "preventive maintenance for maintaining the functions of pavement structure for a long period of time (long-life pavement)."

2-4 Setting of target administrative values

Overall target values used as target values for all roads under administration and individual target values used for selecting individual road sections to be repaired must be separately determined as target administrative values (**Appendix Table-2.2.4.1**). These values depend closely on the budget and must be reviewed in response to changes in financial circumstances.

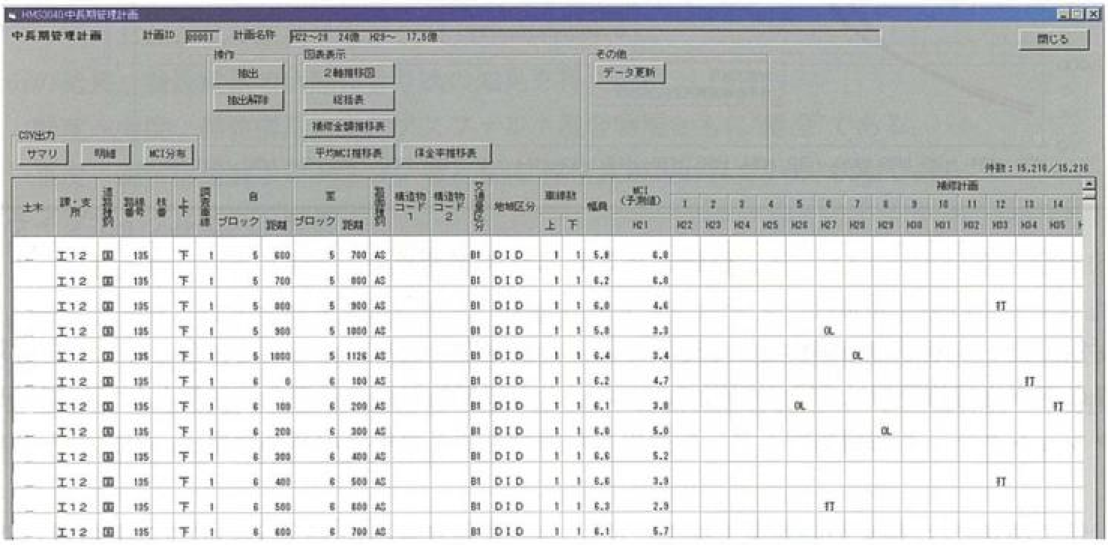
Appendix Table-2.2.4.1: Individual target values (repair criteria)

Reference MCI value	Method
Less than 3.5	Replacement
3.5 or more but less than 5.0	Mill and overlay
Whenever the value becomes less than 5.5	Crack sealing

2-5 Formulation of maintenance and repair plans

LCC analysis based on past surface characteristics data was performed on all roads under administration using past repair records and prediction equations. Medium- and long-term maintenance and repair plans were formulated based on maintenance and repair plans developed for individual fiscal years, which were prepared according to the results of the LCC analysis (**Appendix Figure-2.2.5.1**). For the most economically efficient maintenance and repair plan (**Appendix Figure-2.2.3.1**), required expenses exhibit substantial fluctuations every fiscal year. To level off such fluctuations, priorities were assigned to those road portions to be repaired each fiscal year and repair methods to be used in accordance with the following two policies.

- Low priorities are assigned to road sections with a maintenance control index (MCI) value less than 2, which is close to the allowable limit.
- Higher priorities are assigned to road portions with a larger difference between the LCC calculated by taking the fiscal year concerned as the first fiscal year and the LCC calculated by taking the year following the fiscal year concerned as the first fiscal year.



Appendix Figure-2.2.5.1: Maintenance and repair plan formulated for each fiscal year based on LCC

The economically efficient maintenance and repair plan formulated by leveling off the required expenses was put through LCC analysis under the estimation conditions (budget constraints) listed in **Appendix Table-2.2.6.1**. In this estimation, which assumed that the pattern of Method III would be applied, priorities were assigned to road sections that did not satisfy the individual target values listed in **Appendix Table-2.2.4.1** in accordance with the aforementioned policies so that the budgets listed in **Appendix Table-2.2.6.1** would be satisfied. The 20-year average MCI value and pavement repair rate [3] of all roads under administration were thereby obtained for the maintenance and repair plan (**Appendix Table-2.2.6.2** and **Appendix Figure-2.2.6.1**). The pavement maintenance ratio refers to the percentage of road traffic in a state that allows road users to travel comfortably without suffering from substantial vibration or noise generated due to cracking or rutting of road surfaces (MCI value > 4.0).

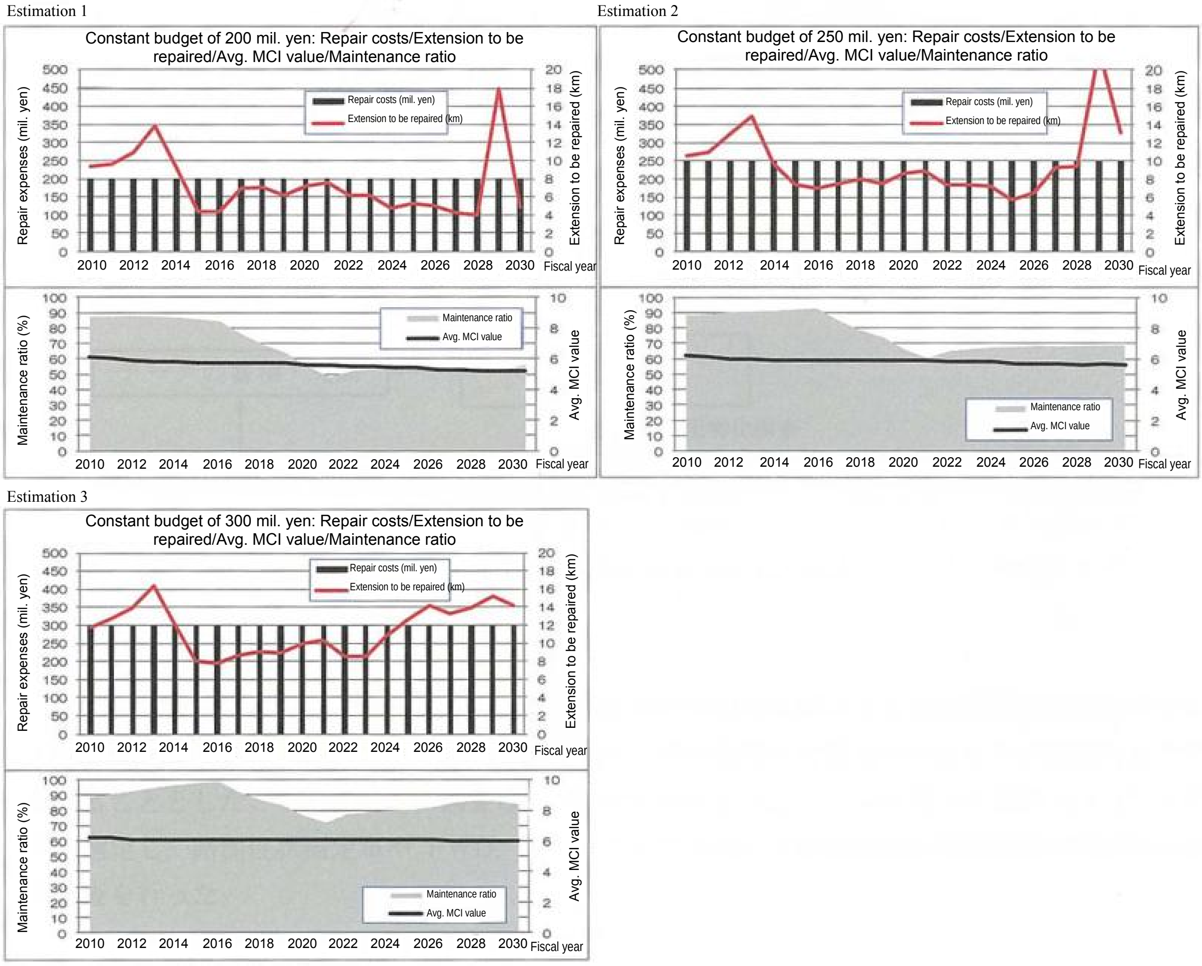
Appendix Table-2.2.6.1: Estimation conditions

	Condition
Estimation 1	Constant budget of 200 mil. yen
Estimation 2	Constant budget of 250 mil. yen
Estimation 3	Constant budget of 300 mil. yen

Appendix Table-2.2.6.2: Estimation result 1

	Lowest value in 20 years		Avg. in 20 years	
	Avg. MCI value	Maintenance ratio	Avg. MCI value	Maintenance ratio
Estimation 1	5.2	48.0	5.6	66.4
Estimation 2	5.6	60.4	5.9	76.5
Estimation 3	6.0	72.1	6.1	86.4

Present condition: Avg. MCI value = 6.1; Maintenance ratio = 92.1



Appendix Figure-2.2.6.1: Estimation result 2

Maintaining the current level requires at least 300 million yen, which is higher than the current budget and equal to the budget in Estimate 3. In all estimations, the pavement maintenance ratio, which is directly related to the risk of administrative faults, will start decreasing rapidly in 2016. For the six years from 2010 to 2016, measures to minimize the decrease in the pavement maintenance ratio must be implemented on road sections with an MCI value of 4 to 5, which are awaiting repair.

2-6 Project implementation and monitoring

Appropriate project implementation is essential to ensure steady progress in road administration implemented in accordance with the maintenance and repair plan. For actual repair, repair methods appropriate for the pavement damage and degradation must be selected in consideration of engineers' judgments. The accuracy of pavement management must be improved through periodic surface characteristics surveys, and repair method performance must be examined by follow-up surveys on an as-needed basis. Results must be reflected in prediction equations.

[References]

1) Japan Road Association: Guidelines for Pavement Design and Construction (2006 edition), p. 83, February 2006
2) Road Management Technology Center: For Effective Use of FWD, March 2005
3) Ministry of Land, Infrastructure, Transport and Tourism website: http://www.mlit.go.jp/road/ir/ir-perform/ta/xl.pdf

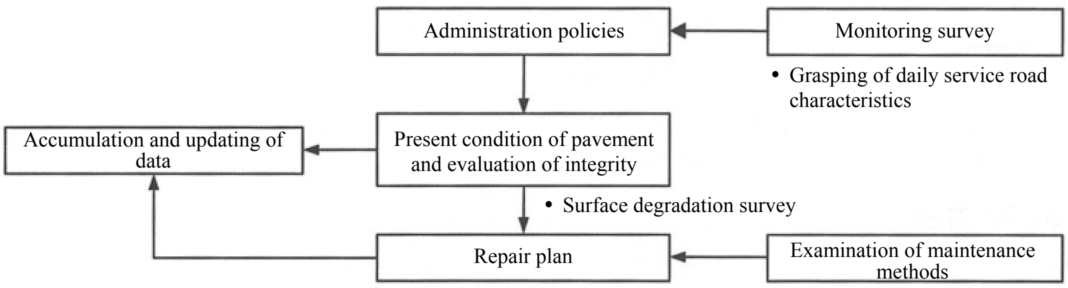
Appendix 3: Concrete Examples of Pavement Administration for Daily Service Roads

Case study of Municipality S

1 Framework

Municipality S administers approximately 1,100 km of roads. Daily service roads account for slightly less than 90% of these, and their administration is an important issue. For trunk roads, various studies on inspection methods, prediction techniques, and other related matters have been reported. For daily service roads, however, such studies have rarely been reported, and no administration methods have been established. Since road construction takes a long time, current paved roads must be maintained appropriately. Most paved roads were built more than 50 years ago during the high-growth period starting around 1960. A large number of routes thus must be reconstructed in the near future. In addition, paved roads are now required to provide not only conventional traffic functions but also various types of new functions, such as those against floods and against the heat island effect. Such requirements are factors that increase expenses, but cost reduction is also required because of the severe financial circumstances.

Municipality S therefore took up pavement management to achieve effective pavement administration. To this end, Municipality S grasped the characteristics of daily service roads, formulated administration policies by considering budget constraints, and evaluated pavement soundness by implementing surface degradation surveys in accordance with these policies. In addition, since appropriate methods are essential for repair plans, Municipality S examined a maintenance method and formulated a repair plan using that method. The plan was formulated not based on the prediction of soundness but rather priorities determined from the results of the evaluation of soundness.



Appendix Figure-3.1.1: Pavement management framework

2 Characteristics of daily service roads

Daily service roads are narrow in width and long in total extension. Performing surface characteristics surveys on such roads in the same manner as trunk roads is impractical. Thus, before grasping present condition of pavement, the characteristics of daily service roads were examined by monitoring surveys. In these surveys, detailed surveys were implemented for several selected sections that had developed typical types of damage (**Appendix Photograph-3.2.1**) using surface characteristics survey vehicles, FWDs, and profilers by focusing on paved road surfaces and pavement structures.

Appendix Photograph-3.2.1: Typical road surface of a daily service road (pavement portions multiple overlap due to recovery)

The following information was gathered during the monitoring surveys

(1) Road surfaces
- Daily service roads often contain pavement portions showing traces of recovery construction.
- Since it is physically difficult for large vehicles to pass over daily service roads, cracking is generally presumed to be caused not by fatigue failure due to repeated traffic loads but by recovery after works related to road occupancy (construction joint opening).
- Traces of recovery transverse of direction often cause faulting and degradation of pavement surface roughness.

(2) Pavement structure
- For traces of recovery after works related to road occupancy, deflection measured with FWD is generally small unless the pavement crack ratio exceeds 35%.
- Existing pavement often exhibits large deflection when measured with FWD regardless of the crack ratio.

3 Administration policies

The following policies on administration of daily service roads were formulated in consideration of their characteristics. Given the budget constraints, administration of daily service roads mainly takes posterior maintenance measures unavoidably. Against this backdrop, policies were formulated so as to ensure objective, transparent administration and safety.

(1) Administrative transparency must be reliably ensured by evaluating soundness determined through road degradation surveys and grasping pavement conditions through road surface images.

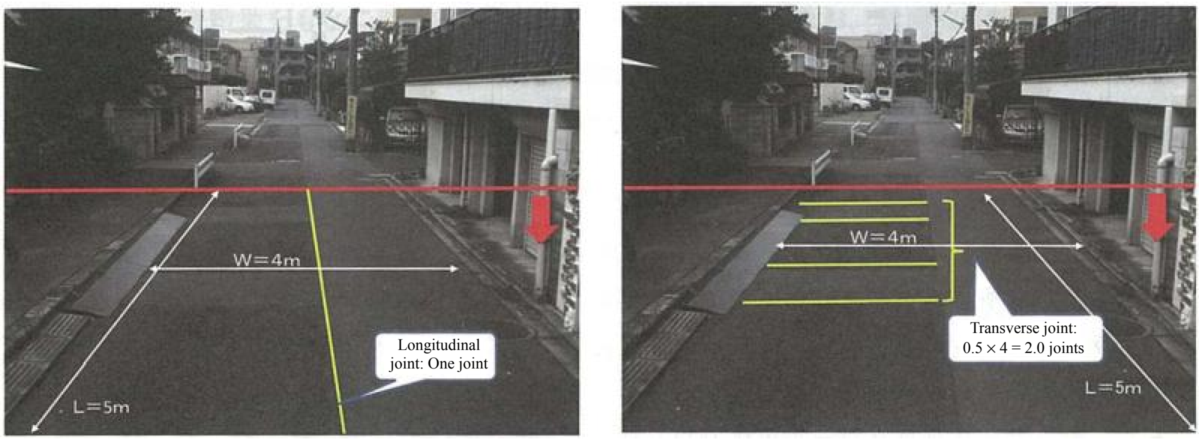
(2) The risk of administrative faults must be reduced by implementing planned maintenance (repair before pavement develops severe damage) as part of operations. In planned maintenance, costs must be reduced by performing local repairs on high soundness pavement with the aid of traces of recovery after works related to road occupancy. Target road sections must be selected by considering pavement soundness as determined from road degradation surveys.

4 Road degradation surveys (present condition of pavement and evaluation of soundness)

As for road degradation surveys, to reduce costs only the minimum surveys necessary to comply with the administration policies were implemented. Surveys were implemented on all roads under administration, and photographs of road surfaces were taken at 5-m intervals using automatic road surface photographing vehicles (**Appendix Photograph-3.4.1**) or bicycles (for road portions where vehicles cannot travel). Pavement soundness was evaluated based on cracking levels and joint lengths (construction joints between pavement recovery after works related to road occupancy and existing pavement).

Appendix Photograph-3.4.1: Automatic road surface photographing vehicle

In the evaluation, cracking was classified into six cracking levels (except for joints), and joint lengths were evaluated as the number of joints contained in each 5-m portion in the road traffic direction (longitudinal direction: 0.5 joints for each 5-m portion in the road traffic direction; transverse direction: 0.5 joints for the road width) (**Appendix Photograph-3.4.2**). Transverse joints may cause faulting and degradation of surface roughness, and the number of longitudinal joints can be used to estimate the rate for the area of existing pavement. This method can identify the numbers of such joints.



Appendix Photograph-3.4.2: Analysis of joint length

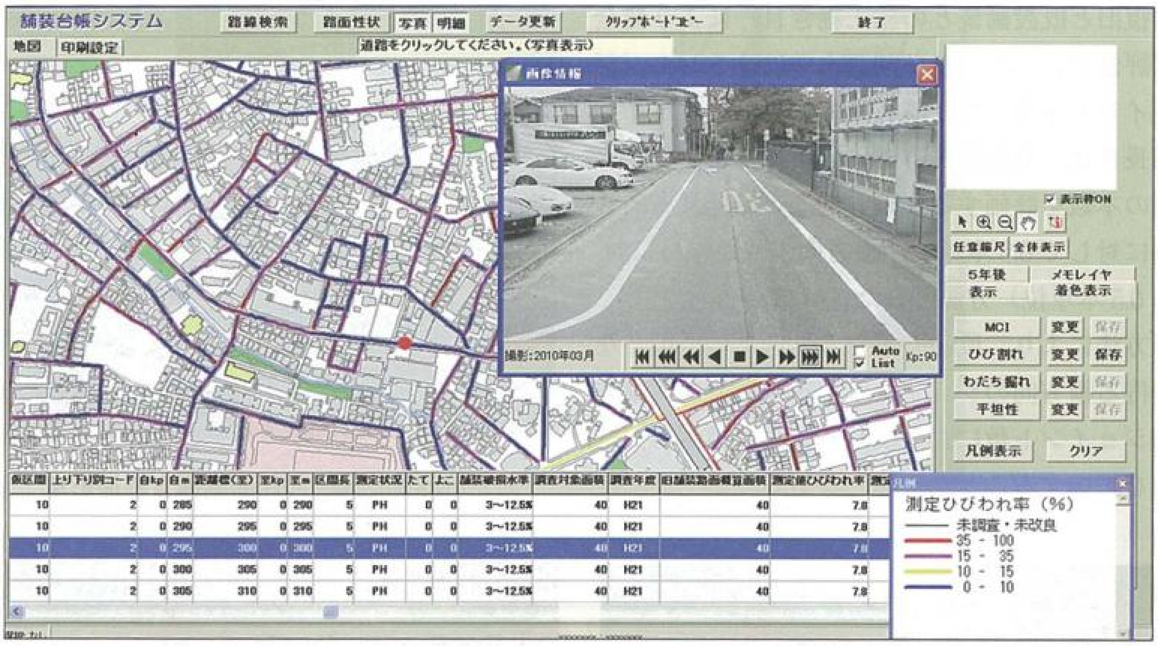
Road surface images and cracking level data were registered in a GIS system and linked to maps (**Appendix Figure-3.4.1**).

Appendix Table-3.4.1 lists the data obtained for each route from data on 5m portions. The average crack ratio obtained for each route expresses that route's overall damage level (average extension length per route: 140 m). Routes with an average crack ratio of 25% or more account for only 1% of all roads. This fact suggests that cracking damage has developed locally, not continuously.

Appendix Table-3.4.1: Data classified by cracking levels (average value per route)

Classification of route avg. cracking levels	No. of routes*	Extension* (m)	Area (m^2)	Est. area of existing pavement (m^2)	Extension of joints (m)
0%	1	24	72	71	2
0～3%	284	40,167	194,248	175,130	15,073
3～12.5%	5,030	751,793	3,557,431	3,286,871	242,272
12.5～25%	1,296	136,536	618,751	548,829	66,752
25～50%	67	5,360	21,932	19,220	2,815
50～75%	3	110	543	527	33
Total	6,681	933,990	4,392,976	4,030,648	326,946

* ILB, stairs, gravel roads, etc. (equivalent to 2,116 m) are not included.



Appendix Figure-3.4.1: Database linked to maps

5 Examination of maintenance methods

Crack sealing was examined as a planned maintenance method. It has been applied to preventive maintenance and in various other pavement maintenance cases as a preventive maintenance method; however, in most of these cases, it has been applied to trunk roads. When crack sealing is applied to daily service roads, consideration must be given not only to its performance but also to various other matters, such as the visual impact for roadside residents. For example, crack sealing traces must be made as unobtrusive as possible. To this end, trial construction and follow-up surveys were implemented on a method for making the entire road surface blackish by applying surface treatment after crack sealing (**Appendix Photograph-3.5.1**) and a method applying a color crack seal (**Appendix Photograph-3.5.2**) with a color tone suitable for the paved road surfaces that had undergone long-term service use. Municipality S will continue to study efficient maintenance methods applicable to daily service roads.

Appendix Photograph-3.5.1: Small-scale surface treatment

Appendix Photograph-3.5.2: Color crack sealing

6 Maintenance plan

Expenses for planned maintenance were estimated based on the results of surface degradation surveys. This planned maintenance consists of road surface repairs (to portions selected based on cracking levels, except for joints) and joint repairs (**Appendix Table-3.6.1**).

Appendix Table-3.6.1: Criteria for planned maintenance

Cracking level	Repair method	
	Road surface repair	Joint repair
0%	-	-
0–3%	-	-
3–12.5%	-	-
12.5–25%	-	Crack sealing
25–50%	Surface treatment	Crack sealing
50–75%	Replacement	Crack sealing

The total expenses for planned maintenance were 221 million yen, which is the sum of 99.5 million yen for small-scale road surface repair and 121.8 million yen for joint repair. This is 74 million yen/year for three-year implementation or 55 million yen/year for four-year implementation (**Appendix Table-3.6.2**).

Appendix Table-3.6.2: Expenses for planned maintenance

Classification of route avg. cracking levels	No. of routes*	Extension* (m)	Est. area of existing pavement (m^2)	Extension of joints (m)	Road surface repair (Replacement/Surface treatment)		Joint repair (Crack sealing)	
					Unit price	Expenses	Unit price	Expenses
0%	1	24	71	2				
0～3%	284	40,167	175,130	15,073				
3～12.5%	5,030	751,793	3,286,871	242,272				
12.5～25%	1,296	136,536	548,829	66,752			1,750	116,816,525
25～50%	67	5,360	19,220	2,815	4,990	95,908,399	1,750	4,925,375
50～75%	3	110	527	33	6,818	3,589,677	1,750	57,750
Total	6,681	933,990	4,030,648	326,946		99,498,076		121,799,650

* ILB, stairs, gravel roads, etc. (equivalent to 2,116 m) are not included.

Appendix 4: Modes of Damage to Asphalt Pavement and Causes Thereof

The major types of damage to asphalt pavement are cracking, rutting, and degradation of surface roughness; other types of damage include faulting, potholes, stripping, and corrugation, etc. As is the case with concrete pavement, asphalt pavement sometimes develops each type of damage separately and sometimes develops multiple types of damage nearly in parallel.

Materials, design, construction, fatigue in service use, and other factors may cause damage. Such factors often affect one another, leading to damage regardless of damage type (mode of damage occurrence).

This section outlines the modes and causes of each type of damage to asphalt pavement.

1 Types and causes of damage to asphalt pavement

Asphalt pavement may suffer various types of damage as listed in **Appendix Table-4.1.1**. Pavement materials, pavement structure, construction, degradation and fatigue in service use, and other factors may cause damage; such factors affect one another, leading to damage of various types in various occurrence modes.

Appendix Table-4.1.1: Major types of damage to asphalt pavement

<table>
<tr><th colspan="3">Damage type</th><th>Subdivision according to damage causes, etc.</th></tr>
<tr><td rowspan="13">Cracking</td><td rowspan="7">Linear cracking</td><td rowspan="4">Longitudinal cracking</td><td>Fatigue cracking</td></tr>
<tr><td>Top-down cracking</td></tr>
<tr><td>Cracking at construction joints</td></tr>
<tr><td>Cracking due to frost heaving</td></tr>
<tr><td rowspan="3">Transverse cracking</td><td>Reflection cracking</td></tr>
<tr><td>Cracking due to thermal stress</td></tr>
<tr><td>Cracking at construction joints</td></tr>
<tr><td colspan="2" rowspan="6">Alligator cracking</td><td>Cracking due to decreased bearing capacity of subgrade or base course</td></tr>
<tr><td>Cracking due to settlement of subgrade or base course</td></tr>
<tr><td>Cracking due to degradation or aging of asphalt mixture</td></tr>
<tr><td>Cracking due to frost heaving</td></tr>
<tr><td>Cracking around structures</td></tr>
<tr><td>Cracking due to stripping of binder course</td></tr>
<tr><td colspan="3" rowspan="3">Rutting</td><td>Rutting due to compressive deformation of subgrade or base course</td></tr>
<tr><td>Rutting due to plastic deformation of asphalt mixture</td></tr>
<tr><td>Rutting due to abrasion of asphalt mixture</td></tr>
<tr><td colspan="3">Degradation of surface roughness</td><td>Longitudinal irregularities</td></tr>
<tr><td colspan="3" rowspan="10">Other types of damage</td><td>Faulting</td></tr>
<tr><td>Potholes</td></tr>
<tr><td>Stripping</td></tr>
<tr><td>Corrugation</td></tr>
<tr><td>Bumps</td></tr>
<tr><td>Depressions</td></tr>
<tr><td>Scattering of aggregate of porous asphalt pavement</td></tr>
<tr><td>Void choking and void clogging in porous asphalt pavement</td></tr>
<tr><td>Partial bumps in porous asphalt pavement (lateral flow)</td></tr>
<tr><td>Road surface collapse</td></tr>
</table>

2 Modes and causes of each type of damage

2-1 Cracking

Cracking of asphalt pavement are phenomenon in which cracks occur on pavement surfaces.

Modes of cracking include linear cracking (in the longitudinal or transverse direction), alligator cracking, and linear and alligator cracking in the same location.

As listed in **Appendix Table-4.2.1**, cracking is roughly classified into various types according to cracking modes, locations, and other factors.

Appendix Table-4.2.1: Modes, locations, and types of cracking

Mode		Locations, etc.	Type
Linear cracking	Longitudinal cracking	Wheel paths	Fatigue cracking
			Top-down cracking
		Construction joints	Cracking at construction joints
		Various locations (e.g., construction joints and BWP)	Cracking due to frost heaving
	Transverse cracking	At equal intervals	Reflection cracking
			Cracking due to thermal stress
		Construction joints	Cracking at construction joints
Alligator cracking		Wheel paths	Cracking due to decreased bearing capacity of subgrade or base course
			Cracking due to settlement of subgrade or base course
		Entire paved surface	Cracking due to degradation or aging of asphalt mixture
			Cracking due to freezing or thawing
		Partial cracking	Cracking around structures
			Cracking due to stripping of binder course

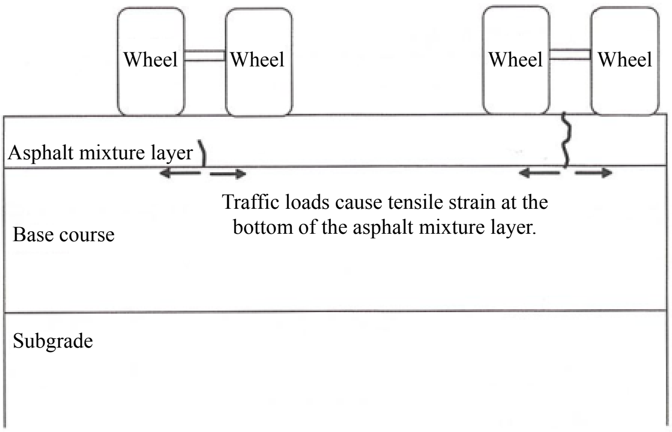
(1) Longitudinal cracking

1) Fatigue cracking

Fatigue cracking occurs due to fatigue failure as defined in the *Technical Standards for Pavement Structures*; it is a type of linear cracking running longitudinally at the wheel paths (**Appendix Photograph-4.2.1**).

As illustrated in **Appendix Figure-4.2.1**, traffic loads cause tensile strain at the bottom of the asphalt mixture layer. Under the repeated action of such tensile strain, cracking occurs on the bottom. This cracking gradually extends upward before finally reaching the pavement surface.

Appendix Photograph-4.2.1: Fatigue cracking

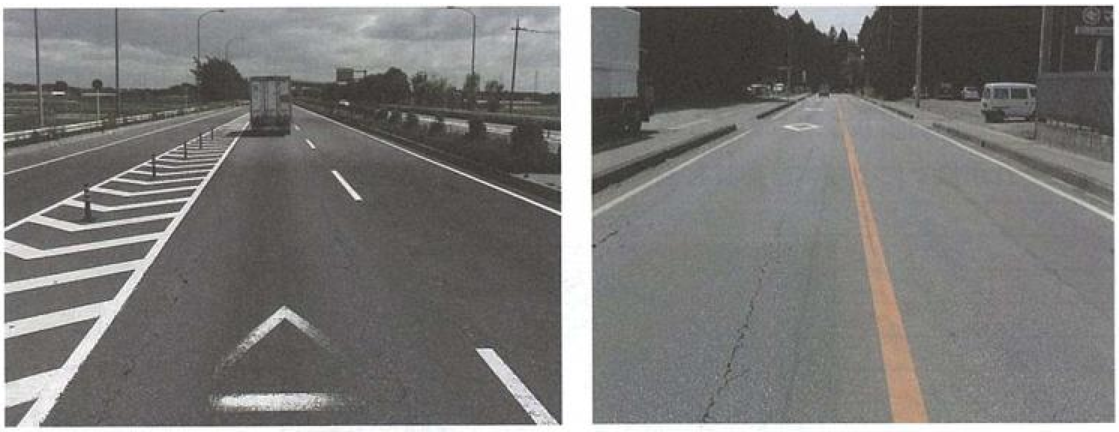


Appendix Figure-4.2.1: Occurrence mechanism of fatigue cracking

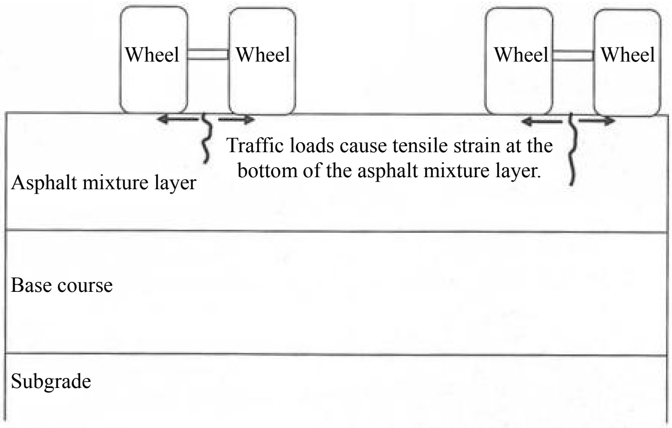
2) Top-down cracking

Like fatigue cracking, top-down cracking occurs in the form of linear cracking running longitudinally in wheel-trace portions (**Appendix Photograph-4.2.2**).

No unified explanation of its causes and occurrence mechanism, etc. has been established. One explanation describes the phenomenon as follows. As illustrated in **Appendix Figure-4.2.2**, traffic loads cause tensile strain on the asphalt mixture layer's surface. Under the repeated action of such tensile strain, cracking occurs on the surface and gradually extends downward. According to this explanation, top-down cracking often occurs when various conditions such as a thick asphalt mixture layer, high road surface temperature, and high large vehicle traffic volume combine with one another.



Appendix Photograph-4.2.2: Top-down cracking

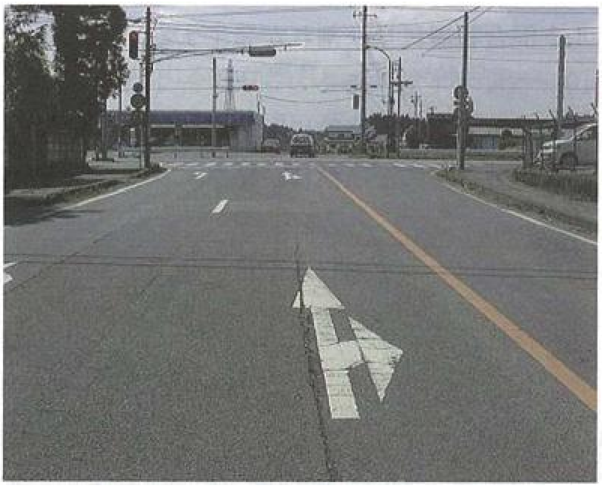


Appendix Figure-4.2.2: Occurrence mechanism of top-down cracking

3) Cracking at construction joints

Cracking at construction joints occurs at longitudinal construction joints (**Appendix Photograph-4.2.3**).

It sometimes occurs during an early stage after the start of service use when construction (e.g., bonding or compaction) was insufficient at the joints.

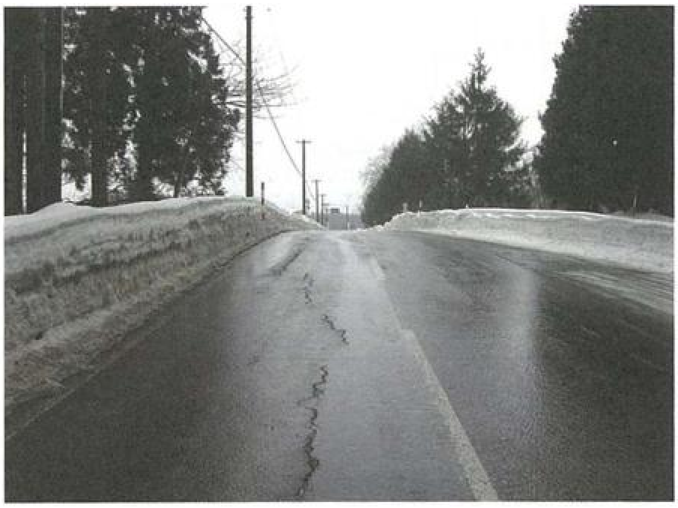


Appendix Photograph-4.2.3: Cracking at a construction joint

4) Cracking due to frost heaving

Cracking due to frost heaving occurs when the ground surface is lifted by an ice lens, meaning a large ice layer forms in subgrade during a low temperature in winter (**Appendix Photograph-4.2.4**).

This type of cracking occurs in various locations, such as at construction joints and lane centers.



Appendix Photograph-4.2.4: Cracking due to frost heaving

(2) Longitudinal cracking

1) Reflection cracking

In asphalt pavement constructed on concrete slabs, transverse joints on the slabs may induce the asphalt mixture layers immediately above the joints to crack (**Appendix Photograph-4.2.5**).

Such cracking occurs at approximately 5 to 10m intervals (equal to the intervals of the joints on the concrete slabs).

Shrinkage cracking occurring on base courses formed by cement stabilization or base courses made of slag may induce the asphalt mixture layers immediately above the shrinkage cracking to crack; cracking of such asphalt mixture layers occurs at approximately 3 to 5m intervals.

When performing overlay or mill and overlay on pavement with cracks, the cracks sometimes grow and reach the pavement's surface course during an early stage. This type of cracking is also classified as reflection cracking.

Appendix Photograph-4.2.5: Reflection cracking on a concrete slab

2) Cracking due to thermal stress (low temperature cracking)

Cracking due to thermal stress occurs when asphalt mixture suffers fatigue under repeated expansion and contraction due to temperature changes. This type of cracking occurs across the entire pavement surface at 5 to 10m intervals, particularly in locations exposed to temperatures lower than −20°C (**Appendix Photograph-4.2.6**).

Appendix Photograph-4.2.6: Cracking due to thermal stress

3) Cracking at construction joints

Cracking at construction joints occurs at transverse construction joints (**Appendix Photograph-4.2.7**).

It sometimes occurs during an early stage after the start of service use when construction (e.g., bonding or compaction) was insufficient at the joints.

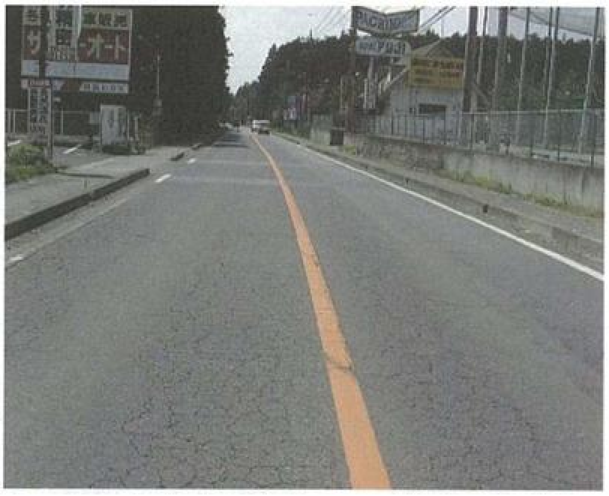
Appendix Photograph-4.2.7: Cracking at a construction joint

(3) Alligator cracking

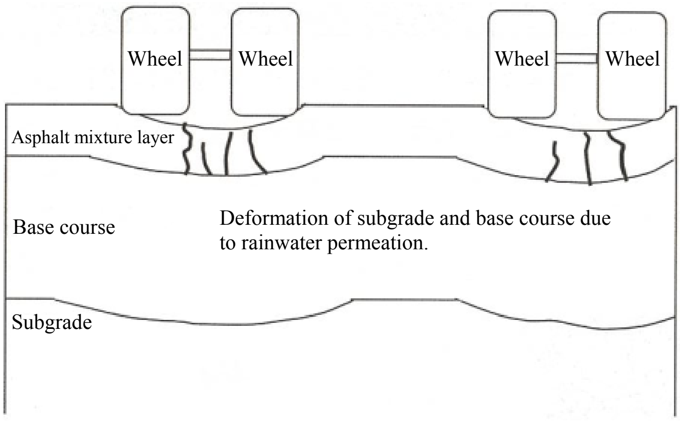
1) Decreased bearing capacity of subgrade or base course

A typical type of cracking is that due to decreased bearing capacity of subgrade or base course. It occurs mainly along wheel paths (**Appendix Photograph-4.2.8**).

Rainwater will permeate into subgrade and base course through cracks if such cracks have reached the bottom of the asphalt mixture layer. Permeation of rainwater decreases the bearing capacity of subgrade and base course. Existing linear cracking consequently develops into alligator cracking. Cracking of this type is often accompanied by settlement due to deformation of subgrade or base course (**Appendix Figure-4.2.3**).



Appendix Photograph-4.2.8: Alligator cracking due to decreased bearing capacity of subgrade or base course



Appendix Figure-4.2.3: Occurrence mechanism of cracking due to decreased bearing capacity of subgrade or base course

2) Cracking due to settlement of subgrade or base course (cracking due to differential settlement)

Cracking due to settlement of subgrade or base course occurs due to differential settlement of subgrade or base course (**Appendix Photograph-4.2.9**).

It is caused by various factors, such as differences in bearing capacity between embankments and natural ground, insufficient compaction in narrow road portions, and insufficient bearing capacity of subgrade or base course. Cracking of this type sometimes occurs around structures.

Appendix Photograph-4.2.9: Cracking due to settlement of subgrade or base course

3) Cracking due to degradation or aging of asphalt

Cracking due to degradation or aging of asphalt occurs across the entire pavement surface as well as in wheel paths (**Appendix Photograph-4.2.10**).

Since it is caused by degradation or aging of asphalt, it occurs even in road portions with low traffic volume; it is often not accompanied by settlement.

Appendix Photograph-4.2.10: Cracking due to degradation or aging of asphalt

4) Cracking due to decreased bearing capacity of subgrade or base course during thawing

Ice lenses (i.e., ice layers formed in foundations) thaw in spring. Cracking due to decreased bearing capacity of subgrade or base course during thawing occurs when traffic loads are exerted on pavement having subgrade with decreased bearing capacity due to such thawing (**Appendix Photograph-4.2.11**).

Appendix Photograph-4.2.11: Cracking due to decreased bearing capacity of subgrade or base course during thawing

5) Cracking around structures

Cracking around structures includes cracking near utility holes and catch basins (**Appendix Photograph-4.2.12**).

High impact loads exerted by passing vehicles on faulting portions on boundaries between structures and pavement cause alligator cracking. Insufficient compaction due to obstruction of structures during construction can also cause such cracking.

Appendix Photograph-4.2.12: Cracking around structures

6) Cracking due to stripping of binder course

Cracking due to stripping of binder course occurs in wheel paths on bridge and porous asphalt pavement. Alligator cracking of this type occurs when binder course loses its bearing capacity due to stripping of binder course mixture.

2-2 Rutting

Rutting refers to the continuous formation of dents in wheel paths in vehicles' traveling directions. This mode of damage adversely affects road users. For example, severely rutted portions catch vehicles' wheels, decreasing driving stability. In rainy weather, water accumulating in large ruts splashes towards drivers, pedestrians, and roadside residents, impairing visibility for drivers and causing discomfort for pedestrians and residents.

Rutting occurs mainly in the following three modes.

1. Compressive deformation of subgrade and base courses
2. Plastic deformation of asphalt mixture
3. Abrasion of asphalt mixture

As listed in **Appendix Table-4.2.2**, rutting factors are classified into the following two categories: external factors (e.g., climate and traffic conditions) and internal factors (e.g., asphalt mixture and asphalt pavement structure).

Appendix Table-4.2.2: Rutting factors

Classification	Rutting factors
External factors	Traffic loads: Traffic volume, ratio of large vehicles, traffic congestion, and intersections Climate conditions: High temperatures in summer
Internal factors	Compressive deformation of subgrade and base courses Plastic deformation and abrasion of asphalt mixture, pavement structure

(1) Rutting due to compressive deformation of subgrade or base course

Appendix Photograph-4.2.13 shows a typical case of rutting due to compressive deformation of subgrade or base course.

Compressive deformation of subgrade or base course is accelerated by decreased bearing capacity of subgrade or base course, insufficient compaction of base course, weakening of subgrade or base course due to permeation of rainwater, etc. through cracks, and traveling that exerts excessive loads on pavement structure. Asphalt mixture layers follow this compressive deformation, inducing rutting due to compressive deformation of subgrade or base course.

Appendix Table-4.2.3 lists the characteristics of rutting caused mainly by compressive deformation of subgrade or base course.

The surface characteristics of roads change when asphalt mixture layers follow the deformation of their subgrade or base courses due to asphalt mixture suffering compressive deformation. When asphalt mixture layers predominantly follow deformation of their subgrade or base courses, asphalt mixture will form only small protrusions toward the outside of rutting portions, and cracking often occurs.

Appendix Photograph-4.2.13: Rutting due to compressive deformation of subgrade or base course

Appendix Table-4.2.3: Rutting factors and their characteristics (compressive deformation of subgrade or base course)

Major cause		• Decreased bearing capacity of subgrade or base course; insufficient compaction of base course • Excessive traveling loads for the pavement structure • Long-term vehicle parking and vibrations
Location		• Portions with relatively thin asphalt pavement • Parking lots and yards, PAs/SAs of expressways, and farm roads
Characteristics	Rutting width	Relatively wide
	Protrusion from baseline	Relatively few
	Rutting progress rate	Progress in early stage after start of service use; relatively slow progress in later stages
	Double rutting (shape)	Overall concave in shape; double rutting has a low occurrence rate
	Existence of cracks	Often occurs with cracking
	Scattering of aggregate	-
	Surface texture	-
	Trafficability (longitudinal direction)	Generally not adversely affected

(2) Rutting due to plastic deformation of asphalt mixture

Appendix Photograph-4.2.14 shows a typical case of rutting due to plastic deformation of asphalt mixture.

Rutting due to plastic deformation of asphalt mixture occurs when asphalt mixture develops permanent deformation under the repeated action of traffic loads at high temperatures, mainly in summer. It often occurs for road portions such as intersections and routes having a high large vehicle traffic volume. Rutting of this type occurs at different levels depending on asphalt mixture types, summer temperatures, and other factors. It is characterized by double rutting at the wheel paths and protrusions toward the outside of wheel paths.

Appendix Table-4.2.4 lists the characteristics of rutting caused mainly by plastic deformation of asphalt mixture.

Appendix Photograph-4.2.14: Rutting due to plastic deformation of asphalt mixture

Appendix Table-4.2.4: Rutting factors and their characteristics (plastic deformation of asphalt mixture)

<table>
<tr><td colspan="2">Major cause</td><td>• Insufficient plastic deformation resistance of surface course
• Insufficient compaction of asphalt mixture
• Severe external factors (long-term loads of vehicles in intersections, etc., high traffic volume, and high road-surface temperature for a long period of time)</td></tr>
<tr><td colspan="2">Location</td><td>• Access portions and stopping locations at intersections/portions with traffic congestion
• Parking lots in PAs/SAs of expressways
• Routes with high traffic volume, entrances for large vehicles, and portions with high traffic volume
• Road surfaces for which traffic control was ended after thick layer construction in summer</td></tr>
<tr><td rowspan="8">Characteristics</td><td>Rutting width</td><td>Relatively narrow widths</td></tr>
<tr><td>Protrusion from baseline</td><td>Sometimes large protrusions form</td></tr>
<tr><td>Rutting progress rate</td><td>Relatively fast progress in summer</td></tr>
<tr><td>Double rutting (shape)</td><td>Sometimes double rutting forms</td></tr>
<tr><td>Existence of cracks</td><td>Often, no cracking forms</td></tr>
<tr><td>Scattering of aggregate</td><td>-</td></tr>
<tr><td>Surface texture</td><td>-</td></tr>
<tr><td>Trafficability (longitudinal direction)</td><td>Double-rutting portions catch vehicles’ wheels, impairing driving stability.</td></tr>
</table>

(3) Rutting due to abrasion of asphalt mixture

Appendix Photograph-4.2.15 shows a typical case of rutting due to abrasion of asphalt mixture.

Rutting due to abrasion of asphalt mixture is often observed in roads in snowy regions. It occurs when asphalt mixture surfaces abrade under the action of repeated loads of traveling vehicles equipped with tire chains in winter. In this phenomenon, the abrasion of surface asphalt mortar predominates over asphalt mixture deformation. As a result, transverse irregularities develop on road surfaces, forming depressions at the wheel paths.

Appendix Table-4.2.5 lists the characteristics of rutting caused mainly by abrasion of asphalt mixture.

Since the number of road surfaces covered with porous asphalt has been increasing, abrasion sometimes leads to scattering of aggregate over road surfaces. Such abrasion occurs, for example, when routes that generally see no snowfall are covered with snow due to unusual weather or when even in snowy regions, above-average snowfall requires more frequent deployment of chain-equipped snowplows.

Appendix Photograph-4.2.15: Rutting due to abrasion of asphalt mixture

Appendix Table-4.2.5: Rutting factors and their characteristics (abrasion of asphalt mixture)

Major cause		• Abrasion of road surfaces due to traveling vehicles equipped with tire chains in winter • Use of soft aggregate
Location		Roads in snowy regions
Characteristics	Rutting width	Relatively wide
	Protrusion from baseline	Almost no protrusions form
	Rutting progress rate	Extensive progress of rutting in winter
	Double rutting (shape)	Overall abrasions often concave in shape
	Existence of cracks	-
	Scattering of aggregate	Scattering of fine grains/aggregate onto road shoulders as a result of abrasion
	Surface texture	Abrasion of mortar portions near road surfaces
	Trafficability (longitudinal direction)	Generally not adversely affected

2-3 Degradation of surface roughness

Longitudinal irregularities are unevenness with relatively long wavelengths that occur in roads' longitudinal directions.

They are caused mainly by differential settlement due to non-uniform bearing capacity of subgrade, base course, or other layers and frost heaving.

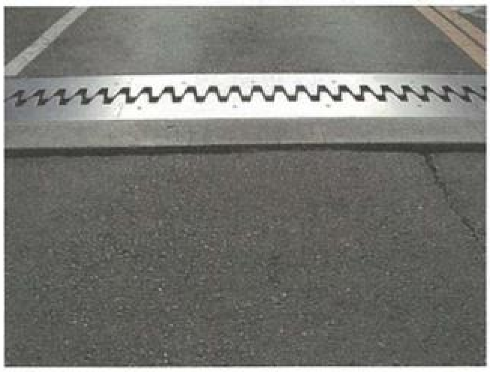
2-4 Other types of damage

This section outlines the following 11 other types of damage to asphalt pavement and other structures.

1. Faulting
2. Potholes
3. Stripping
4. Corrugation
5. Bumps
6. Depressions
7. Decreased skid resistance
8. Scattering of aggregate of porous asphalt pavement
9. Void choking and void clogging in porous asphalt pavement
10. Partial bumps in porous asphalt pavement (lateral flow)
11. Road surface collapse

(1) Faulting

Faulting refers to portions with a steep change in road surface height as seen in structure-mounted portions and pavement joints. Several causes contribute to its occurrence, including differential settlement caused by differences in pavement structure from ordinary portions in pavement (e.g., pavement with facilities and buried objects) and inappropriate construction of joints between existing and additional pavement (**Appendix Photograph-4.2.16**). In such road portions, base courses and asphalt mixture layers are often insufficiently compacted, and this contributes to uneven formation.



Faulting at a bridge joint

Faulting at a utility hole

Appendix Photograph-4.2.16: Faulting between structures and pavement

(2) Potholes

Potholes are 10 to 100cm holes formed atop pavement surfaces. They occur as a result of the progress of other types of damage, such as scattering of material from alligator cracking portions or stripping of asphalt mixture (**Appendix Photograph-4.2.17**).

In porous asphalt pavement, potholes sometimes occur due to oil permeation, progress of scattering of aggregate, or stripping of binder course.

Factors that contribute to pothole formation include material defects in asphalt mixture and insufficient compaction during construction.

Appendix Photograph-4.2.17: Potholes

(3) Stripping

Stripping is a phenomenon in which asphalt coating falls off of aggregate. It generally starts from the bottom of asphalt mixture.

Asphalt coating falls off of aggregate mainly due to the presence of water; consequently, asphalt mixture granulates, which causes cracking and settlement, leading to rapid pothole formation (**Appendix Photograph-4.2.18**).

Stripping sometimes occurs under conditions that allow water to remain within asphalt pavement, such as use of a material with low water resistance, insufficient compaction, or low drainage performance of bridge decks.

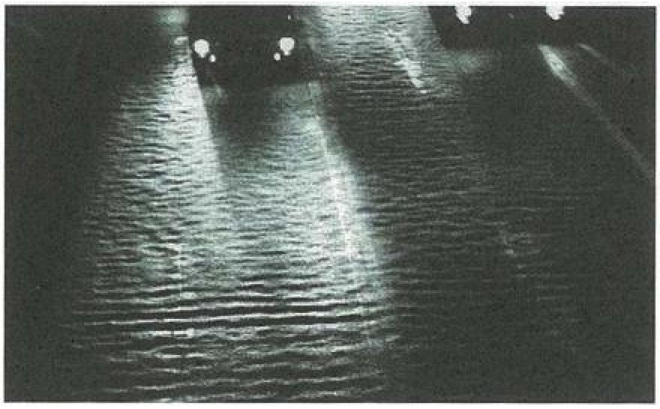
When porous asphalt mixture is used in surface courses, asphalt mixture in binder courses is sometimes stripped due to the action of accumulated rainwater, etc.

Appendix Photograph-4.2.18: Stripping

(4) Corrugation

Corrugation is continuous wave-like irregularities with relatively short wavelengths that occur in roads' longitudinal directions. Corrugation tends to occur in road portions where vehicles frequently brake or stop, such as access portions of intersections, curved portions, downward slopes, and routes with traffic congestion (**Appendix Photograph-4.2.19**).

Several causes contribute to its occurrence: for example, low plastic deformation resistance or other material defects in asphalt mixture; or bonding failures between mixture layers due to material defects and excessive application of tack coating.



Appendix Photograph-4.2.19: Corrugation

(5) Bumps

Bumps are local protrusions formed atop road surfaces; they are sometimes called humps (**Appendix Photograph-4.2.20**).

Bumps are caused mainly by bonding failures between mixture layers due to excessive application of prime or tack coating, rainwater permeation, or other factors that impair bonding.

Appendix Photograph-4.2.20: Bumps

(6) Depressions

Depressions are portions that have locally sunk lower than the surrounding road surface (**Appendix Photograph-4.2.21**).

Their causes include deformation due to material defects in surface-course asphalt mixture and local settlement of subgrade in filled-up ground.

Appendix Photograph-4.2.21: Depression

(7) Decreased skid resistance

Polishing is a type of damage that leads to decreased skid resistance.

Polishing is a phenomenon in which pavement surfaces abraded by traveling vehicles become flat and smooth due to abrasion of mortar and aggregate in pavement (**Appendix Photograph-4.2.22**).

It is often caused by material defects in coarse aggregate.

Appendix Photograph-4.2.22: Polishing

(8) Scattering of aggregate of porous asphalt pavement

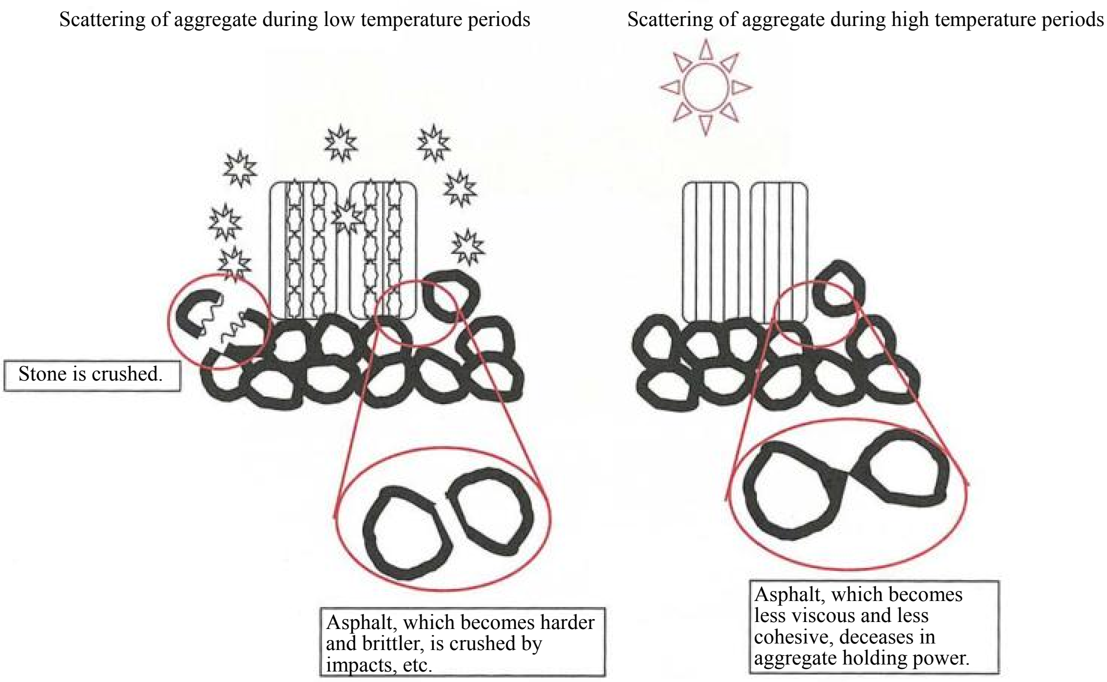
Scattering of aggregate of porous asphalt pavement is a phenomenon in which road surfaces become coarse in response to scattering of aggregate over pavement surfaces. Causes include the impacts of tire chains or other impact loads and torsion exerted by vehicle tires or other forces (**Appendix Photograph-4.2.23**).

Appendix Figure-4.2.4 illustrates the mechanism behind scattering of aggregate.

Scattering of aggregate caused by impacts of tire chains or other impact loads often occurs during low temperature periods. This is because asphalt, which becomes harder and brittler at lower temperatures, is crushed under the impact loads. When soft aggregate is used, breakage sometimes leads to scattering of aggregate.

On the other hand, scattering of aggregate caused by torsion exerted by vehicle tires or other forces often occurs during high temperature periods. This is because asphalt, which becomes less viscous and less cohesive at higher temperatures, decreases in aggregate holding power. Particularly for construction joints and similar portions, where the degree of compaction tends to become low, weak aggregate engagement readily leads to scattering of aggregate.

Appendix Photograph-4.2.23: Scattering of aggregate of porous asphalt pavement



Appendix Figure-4.2.4: Mechanism behind scattering of aggregate of porous asphalt pavement

(9) Void choking and void clogging in porous asphalt pavement

Void choking and void clogging in porous asphalt pavement block voids in pavement (**Appendix Photographs-4.2.24** and **4.2.25**).

Void choking occurs when mud, dust, or other foreign material accumulates in voids in pavement.

Void clogging occurs when voids in pavement are blocked by kneading action due to traveling vehicles or plastic deformation of mixture.

These phenomena do not degrade pavement's traffic function. However, they degrade the functions for reducing environmental burdens, such as tire-road surface noise reduction and drainage performance.

Appendix Photograph-4.2.24: Void choking

Appendix Photograph-4.2.25: Void clogging

(10) Partial bumps in porous asphalt pavement (lateral flow)

Partial bumps in porous asphalt pavement (lateral flow) refer to a phenomenon in which pavement in vehicle-traveling portions partially shifts laterally and is accompanied by sinking (**Appendix Photograph-4.2.26**).

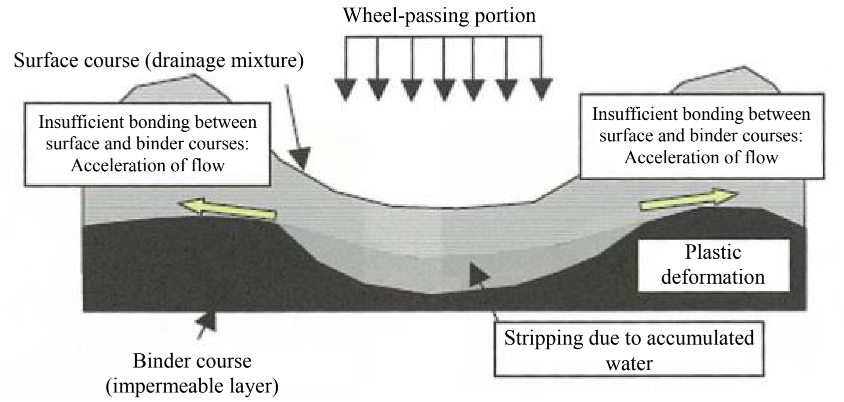
This phenomenon is caused by insufficient bonding between surface and binder courses or damage to binder course mixture.

Stripping is a typical type of damage to binder course material; it leads to plastic deformation of binder course material and degradation of the bonding force between surface and binder courses, resulting in bumps.

Appendix Photograph-4.2.26: Partial bumps in porous asphalt pavement

According to the results of an open-cut survey of partial bumps in porous asphalt pavement at the Pavement Test Field of the Public Works Research Institute, partial bumps in porous asphalt pavement have the following characteristics (**Appendix Figure-4.2.5**: Condition of pavement revealed by the open-cut survey).

1. The binder course developed clear plastic deformation toward the portion where lateral flow occurred.
2. In the central part of the portion subject to wheel loading, the binder course was destroyed by stripping, and the mixture in the surface and binder courses was destroyed beyond recognition.
3. The surface and binder courses slipped on their boundary surfaces, and the surface course shifted laterally to develop flow.
4. In cores sampled from portions developing lateral flow, the surface and binder courses were not bonded together in portions where vehicle wheels pass over, even in cases where the binder course retained its original shape. In approximately half of such cores, the surface and binder courses separated from each other upon core sampling.



Appendix Figure-4.2.5: Condition of pavement revealed by the open-cut survey

(11) Road surface collapse

Road surface collapse is a phenomenon in which cavities formed below road surfaces for one reason or another cause road surfaces to collapse.

The causal relationship between road conditions and cavity formation has not yet been elucidated. However, roads meeting the following conditions are thought to be highly likely to form cavities.

1) Road sections that have the same road structure (pavement structure and buried objects) as road portions in which road surface collapses have occurred in the past

2) Roads with the following types of buried objects, such as underground structures or lifelines, below their surfaces:
   - Subways, common ducts, utility tunnels, underpasses, and underground malls
   - Water supplies, sewers, gas pipelines, electrical lines, telephone lines, crossing channels, etc.

3) Roads affected by water from rivers, seashores, etc.

Cavities sometimes lead to road surface deformation as they develop. **Appendix Photograph-4.2.27** shows such deformation.

Many aspects of the occurrence mechanism of cavities and their progress toward road surface collapse have not yet been elucidated. This is because the phenomenon, which progresses underground, cannot be visually observed and also because the phenomenon is affected by differences in material properties between layers in pavement bodies, traffic loads acting during service use, cavity formation factors, and other factors. To prevent road surface collapse, it is effective to periodically perform surveys (e.g., cavity surveys from road surfaces using an ground penetrating radar and surveys with FWD) as well as visual inspections of road surfaces by patrols or other approaches. When portions that are likely to suffer from road surface collapse are detected, necessary measures must be taken immediately. Their locations and conditions must be recorded in detail to the extent possible. **Appendix Photograph-4.2.28** shows a cavity that has formed below a road surface.

Appendix Photograph-4.2.27: Road surface that is likely to collapse

Appendix Photograph-4.2.28: Cavity formed below a road surface

Appendix 5: Modes of Damage to Concrete Pavement and Causes Thereof

The major types of damage to concrete pavement are cracking, damage to joints, and faulting; other types of damage include rutting, potholes, scaling, and polishing. As is the case with asphalt pavement, concrete pavement sometimes develops each type of damage separately and sometimes develops multiple types of damage nearly in parallel.

Materials, design, construction, fatigue in service use, and other factors may cause damage. Such factors often affect one another, leading to damage regardless of damage type (mode of damage occurrence).

This section outlines the modes and causes of each type of damage to concrete pavement.

1 Types and causes of damage to concrete pavement

Concrete pavement may suffer various types of damage as listed in **Appendix Table-5.1.1**. Pavement materials, pavement structure, construction, degradation and fatigue in service use, and other factors may cause damage; such factors affect one another, leading to damage of various types in various occurrence modes.

Appendix Table-5.1.1: Major types of damage to concrete pavement

Damage type		Damage causes, etc.
Cracking	Transverse cracking	Fatigue in service use, improper design, or inappropriate construction
	Longitudinal cracking	Fatigue in service use and settlement
	Y-shaped or cluster-type cracking	Improper design or inappropriate construction
	Edge cracking	Fatigue in service use
	Durability cracking (D-Cracking)	Material defects, etc.
	Cracking due to drying	Inappropriate construction
	Arc cracking	Cracking due to construction
	Setting shrinkage cracking	Material defects
	Irregular cracking	Improper design
	Sheet and alligator cracking	Fatigue in service use
Damage to joints	Protrusion and scattering of joint filler	Influence of climate and traveling loads in service use
	Edge defects at joints	Inappropriate construction, inappropriate road administration, and influence of traveling loads
Faulting	Faulting between slabs	Erosion and influence of traveling loads
	Faulting from adjacent structures	Differences in material quality
	Faulting due to buried objects	Differential settlement and inappropriate construction
	Faulting from asphalt pavement	Flow of asphalt mixture, consolidation, and traveling loads
Other types of damage	Rutting	Material defects and traveling of vehicles equipped with tire chains
	Potholes	Material defects and inappropriate construction
	Scaling	Insufficient hardening (curing) as well as freezing and thawing
	Polishing	Materials defects and traveling vehicles

2 Modes and causes of each type of damage

2-1 Cracking

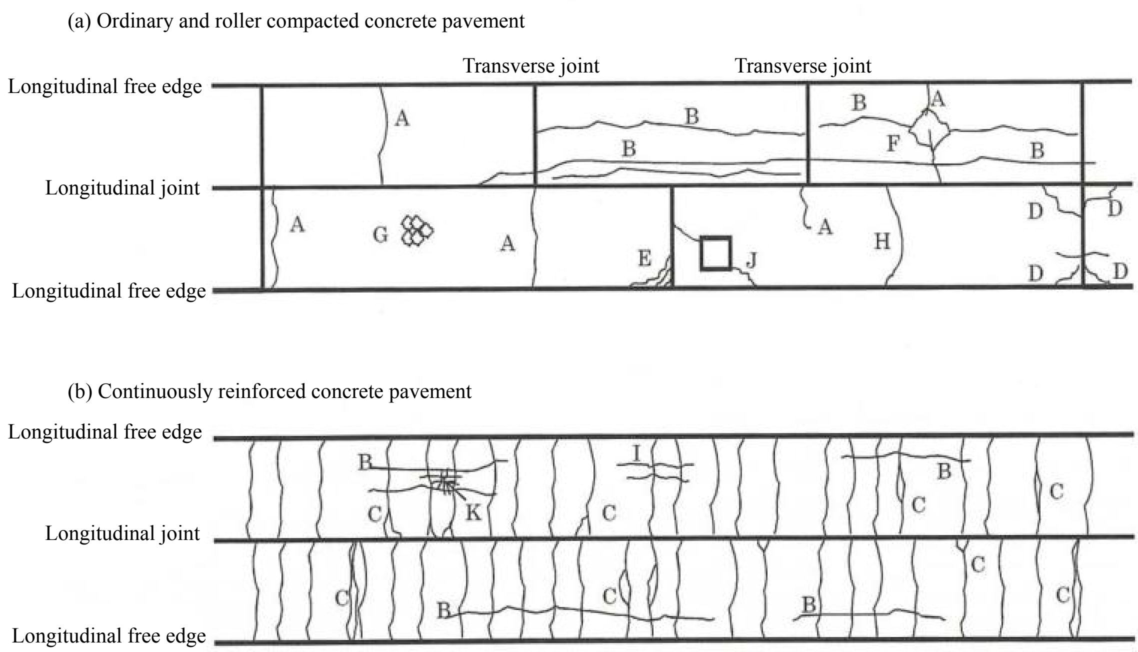
Cracking of concrete pavement slabs is classified based on shape, location, and other factors as seen in **Appendix Figure-5.2.1**. **Appendix Figure-5.2.2** illustrates typical locations where transverse cracking occurs. The letters in **Appendix Figure-5.2.2** correspond to those in **Appendix Figure-5.2.1**, indicating the types of cracking.

This section outlines the modes and causes of cracking in reference to the classification illustrated in **Appendix Figure-5.2.1**.

Cracking of concrete pavement slabs

- A: Transverse cracking → Fatigue in service use, improper design, or inappropriate construction
- B: Longitudinal cracking → Fatigue in service use or settlement
- C: Y-shaped or cluster-type cracking → Improper design or inappropriate construction
- D: Edge cracking → Fatigue in service use
- E: D cracking → Material defects
- F: Sheet and alligator cracking, etc. → Fatigue in service use
- G: Cracking due to drying → Inappropriate construction
- H: Arc cracking → Inappropriate construction
- I: Setting shrinkage cracking → Material defects
- J: Irregular (restricted) cracking → Improper design
- K: Punching out → Fatigue in service use, inappropriate construction, or material defects (corrosion of reinforcements, etc.)

Appendix Figure-5.2.1: Classification of types of cracking of concrete pavement slabs and major causes thereof



Appendix Figure-5.2.2: Examples of cracking patterns on concrete pavement slabs

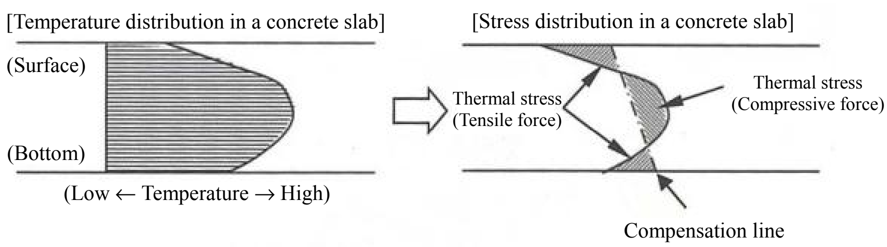
(1) Transverse cracking

Transverse cracking occurs in a direction almost perpendicular to vehicles' traveling direction. **Appendix Photograph-5.2.1** shows a typical case of transverse cracking.

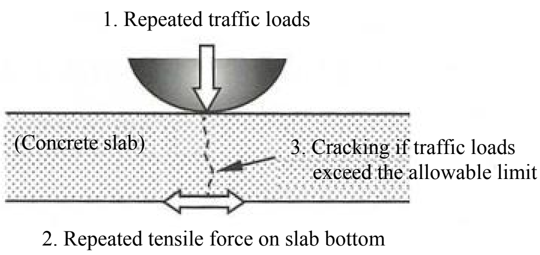
(a) Ordinary concrete pavement (b) Continuously reinforced concrete pavement

Appendix Photograph-5.2.1: Transverse cracking on a concrete pavement slab

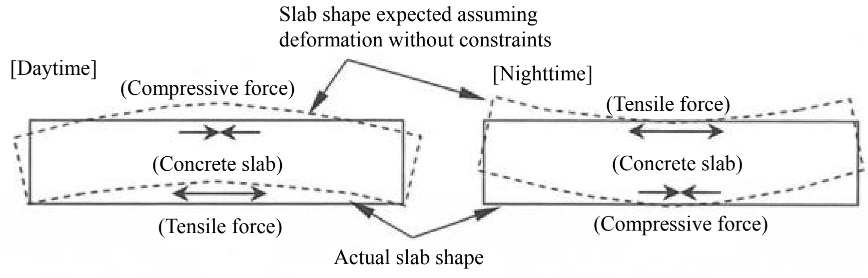
Transverse cracking is roughly classified into the following three types according to its cause. In some cases, initial cracking is caused by the heat of cement hydration in the hardening process (e.g., inappropriate initial curing after concrete placement). Fatigue cracking is caused by the repeated action of traffic loads in service use. Cracking due to thermal stress occurs in concrete pavement having inappropriate joint intervals (slab lengths) if concrete slabs cannot withstand their internal stress, or restriction stress develops on the boundary surfaces between slabs and their base courses. **Appendix Figures-5.2.3** to **5.2.5** illustrate the mechanisms of each type of cracking. Transverse cracking occurs if the stress or strain developed in the concrete slabs exceeds their actual strength or extensibility.



Appendix Figure-5.2.3: Mechanism of initial cracking caused by heat of hydration



Appendix Figure-5.2.4: Mechanism of transverse cracking caused by fatigue under repeated loading



Appendix Figure-5.2.5: Mechanism of transverse cracking caused by thermal stress

Continuously reinforced concrete pavement is designed to disperse cracking due to dry shrinkage and temperature changes in concrete by employing longitudinal reinforcements to minimize each crack's width. Transverse cracking on such pavement is accordingly not classified into any of the aforementioned cracking types (**Appendix Photograph-5.2.1** (b)).

(2) Longitudinal cracking

Longitudinal cracking occurs in the same direction as vehicles travel. **Appendix Photograph-5.2.2** shows a typical case of longitudinal cracking.

(a) Ordinary concrete pavement (b) Continuously reinforced concrete pavement

Appendix Photograph-5.2.2: Longitudinal cracking of a concrete pavement slab

Longitudinal cracking generally refers to a type of fatigue cracking caused by repeated traffic loads during service use. It tends to occur in locations where vehicles pass over the same road portions in narrow lanes. Wide concrete slabs without joints that cover two or more lanes may develop cracking longitudinally due to thermal stress (**Appendix Photograph-5.2.2** (b)). The cracking mechanisms for these types are illustrated in **Appendix Figures-5.2.4** and **5.2.5**. Longitudinal cracking occurs if the stress or strain developed in concrete slabs exceeds their actual strength or extensibility.

(3) Y-shaped or cluster-type cracking

Y-shaped and cluster-type cracking are types of cracking unique to continuously reinforced concrete pavement. Y-shaped cracking forms cracks in the shape of the letter Y at slab ends. Cluster-type cracking forms cracks of non-uniform density at short intervals. **Appendix Photograph-5.2.3** shows typical cases of Y-shaped and cluster-type cracking.

(a) Y-shaped cracking (b) Cluster-type cracking

Appendix Photograph-5.2.3: Y-shaped and cluster-type cracking of a continuously reinforced concrete slab

As described above, continuously reinforced concrete pavement is designed to disperse cracking due to dry shrinkage and temperature changes in concrete by employing longitudinal reinforcements to minimize each crack's width (approximately 50 to 200 cm). Transverse cracking on such pavement is accordingly not classified as damage to pavement.

However, since Y-shaped and cluster-type cracking sometimes develop into edge defects or punching out, they are often regarded as damage to concrete slabs. Possible causes of such damage include improper design (e.g., insufficient slab thickness), insufficient compaction during construction, and material segregation.

(4) Edge cracking

Edge cracking occurs at the edges of concrete slabs that have joints. **Appendix Photograph-5.2.4** shows a typical case of edge cracking.

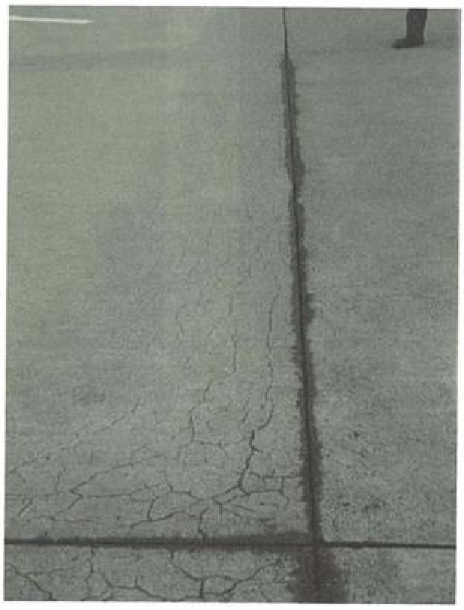
Appendix Photograph-5.2.4: Edge cracking on a concrete pavement slab

Edge cracking often occurs when concrete slabs are thin or lack both steel nets and dowel bars.

(5) D-cracking (Durability cracking)

The D in D-cracking refers to "durability" cracking. Like edge cracking, it occurs along the edges of concrete slabs. Compared to edge cracking, D-cracking forms dense cracks. **Appendix Photograph-5.2.5** shows a typical case of D-cracking.

D-cracking is thought to be caused by the action of reactive aggregate or the expansion pressure of aggregate when thawing.



Appendix Photograph-5.2.5: D-cracking of a concrete pavement slab

(6) Sheet and alligator cracking

Sheet and alligator cracking forms longitudinal and transverse composite cracks in a sheet-like or tortoise-shell pattern. **Appendix Photograph-5.2.6** shows typical cases of sheet and alligator cracking.

Cracking of this type occurs as a result of the action of multiple factors, such as loads and temperature. Concrete slabs that are developing sheet and alligator cracking are regarded as being in the final stage of their destruction.

Appendix Photograph-5.2.6: Sheet and alligator cracking of a concrete pavement slab

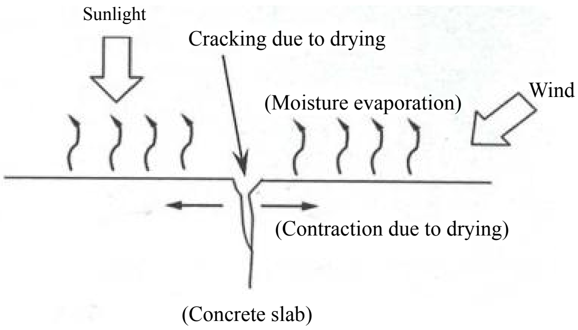
(7) Cracking due to drying

Cracking due to drying forms fine cracks during an early curing stage after concrete placement. **Appendix Photograph-5.2.7** shows a typical case of cracking due to drying.

Cracking of this type occurs when the surface of fresh concrete is rapidly dried by sunlight, wind, or under some other conditions. **Appendix Figure-5.2.6** illustrates the mechanism of cracking due to drying.

It is thought that cracking due to drying generally occurs only on the surfaces of concrete slabs and does not seriously damage the structure.

Appendix Photograph-5.2.7: Cracking due to drying of a concrete pavement slab

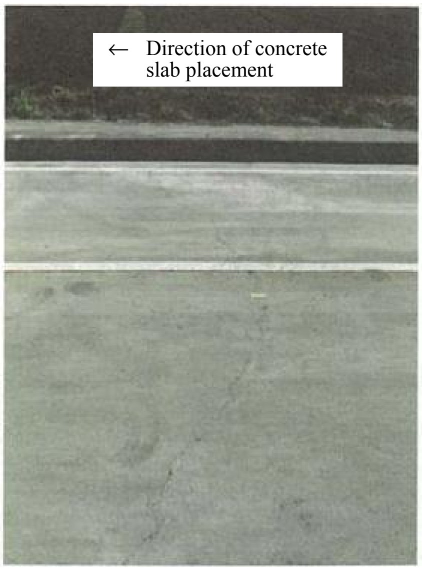


Appendix Figure-5.2.6: Mechanism of cracking due to drying

(8) Arc cracking

Arc cracking forms concave cracks running in concrete slabs' direction of placement. **Appendix Photograph-5.2.8** shows a typical case of arc cracking.

Causes of cracking of this type are thought to include material segregation and interruptions in construction.



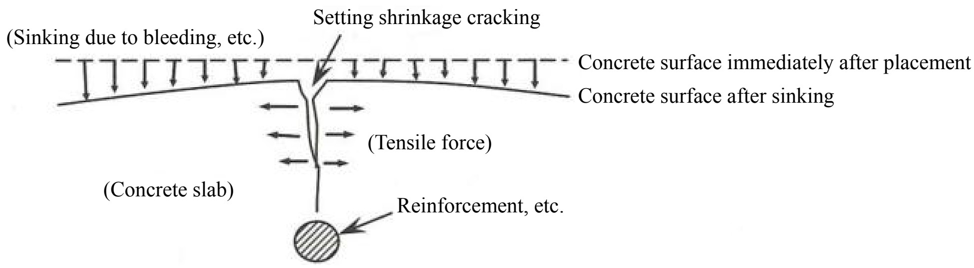
Appendix Photograph-5.2.8: Arc cracking of a concrete pavement slab

(9) Setting shrinkage cracking

Setting shrinkage cracking occurs mainly due to the sinking of concrete during an early curing stage of continuously reinforced concrete pavement. **Appendix Photograph-5.2.9** shows a typical case of setting shrinkage cracking.

Cracking of this type occurs over reinforcements if they prevent concrete from sinking due to bleeding or the presence of voids after placement if fresh concrete has inappropriate consistency or insufficient compaction. **Appendix Figure-5.2.7** illustrates the mechanism of setting shrinkage cracking.

Appendix Photograph-5.2.9: Setting shrinkage cracking of a concrete pavement slab

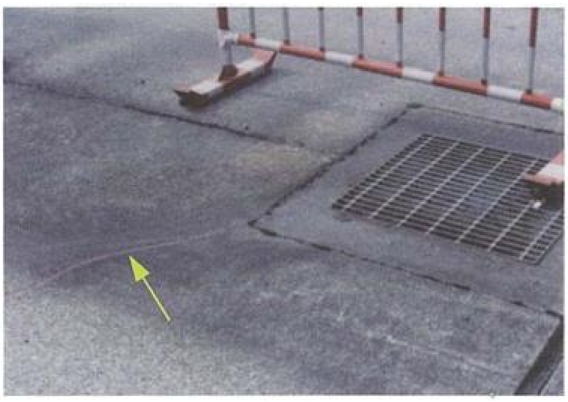


Appendix Figure-5.2.7: Mechanism of setting shrinkage cracking

(10) Irregular (restricted) cracking

Irregular (restricted) cracking forms irregular cracks in portions other than joints when structures, etc. are present within concrete slabs. **Appendix Photograph-5.2.10** shows a typical case of irregular cracking.

Cracking of this type, which is caused by slabs containing different types of structures, often occurs if joints are not constructed at appropriate locations.



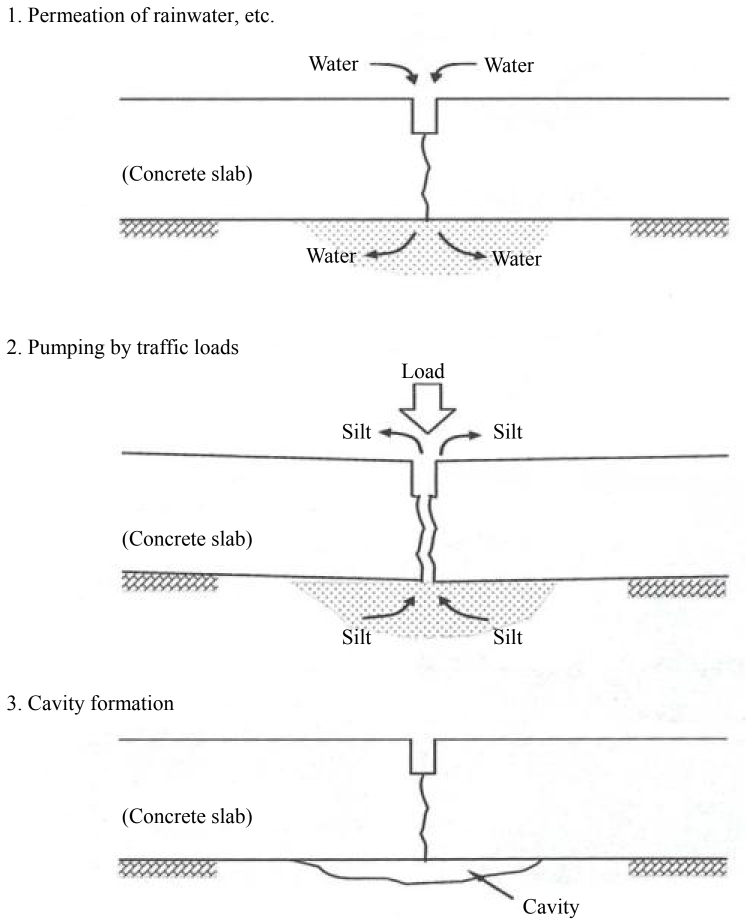
Appendix Photograph-5.2.10: Irregular (restricted) cracking of a concrete pavement slab

(11) Other type of cracking (erosion due to pumping)

If base courses or subgrade are saturated with rainwater permeating through cracks, joints, or other portions, concrete slabs will sometimes be deflected by traffic loads to eject fine gains (e.g., silt or clay) through such cracks or joints. This phenomenon is called pumping. As a result, portions (in base courses) below the cracks or joints may form cavities; this is known as erosion. Erosion decreases the bearing capacity of base courses, advancing the damage to concrete slabs.

Appendix Photograph-5.2.11 shows a typical case of pumping, while **Appendix Figure-5.2.8** illustrates the mechanism of erosion.

Appendix Photograph-5.2.11: Trace of pumping on a concrete pavement slab



Appendix Figure-5.2.8: Mechanism of erosion

2-2 Damage to concrete pavement joints

Damage to concrete pavement joints often leads to serious damage, such as faulting in concrete slabs. This section outlines the following two types of damage to joints.

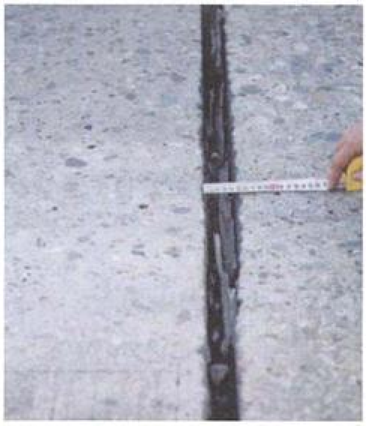
- Protrusion and scattering of joint filler
- Edge defects at joints

(1) Protrusion and scattering of joint filler

Protrusion and scattering of joint filler used in the joints of concrete pavement may cause degradation of surface roughness, permeation of rainwater, clogging by dust and sand, or other problems, thereby significantly damaging the joints. **Appendix Photograph-5.2.12** shows protrusion of joint filler at a transverse contraction joint, while **Appendix Photograph-5.2.13** depicts scattering of joint filler at an expansion joint.

Protrusion and scattering of joint filler often occur at high temperatures in summer. Concrete slabs that have expanded at high temperatures push out joint filler from the joints, and the protruded joint filler is stripped and scattered by traveling vehicles, etc.

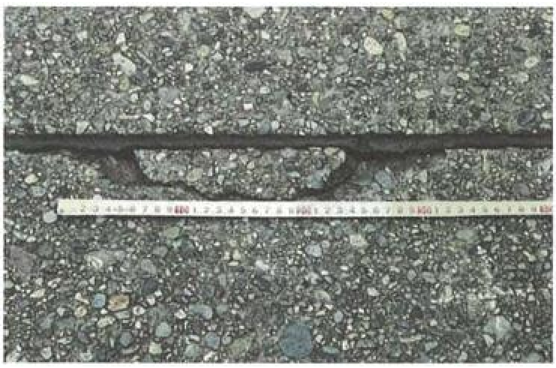
Appendix Photograph-5.2.12: Protrusion of joint filler



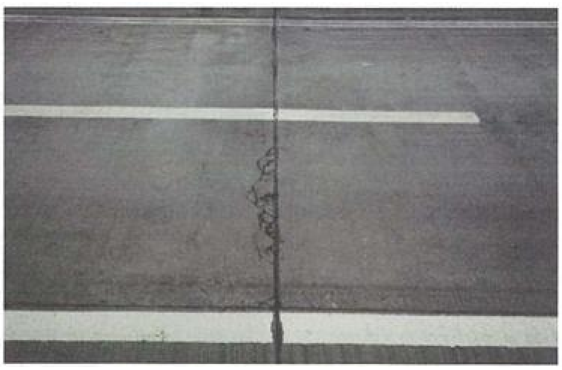
Appendix Photograph-5.2.13: Scattering of joint filler

(2) Edge defects at joints

Edge defects at joints may adversely affect the traveling performance, safety, and ride quality for vehicles as well as deteriorate roadside environments by generating vibrations and noise. Edge defects may also lead to significant damage under traveling loads. **Appendix Photograph-5.2.14** shows an edge defect at a transverse contraction joint, while **Appendix Photograph-5.2.15** shows an edge defect at an expansion joint.

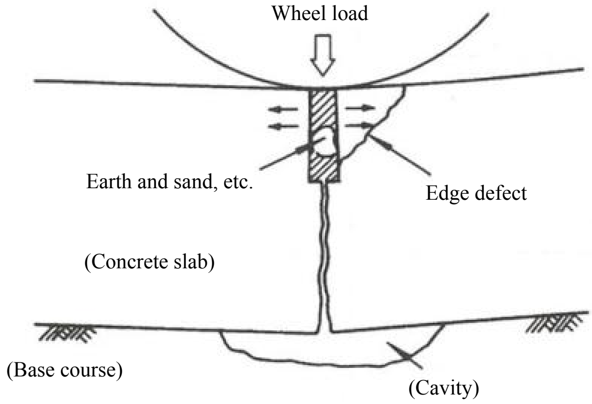


Appendix Photograph-5.2.14: Edge defect at a transverse contraction joint



Appendix Photograph-5.2.15: Edge defect at an expansion joint

Edge defects at joints occurring during an early stage of service use are often caused by partial material segregation resulting from inappropriate construction work (e.g., excessive trowel finish). They also sometimes occur when crack guiding positions are not in agreement with cutter cutting positions. Edge defects at joints occurring relatively late after the start of service use are caused by increased deflection due to traveling loads as well as entry of foreign objects due to inappropriate administration of joints (**Appendix Figure-5.2.9**).



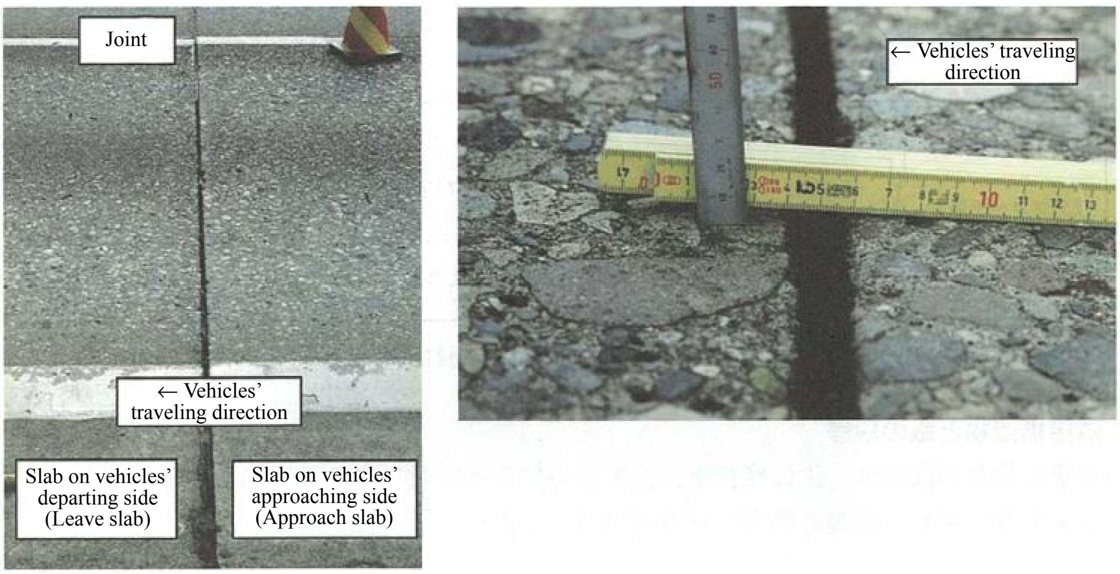
Appendix Figure-5.2.9: Occurrence mechanism of edge defects (foreign objects and traveling loads)

2-3 Faulting

Major types of faulting in concrete pavement slabs are as follows: 1. faulting between slabs at joints or in cracking portions; 2. faulting between slabs and their adjacent structures in bridge anchorages, etc.; 3. faulting due to buried structures (e.g., pipes and drains) running below pavement; and 4. faulting formed at joints between slabs and asphalt pavement. This section outlines the modes and causes of these four types of faulting.

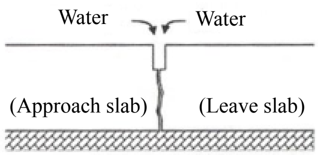
(1) Faulting between slabs

Appendix Photograph-5.2.16 shows a typical case of faulting between concrete pavement slabs at joints or in cracking portions.

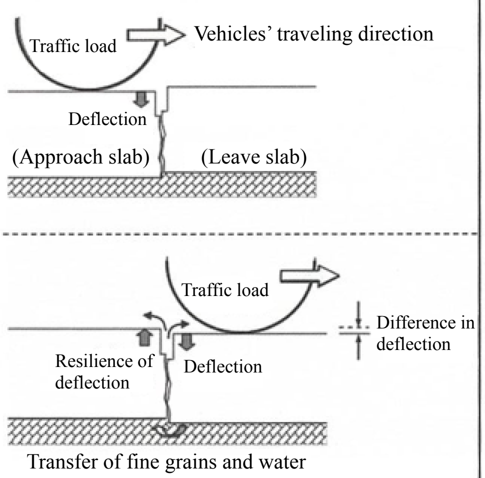


Appendix Photograph-5.2.16: Faulting between concrete pavement slabs at joints

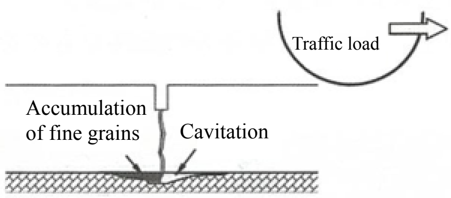
As illustrated in **Appendix Figure-5.2.10**, faulting between slabs is triggered by rainwater, etc. permeating joints or cracks. During service use, joint structures are damaged by repeated vehicle loads, and rainwater, etc. permeating the damaged joint structure scours the base course and other portions. This scouring ultimately induces faulting between slabs, which may develop into structural damage for concrete pavement slabs. Application of sealant to joints and cracking portions is critically important to maintain concrete pavement.



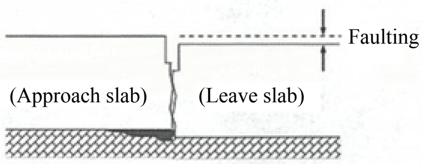
1. Rainwater, etc. permeates cracking portions or joints that have lost their joint filler due to scattering or stripping, and degrades the base course's bearing capacity.



2. The deflection (sinking) of the approach slab (slab on the vehicles' approaching side) and the leave slab (slab on the vehicles' departing side) and their resilience to such deflection act as pumping to compress water on the upper surface of the base course. The compressed water is ejected rapidly together with fine grains present on the upper surface. In this process, part of the fine grains is ejected together with the water from the joints onto the concrete slab's surface.



3. Fine grains below the lower surface of the leave slab are scoured and transferred, leaving a cavity.

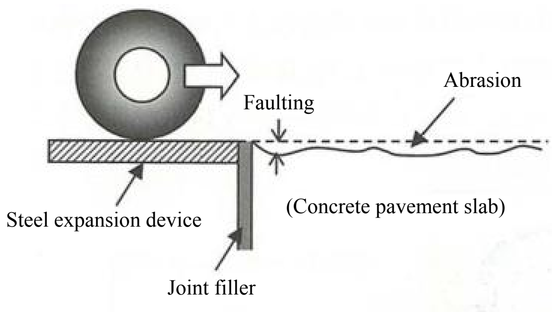


4. The formed cavity induces faulting. The cavity may cause tensile stress on the leave slab's surface, resulting in cracking. Thus, whenever faulting occurs, leave slabs will always sink.

Appendix Figure-5.2.10: Process of occurrence of faulting at joints and in cracking portions of concrete pavement slabs

(2) Faulting between slabs and their adjacent structures

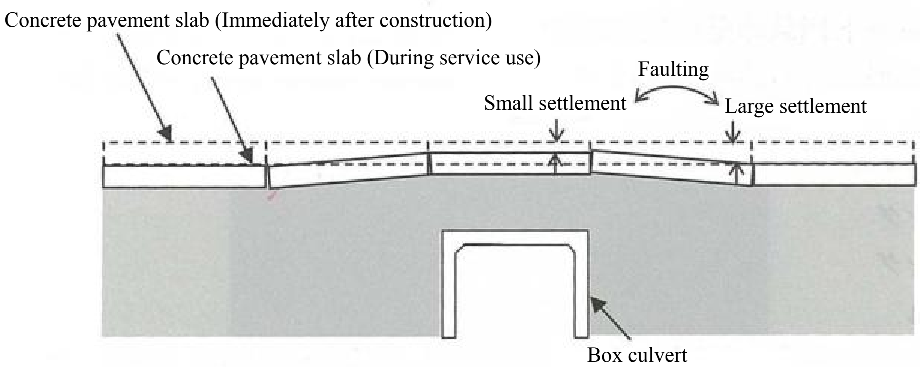
Faulting between slabs and their adjacent structures is caused mainly by differences in abrasion resistance. **Appendix Figure-5.2.11** illustrates faulting between an expansion device for bridges and a concrete pavement slab.



Appendix Figure-5.2.11: Faulting between an expansion device for bridges and a concrete pavement slab

(3) Faulting due to buried structures

Non-uniform compaction around buried structures, differences in the stiffness of pavement containing buried structures, and similar factors contribute to differential settlement of foundations, which is the cause of faulting due to buried structures. **Appendix Figure-5.2.12** illustrates faulting occurring on concrete pavement slabs in the case in which a box culvert runs below the pavement.



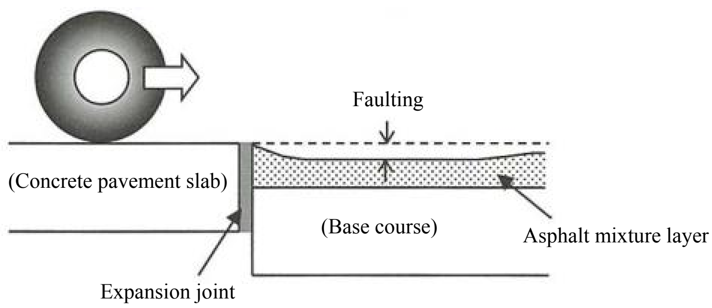
Appendix Figure-5.2.12: Faulting occurring on concrete pavement slabs over a box culvert

(4) Faulting formed at joints between slabs and asphalt pavement

Appendix Photograph-5.2.17 shows a typical case of faulting formed at a joint between a concrete pavement slab and asphalt pavement.

Appendix Photograph-5.2.17: Faulting formed at a joint between a concrete pavement slab and asphalt pavement

Faulting formed at joints between slabs and asphalt pavement often occurs in response to flows and consolidation of asphalt mixture under high temperatures. **Appendix Figure-5.2.13** illustrates faulting formed at joints between slabs and asphalt pavement. Once asphalt mixture has developed plastic deformation due to flows or consolidation, deformed portions receive impact loads from vehicles; thus, faulting tends to become larger spontaneously.



Appendix Figure-5.2.13: Faulting formed at a joint between a slab and asphalt pavement

2-4 Other types of damage to concrete pavement

This section outlines the following four other types of damage to concrete pavement.

- Rutting
- Potholes
- Scaling
- Polishing

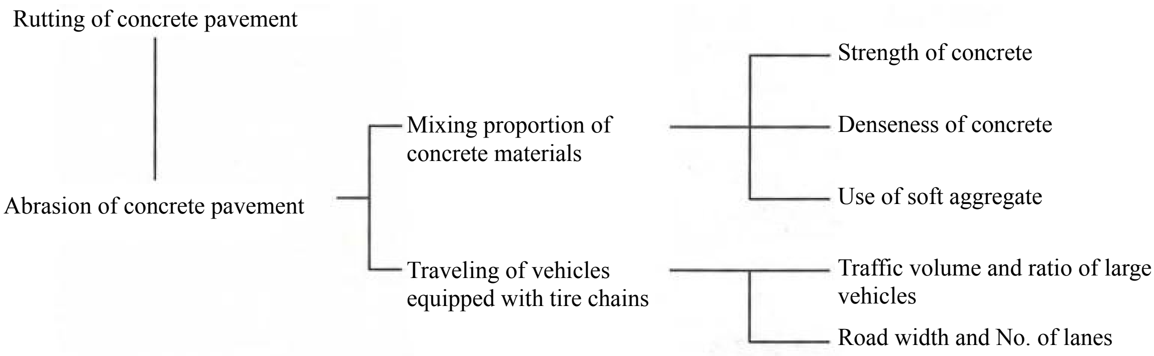
(1) Rutting

Rutting of concrete pavement occurs as continuous transverse irregularities in wheel paths (**Appendix Photograph-5.2.18**). When developing, rutting may adversely affect traveling performance, safety, and ride quality for vehicles as well as deteriorate roadside environments by generating vibrations and noise.

Appendix Photograph-5.2.18: Rutting of a concrete pavement slab

Most rutting of concrete pavement is abrasion rutting, which is caused by abrasion due to the traveling of vehicles equipped with tire chains. Abrasion rutting occurs when coarse aggregate is abraded after surface mortar has been stripped away. Before the use of spike tires was prohibited, large rutting as deep as several centimeters or more was often observed (**Appendix Photograph-5.2.18**). These days, rutting of concrete pavement is rarely seen.

Appendix Figure-5.2.14 lists the factors responsible for rutting of concrete pavement, the primary cause of which is abrasion due to traveling of vehicles equipped with tire chains, though the mixing proportion of concrete materials and the simultaneous action of multiple factors are also thought to contribute.



Appendix Figure-5.2.14: Rutting factors for concrete pavement

(2) Potholes

Potholes on concrete pavement refer to small holes 10 to 100 cm in diameter that are formed atop the surface of concrete pavement (**Appendix Photograph-5.2.19**).

Appendix Photograph-5.2.19: Pothole

Causes of potholes on concrete pavement include local material segregation, use of low-quality coarse aggregate that expands when absorbing moisture, and the presence of woodchips or other foreign materials from construction.

(3) Scaling

Scaling of concrete pavement refers to stripping of mortar from slab surfaces. Serious scaling may adversely affect traveling performance, safety, and ride quality for vehicles as well as deteriorate roadside environments by generating vibrations and noise.

Scaling occurs as a result of insufficient hardening of concrete slab surfaces or initial frost damage to them (**Appendix Photograph-5.2.20**). It also sometimes occurs due to freezing or thawing during service use, application of snow melting agents, insufficient containment of air in concrete, and other causes (**Appendix Photograph-5.2.21**).

Appendix Photograph-5.2.20:
Scaling due to initial frost damage

Appendix Photograph-5.2.21:
Scaling due to freezing and thawing

(4) Polishing (decreased skid resistance)

Polishing is a phenomenon in which surfaces finished by surface texturing are damaged by being polished. Polishing decreases the skid resistance of concrete pavement slabs (**Appendix Photograph-5.2.22**).

Appendix Photograph-5.2.22: Polishing

Polishing of concrete pavement occurs, for example, when surface texture is lost or when exposed soft aggregate is polished under the action of ordinary traveling of vehicles as well as the traveling of vehicles equipped with tire chains.

Appendix 6 Road Classifications and Pavement Design

1 Road classifications

Roads in Japan are classified into four types, each of which is further classified into several classes, depending on factors such as whether they are national expressways, motorways or other roads, the areas in which they are located, topographical situations, and designed daily volume, in accordance with the Government Order on Road Design Standards. Those types and classes are Type 1 Classes 1 to 4, Type 2 Classes 1 and 2, Type 3 Classes 1 to 5, and Type 4 Classes 1 to 4. The Government Order on Road Design Standards specifies design speeds, access control, designed daily volumes, and other conditions on roads (**Appendix Table-6.1.1**). The Government Order on Road Design Standards also specifies other matters related to road structures, such as road widths, central strip widths, and road shoulder widths.

Appendix Table-6.1.1: System of classification of road types and classes created from 1)

<table>
<tr><th rowspan="2"></th><th rowspan="2">Area</th><th rowspan="2">Type</th><th rowspan="2">Class</th><th rowspan="2" colspan="2">Design speed (km/h)</th><th rowspan="2">Access control</th><th colspan="4">Designed daily volume (vehicles/day)</th><th rowspan="2">Remarks</th></tr>
<tr><th>30,000 or more</th><th>20,000– 29,999</th><th>10,000– 19,999</th><th>Less than 10,000</th></tr>
<tr><td rowspan="9">National expressways and motorways</td><td rowspan="7">Rural area</td><td rowspan="7">Type 1</td><td>Class 1</td><td>120</td><td>100</td><td>F</td><td>Expressway on flatland</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Class 2</td><td rowspan="2">100</td><td rowspan="2">80</td><td rowspan="2">F•P</td><td>Expressway on mountain land</td><td colspan="2">Expressway on flatland</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="2">Motorway on flatland</td><td></td></tr>
<tr><td rowspan="2">Class 3</td><td rowspan="2">80</td><td rowspan="2">60</td><td rowspan="2">F•P</td><td></td><td colspan="2">Expressway on mountain land</td><td>Expressway on flatland</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Motorway on flatland</td><td colspan="2">Motorway on flatland</td></tr>
<tr><td rowspan="2">Class 4</td><td rowspan="2">60</td><td rowspan="2">50</td><td rowspan="2">F•P</td><td rowspan="2"></td><td rowspan="2"></td><td></td><td>Expressway on mountain land</td><td rowspan="2">Only 60 for the design speed of expressways</td></tr>
<tr><td colspan="2">Motorway on mountain land</td></tr>
<tr><td rowspan="2">Urban area</td><td rowspan="2">Type 2</td><td>Class 1</td><td>80</td><td>60</td><td>F</td><td colspan="4">Expressway and motorway in areas other than city centers</td><td></td></tr>
<tr><td>Class 2</td><td>60</td><td>50
40</td><td>F</td><td colspan="4">Motorway in city centers</td><td></td></tr>
</table>

<table>
<tr><th rowspan="2"></th><th rowspan="2">Area</th><th rowspan="2">Type</th><th rowspan="2">Class</th><th rowspan="2" colspan="2">Design speed (km/h)</th><th rowspan="2">Access control</th><th colspan="6">Designed daily volume (vehicles/day)</th><th rowspan="2">Remarks</th></tr>
<tr><th>20,000 or more</th><th>10,000–19,999</th><th>4,000–9,999</th><th>1,500–3,999</th><th>500–1,499</th><th>Less than 500</th></tr>
<tr><td rowspan="15">Other roads</td><td rowspan="8">Rural area</td><td rowspan="8">Type 3</td><td>Class 1</td><td>80</td><td>60</td><td>P•N</td><td>National road on flatland</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Class 2</td><td rowspan="2">60</td><td rowspan="2">50
40</td><td rowspan="2">P•N</td><td>National road on mountain land</td><td colspan="2">National road on flatland</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="3">Prefectural or city road on flatland</td></tr>
<tr><td rowspan="2">Class 3</td><td rowspan="2">60
50
40</td><td rowspan="2">30</td><td rowspan="2">N</td><td></td><td colspan="2">National road on mountain land</td><td colspan="3">National or prefectural road on flatland</td><td rowspan="2"></td></tr>
<tr><td colspan="3">Prefectural or city road on mountain land</td><td>City road on flatland</td><td></td><td></td></tr>
<tr><td rowspan="2">Class 4</td><td rowspan="2">50
40
30</td><td rowspan="2">20</td><td rowspan="2">N</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="3">National or prefectural road on mountain land</td><td rowspan="2"></td></tr>
<tr><td>City road on mountain land</td><td>City road on flatland or mountain land</td><td></td></tr>
<tr><td>Class 5</td><td>40
30
20</td><td>-</td><td>N</td><td></td><td></td><td></td><td></td><td></td><td>City road on flatland or mountain land</td><td></td></tr>
<tr><td rowspan="7">Urban area</td><td rowspan="7">Type 4</td><td rowspan="2">Class 1</td><td rowspan="2">60</td><td rowspan="2">50
40</td><td rowspan="2">P•N</td><td colspan="3">National road</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="2">Prefectural or city road</td><td></td></tr>
<tr><td rowspan="2">Class 2</td><td rowspan="2">60
50
40</td><td rowspan="2">30</td><td rowspan="2">N</td><td rowspan="2"></td><td rowspan="2"></td><td></td><td colspan="3">National road</td><td rowspan="2"></td></tr>
<tr><td>Prefectural or city road</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Class 3</td><td rowspan="2">50
40
30</td><td rowspan="2">20</td><td rowspan="2">N</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="3">Prefectural road</td><td rowspan="2"></td></tr>
<tr><td colspan="2">City road</td><td></td></tr>
<tr><td>Class 4</td><td>40
30
20</td><td>-</td><td>N</td><td></td><td></td><td></td><td></td><td></td><td>City road</td><td></td></tr>
</table>

[Note 1] Terms used in this table have the following meanings.
Expressway: National expressway; Motorway: Motorways other than national expressways
National road: General national road; Prefectural road: Road managed by a prefecture; City road: Road managed by a city, town, or village
Flatland: Flatland area; Mountain land: mountainous area; City center: Central area of a large city
F: Full access control; P: Partial access control; N: No access control

[Note 2] The design speed values indicated to the right of the Design speed column will be applied only in cases where there is no other choice due to the topography or some other situation.

[Note 3] The designed daily volume refers to the daily traffic volume of vehicles expected on the road to be planned or designed. It is different from the designed daily volume for pavement.

[Note 4] A class immediately lower than the relevant class can be applied in cases where there is no other choice due to the topography or some other situation.

2 Pavement design

In pavement design, pavement structure is concretely specified so that the set values of pavement performance indices will be satisfied. Necessary conditions must be clearly specified in the design. Therefore, it is necessary to sufficiently understand and grasp design considerations, such as the structure and roles of the pavement and the design workflow.

In pavement design, appropriate pavement performance is specified by considering environmental preservation and improvement and other factors on the basis of road surveys and areas along the road. Pavement is designed such that its performance will be maintained throughout the design period. In this process, it is best to consider viewpoints unique to pavement, such as lifecycle cost and use of recycled resources, and when needed, external factors such as policies on the management of structures associated with lifelines. Pavement design consists basically of road surface design and structural design.

Road surface design is performed to ensure that the road surface has the required performance, such as surface roughness, plastic deformation resistance, and water permeability, to deliver a safe, smooth, and comfortable road with excellent driveability and environmental preservation and improvement effects.

Structural design is performed to determine the pavement structure and the thickness of each layer mainly to ensure fatigue failure resistance for the required design period. There are both empirical and theoretical structural design methods focusing on fatigue failure resistance. Either type of design method can be chosen. Empirical structural pavement design is basically performed by converting the daily traffic volume of large vehicles in each direction to the traffic volume of 49-kN equivalent wheel loads. Actual wheel loads are converted to 49-kN equivalent wheel loads by using a biquadratic law. According to this law, which is based on the outcome of the AASHO Road Test [2), 3)], damage to pavement due to load transfer exponentially increases in proportion to the biquadrate of the ratio between the wheel load and the standard load.

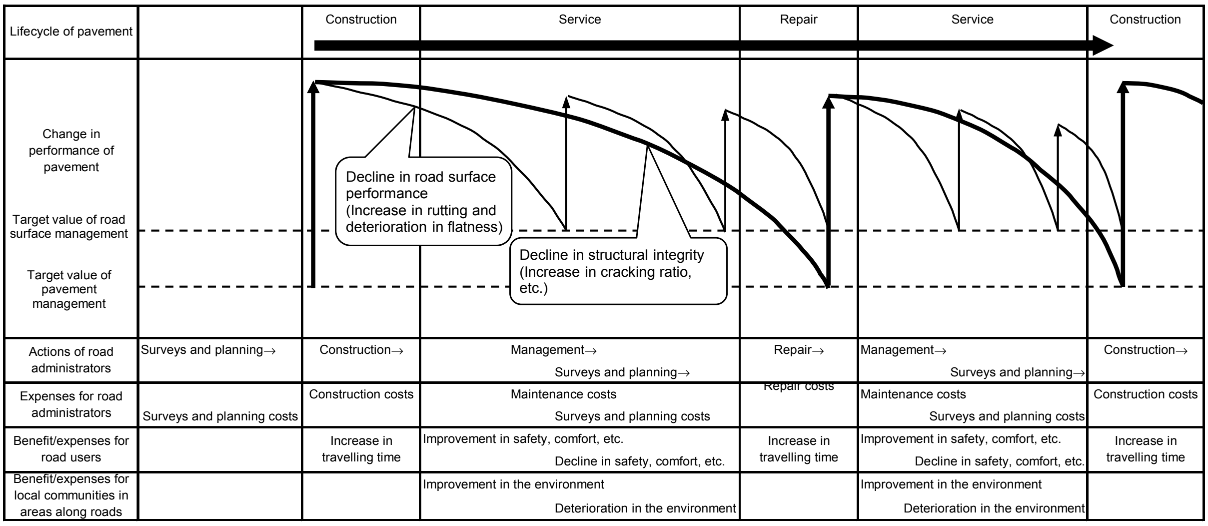
Theoretical design methods are performed on the basis of the multilayer elasticity theory. Since the methods apply fracture criteria related to serviceability (experience) by theoretically performing dynamic analysis on the behavior of pavement varying depending on the traffic load, they are also called dynamic empirical design methods. Thus, empirical methods and theoretical design methods are available for structural pavement design. However, an empirical method is generally applied.

The following sections overview design conditions, performance indices, and an empirical design method (the T_A method) that are applied to pavement in Japan.

2-1 Design period

The design period for pavement is determined by a road administrator with comprehensive consideration given to factors such as the cost of construction and management of the relevant pavement, the impacts of construction on road traffic and the relevant area, and the on-road construction plan.

Ten years had been applied as the design period for asphalt pavement, and 20 years had been applied for concrete pavement. However, since the technical standards on pavement structure were established in response to the 2001 revision of the Government Order on Road Design Standards, the design period has not been uniformly specified, but the optimum design period has been determined from the perspective of lifecycle cost. The lifecycle cost consists of three factors: expenses for road administrators, expenses for road users (benefit), and expenses for local communities in areas along roads (benefit). **Appendix Figure-6.2.1** illustrates the concepts of the lifecycle and lifecycle cost of pavement.



Appendix Figure-6.2.1: Concepts of the lifecycle and lifecycle cost of pavement [1)]

2-2 Designed daily volume for pavement

The designed daily volume for pavement is the average traffic volume of large vehicles passing on pavement during its design period. It is different from the designed daily volume, which is defined as the traffic volume of vehicles expected for the final fiscal year of the planned period for the road. For roads with only one or two lanes in each direction, the designed daily volume for pavement is calculated on the assumption that large vehicles (classified as buses, general tracks, or special vehicles) passing in one direction on a given day all travel in one lane. For roads with three or more lanes in one direction, it is calculated on the assumption that 70 to 100% of large vehicles passing in each direction on a given day travel in one lane on the basis of the distribution of the traffic of large vehicles in each lane. The Ministry of Construction (the current Ministry of Land, Infrastructure, Transport and Tourism) performed vehicle weight surveys on national roads under their direct control across Japan. According to an analysis of the traffic volume ratio of each lane of multilane roads on the basis of the data of the above-mentioned surveys, 75% of the traffic volume of large vehicles and 93.6% of the number of 49-kN equivalent wheel loads concentrate in one lane of some two-lane roads. In contrast, the concentration of the traffic volume of large vehicles and that of the number of 49-kN equivalent wheel loads do not reach 70% in one lane of three-lane roads (**Appendix Table-6.2.1**). Therefore, measures to reduce traffic volume are not implemented for roads with two lanes in each direction, but measures to reduce the designed daily volume for pavement to a little over 70% of the traffic volume of large vehicles in each direction can be implemented on multilane roads with three lanes or more in each direction.

The daily traffic volume of large vehicles in each direction is determined by a road administrator with consideration given to designed daily volume on the relevant road, the trend of future development of the area, the future situation of traffic volume, and other factors.

Appendix Table-6.2.1: Traffic volume ratio between the lanes of multilane roads [4)]

Item	Two-lane road				Three-lane road					
	Ratio of traffic volume of large vehicles (%)		Ratio of the number of 49-kN equivalent wheel loads (%)		Ratio of traffic volume of large vehicles (%)			Ratio of the number of 49-kN equivalent wheel loads (%)		
	First lane	Second lane	First lane	Second lane	First lane	Second lane	Third lane	First lane	Second lane	Third lane
Average X	50.8	49.2	60.2	39.8	17.4	45.8	36.8	14.5	49.1	36.4
Standard deviation σ	11.3	11.3	17.9	17.9	7.74	4.3	11.5	13.5	9.5	15.6
Maximum	78.0	75.8	96.3	81.6	35.8	59.1	46.0	47.1	64.7	62.1
Minimum	24.2	22.0	18.4	3.7	10.0	41.0	12.9	2.6	30.9	6.5
Number of data	142				32					

Note) Lanes are called the first, second, and third lanes from the sidewalk.

2-3 Setting pavement performance indices

Before designing pavement, pavement performance indices and their values are determined by considering factors such as the geological and meteorological conditions of that area of the road, its traffic, and the situation of land use in areas along the road. The values of pavement performance indices are determined in principle as values for the condition required immediately after construction. If performance cannot be sufficiently confirmed with such values, values for the condition required after a certain period of time from the start of service operation are used on an as-needed basis.

2-3-1 Pavement performance indices

Pavement performance indices for driveways and marginal strips are classified into essential performance indices, the performance indices of pavement with a structure allowing rainwater to readily flow through the road surface, and performance indices defined as needed.

(1) Essential performance indices

Essential performance indices are the number of wheel passes causing fatigue failure, the number of wheel passes causing plastic deformation, and surface roughness.

(2) Performance indices of pavement with a structure allowing rainwater to readily flow through the road surface

When pavement has a structure allowing rainwater to readily flow through the road surface, its performance indices include the amount of seepage water in addition to the indices listed in (1).

(3) Performance indices defined as needed

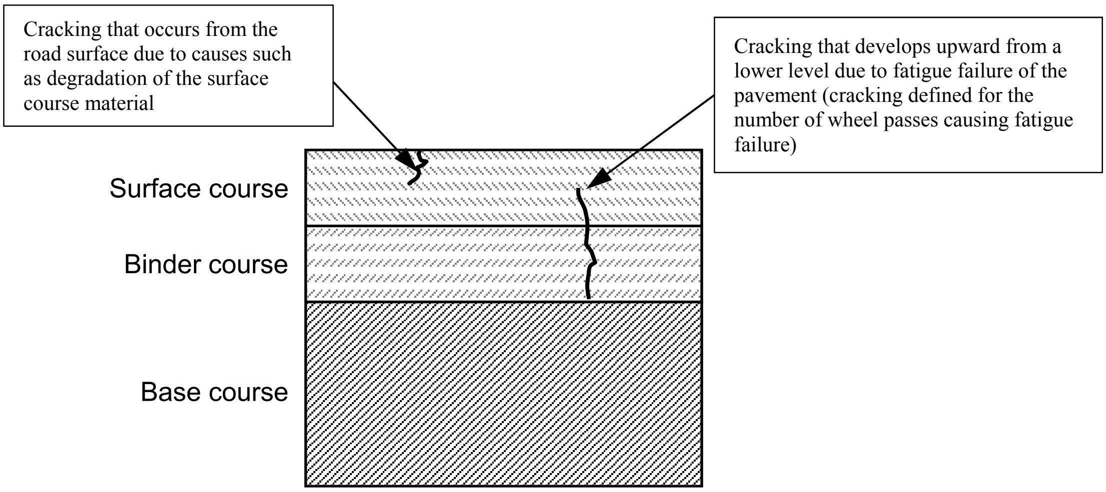
In addition to the pavement performance indices defined in (1) and (2), other performance indices are used from the perspectives of performance, such as skid resistance, resistance to aggregate scattering, abrasion resistance, and noise reduction, on an as-needed basis.

2-3-2 Reference values of pavement performance indices

(1) Essential performance indices

1) Number of wheel passes causing fatigue failure

The number of wheel passes causing fatigue failure is the number of 49-kN wheel loads that are repeatedly exerted on a paved road surface until cracking caused by fatigue failure first occurs on the pavement. This number is specified for each section in which each layer is made of the same material with the same thickness. The cracking defined for the number of wheel passes causing fatigue failure is cracking that develops upward from a lower level due to traffic loads exerted on the road surface. It is distinguished from cracking that occurs from the road surface due to causes such as degradation of the surface course material (**Appendix Figure-6.2.2**).



Appendix Figure-6.2.2: Concept of cracking created from 4)

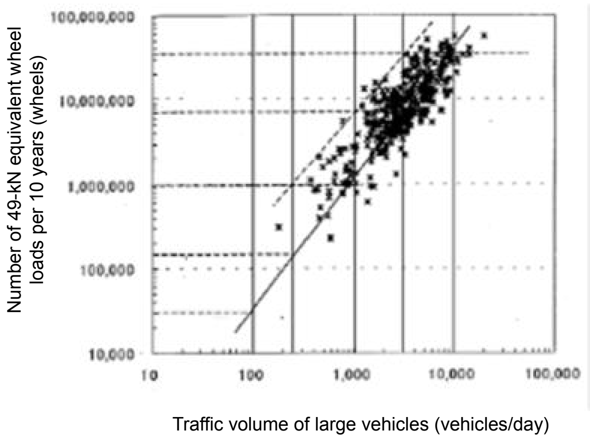
The number of wheel passes causing fatigue failure (standard load: 49-kN) for the condition required immediately after construction is set to be greater than or equal to a value shown in **Appendix Table-6.2.2** depending on the designed daily volume for pavement. When the design period for the pavement is not 10 years, this number must be greater than or equal to the value obtained by multiplying the corresponding number of wheel passes causing fatigue failure shown in the table by the proportion corresponding to 10 years of the relevant design period. The number of wheel passes causing fatigue failure may be set regardless of the values listed in **Appendix Table-6.2.2** when pavement delivers load capacity in conjunction with other structures as seen in pavement on bridges and elevated roads, pavement in tunnels, and pavement on other types of roads with similar structures.

Appendix Table-6.2.2 Reference values for the number of wheel passes causing fatigue failure [1)]

Traffic volume class	Designed daily volume for pavement (Unit: vehicles/day per direction)	Number of wheel passes causing fatigue failure (Unit: times/10 years)
N_7	3,000 or more	35,000,000
N_6	1,000–2,999	7,000,000
N_5	250–999	1,000,000
N_4	100–249	150,000
N_3	40–99	30,000
N_2	15–39	7,000
N_1	0–14	1,500

The relationship between the traffic volume of large vehicles and the number of 49-kN equivalent wheel loads is shown as a solid line in **Appendix Figure-6.2.3**. The average number of wheel loads at the upper limit of the traffic volume in each traffic volume class is used as the typical number of wheel loads corresponding to each traffic volume.

The number of 49-kN equivalent wheel loads is calculated from measured wheel loads by using the biquadratic law.



Appendix Figure-6.2.3 Relationship between the traffic volume of large vehicles and the number of 49-kN equivalent wheel loads [4)]

2) Number of wheel passes causing plastic deformation

The number of wheel passes causing plastic deformation is the number of 49-kN wheel loads that are repeatedly exerted on a paved road surface with a surface course temperature of 60°C until the paved road surface first develops 1-mm downward displacement. This number is specified for each section in which the pavement surface course is made of the same material with the same thickness. It is an index for evaluating the resistance of asphalt mixture to flow rutting. However, it is not used to evaluate rutting caused by abrasion and the settlement of lower layers, such as base and binder courses.

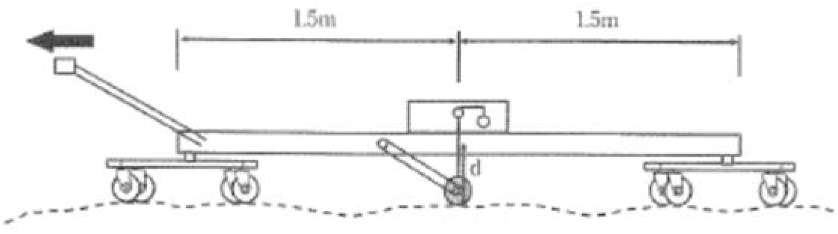
The number of wheel passes causing plastic deformation for the condition required immediately after construction is determined to be greater than or equal to one of the values shown in **Appendix Table-6.2.3** depending on the road classification and the designed daily volume for pavement. However, the number of wheel passes causing plastic deformation may be set to a value other than that determined by this method in cases where the road is in a snowy region, in cases where construction is scheduled for the road in the near future, or in other cases where such a setting is absolutely necessary for a special reason.

Appendix Table-6.2.3: Reference values for the number of wheel passes causing plastic deformation (standard load: 49-kN) [4)]

Classification	Designed daily volume for pavement (Unit: vehicles/day per direction)	Number of wheel passes causing plastic deformation (Unit: times/mm)
Type 1, Type 2, Type 3 Classes 1 & 2, and Type 4 Class 1	3,000 or more	3,000
	Less than 3,000	1,500
Other		500

3) Surface roughness

Surface roughness is specified for each section in which the pavement surface course is made of the same material with the same thickness. Surface roughness for the condition required immediately after construction must be appropriately set to be less than or equal to 2.4 mm by considering conditions such as the requirements for environmental preservation in areas along the road (vibration and noise). Surface roughness is the standard deviation σ of the height difference from the postulated paved flat road surface with respect to its average. The data necessary for calculating surface roughness can be obtained by measuring the height difference from a virtual road surface located at an arbitrary distance from the postulated paved flat road surface (**Appendix Figure-6.2.4**). Surface roughness is calculated by measuring the height difference from a virtual road surface located at an arbitrary distance from the postulated paved flat road surface, generally at 1.5 m intervals.



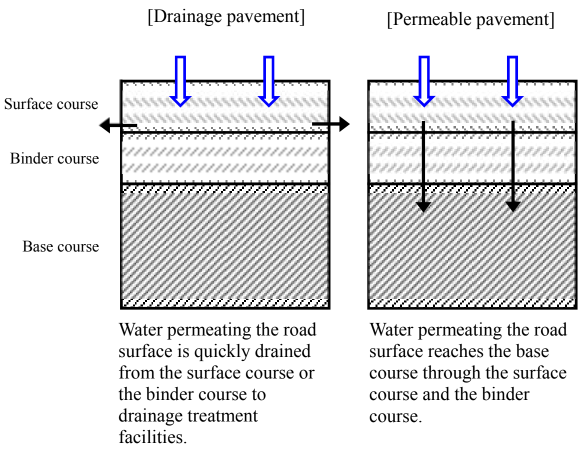
Appendix Figure-6.2.4: Concept of surface roughness (height difference between a virtual road surface located at an arbitrary distance from the postulated paved flat road surface and the paved road surface) [5)]

4) Amount of seepage water (when pavement is to have a structure allowing rainwater to readily flow through the road surface)

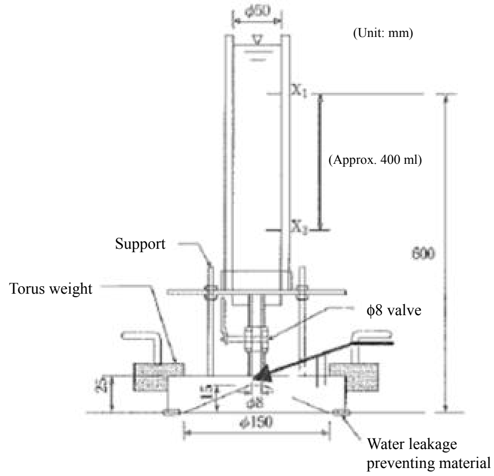
The amount of seepage water is specified for each section in which the pavement surface course is made of the same material with the same thickness. When a pavement structure allowing rainwater to flow through the road surface, such as drainage pavement and permeable pavement, is selected (**Appendix Figure-6.2.5**), the amount of seepage water for the condition required immediately after construction is determined to be a value greater than or equal to the corresponding value shown in **Appendix Table-6.2.4** depending on the road classification. However, the amount of seepage water may be set to a value other than that determined by this method in cases where the road is in a snowy region, in cases where construction is scheduled for the road in the near future, or in other cases where such a setting is absolutely necessary for a special reason. The amount of seepage water is measured with the field permeability tester illustrated in **Appendix Figure-6.2.6**.

Appendix Table-6.2.4: Reference values for the amount of seepage water [4)]

Classification	Amount of seepage water (Unit: ml/15 s)
Type 1, Type 2, Type 3 Classes 1 & 2, and Type 4 Class 1	1,000
Other	300



Appendix Figure-6.2.5: Pavement structure allowing water to flow through the paved road surface into pavement created from 4)



Appendix Figure-6.2.6: Field water permeability tester 4)

(2) Performance indices defined as needed

Pavement performance indices and their values, such as noise value and skid resistance value, are set by referring to actual measurement examples, etc. with consideration given to factors such as the purpose and applications of the pavement. **Appendix Figure-6.2.7** lists examples of pavement performance indices.

Functions of road surfaces Performance of pavement	Specific needs for road surfaces Specific needs for pavement	Requirements for road surfaces Requirements for pavement		Performance of pavement	Pavement indices
Ensuring of safe travel	Stopping within the visible distance by braking	No skidding		Skid resistance	Skid resistance value
	High vehicle Driveability	Reducing rutting	Abrasion resistance	Plastic deformation resistance	Number of wheel passes causing plastic deformation
				Abrasion resistance	Abrasion loss
	No hydroplaning			Resistance to aggregate scattering in cold regions	Impact aggregate scattering value
	No water splashing			Resistance to aggregate scattering at intersections	Torsional aggregate scattering value
	High visibility of road surfaces	Bright		Light coloration	Road surface lightness
	No skidding accidents	Resistance to freezing		Easy ice sheet separation	Adfreezing tensile strength
Ensuring of smooth travel	No fatigue failure	No cracking		Fatigue failure resistance	Number of wheel passes causing fatigue failure
Ensuring of comfortable travel	Good ride quality	Smooth road surface		Surface roughness	Surface roughness
	No damage to loads				
	No water splashing	Water-permeable		Water permeability	Amount of seepage water
Environmental preservation and improvement	No water splashing to roadsides, etc.				
	Replenishing underground water				Maximum outflow ratio
	Reducing (suppressing) city flooding				
	Reducing noise	Low noise		Noise reduction	Noise value
	Reducing vibration	Low vibration		Vibration reduction	Vibration level reduction value
	Suppressing the rise of road surface temperatures	Low road surface temperature		Surface temperature reduction	Road surface temperature reduction value
	Reducing CO_2 emissions	Low CO_2 emissions		Reduction of CO_2 emissions	CO_2 emissions reduction value

Appendix Figure-6.2.7: Examples of pavement performance indices 6)

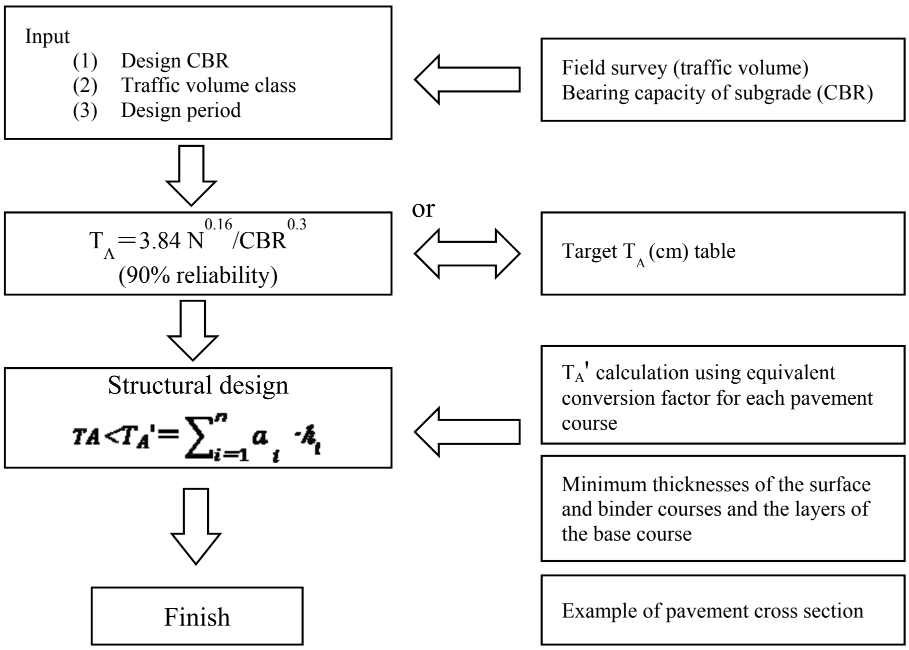
2-4 Designing pavement thickness by using the T_A method

The T_A method is an empirical design method. In the T_A method, the necessary equivalent thickness of asphalt pavement is determined from the design CBR of the subgrade and designed daily volume for pavement, and the material and thickness of each layer is appropriately determined to satisfy the necessary equivalent thickness.

This process uses an equation that was formulated by analyzing the weighted values of the pavement thickness index and traffic loads of the AASHO Road Test data with consideration given to damage data on actual national roads in Japan [7), 8)]. Pavement is basically designed by converting the daily traffic volume of large vehicles (separately in each direction) to the traffic volume of 49-kN wheel loads.

(1) Procedure of the T_A method

Appendix Figure-6.2.8 illustrates the procedure of the T_A method.



Appendix Figure-6.2.8: Procedure of the T_A method

a. Setting input items

Design CBR, the traffic volume class (or designed daily volume for pavement), and the design period for pavement are input. To determine these items, a field survey of the traffic volume and a survey on the bearing capacity of the subgrade are performed in some cases.

b. Calculating T_A

Pavement thickness can be calculated from the number of wheel passes causing fatigue failure (N) and the bearing capacity of the subgrade CBR (design CBR) by using an equation for calculating T_A (required equivalent thickness). In the equations for calculating T_A, different coefficients are used according to their reliability. The details of the equations are described in (2) Basic equations.

Appendix Tables-6.2.5 to **6.2.7** show examples of T_A (cm) calculation, clarifying the relationship between the design CBR of the subgrade and T_A separately for different reliability values. T_A can be determined by using the T_A tables without performing the calculation.

c. Structural design

Pavement structure is determined by referring to cross sections that have been used many times with good results and by calculating T_A' (the equivalent thickness of the determined pavement cross section) from the equivalent conversion factor (ai) and thickness (hi) of each layer. The pavement structure must be set in such a manner that this T_A' will not be lower than T_A. In addition, the minimum thicknesses of the surface and binder courses and the minimum thickness of each layer of the base course must be ensured. The details of these calculation methods and minimum thicknesses are described in (5) Method for determining pavement structure.

(2) Basic equations

Required equivalent thickness (T_A) is expressed by three different equations according to reliability. This reliability has the following meaning as an example: 90% reliability means that 90% of all road segments take longer than the design period for a failure to occur. The basic equation corresponding to 75% reliability and that corresponding to 50% reliability are **Appendix Equations-6.2.2** and **6.2.3**, respectively. The reference values for the number of wheel passes causing fatigue failure listed in **Appendix Table-6.2.2** can substitute as representative values for the accumulated number of 49-kN equivalent wheel loads (N) used in these equations.

90% reliability: $$T_A = \frac{3.84N^{0.16}}{CBR^{0.3}}$$ (**Appendix Equation-6.2.1**),

75% reliability: $$T_A = \frac{3.43N^{0.16}}{CBR^{0.3}}$$ (**Appendix Equation-6.2.2**), and

50% reliability: $$T_A = \frac{3.07N^{0.16}}{CBR^{0.3}}$$ (**Appendix Equation-6.2.3**),

Where T_A : Required equivalent thickness (cm)
N : Accumulated number of 49-kN equivalent wheel loads (number of wheel passes causing fatigue failure: times)
CBR : Design CBR of subgrade soil

Appendix Table-6.2.5: Example of calculated required equivalent thickness T_A (10-year design period and 90% reliability)

Traffic volume class	Designed daily volume for pavement (Unit: vehicles/day per direction)	Number of wheel passes causing fatigue failure (Unit: times/10 years)	Design CBR					
			3	4	6	8	12	20
N_7	3,000 or more	35,000,000	45	41	37	34	30	26
N_6	1,000–2,999	7,000,000	35	32	28	26	23	20
N_5	250–999	1,000,000	26	24	21	19	17	15
N_4	100–249	150,000	19	18	16	14	13	11
N_3	40–99	30,000	15	14	12	11	10*	9*
N_2	15–39	7,000	12	11	10*	9*	8*	7*
N_1	0–14	1,500	9*	9*	8*	7*	7*	7*

* If T_A is less than 11, the minimum thickness may not be satisfied for some materials. Therefore, materials and construction methods must be carefully selected.

Appendix Table-6.2.6: Example of calculated required equivalent thickness T_A (10-year design period and 75% reliability)

Traffic volume class	Designed daily volume for pavement (Unit: vehicles/day per direction)	Number of wheel passes causing fatigue failure (Unit: times/10 years)	Design CBR					
			3	4	6	8	12	20
N_7	3,000 or more	35,000,000	40	37	33	30	27	23
N_6	1,000–2,999	7,000,000	31	29	25	23	21	18
N_5	250–999	1,000,000	23	21	19	17	15	13
N_4	100–249	150,000	17	16	14	13	11	10*
N_3	40–99	30,000	13	12	11	10*	9*	8*
N_2	15–39	7,000	11	10*	9*	8*	7*	7*
N_1	0–14	1,500	8*	8*	7*	7*	7*	7*

* If T_A is less than 11, the minimum thickness may not be satisfied for some materials. Therefore, materials and construction methods must be carefully selected.

Appendix Table-6.2.7: Example of calculated required equivalent thickness T_A (10-year design period and 50% reliability)

Traffic volume class	Designed daily volume for pavement (Unit: vehicles/day per direction)	Number of wheel passes causing fatigue failure (Unit: times/10 years)	Design CBR					
			3	4	6	8	12	20
N_7	3,000 or more	35,000,000	36	33	29	27	24	21
N_6	1,000–2,999	7,000,000	28	26	23	21	19	16
N_5	250–999	1,000,000	21	19	17	16	14	12
N_4	100–249	150,000	15	14	13	12	10*	9*
N_3	40–99	30,000	12	11	10*	9*	8*	7*
N_2	15–39	7,000	10*	9*	8*	7*	7*	7*
N_1	0–14	1,500	8*	7*	7*	7*	7*	7*

* If T_A is less than 11, the minimum thickness may not be satisfied for some materials. Therefore, materials and construction methods must be carefully selected.

(3) How to calculate the accumulated number of 49-kN equivalent wheel loads (the number of wheel passes causing fatigue failure)

In structural pavement design using the T_A method, the number of wheel passes causing fatigue failure is determined by referring to 2-3-2 (1) 1) Number of wheel passes causing fatigue failure. The values listed in **Appendix Table-6.2.2** can generally be used. However, when traffic volume during the design period and the corresponding wheel loads have been set or can be accurately forecast for the road, the number of wheel passes causing fatigue failure is calculated as the number of 49-kN wheel loads obtained by converting the traffic volume (in each direction) without using **Appendix Table-6.2.2**. This calculation is performed by using **Appendix Equations-6.2.6** and **6.2.7** as described below. As seen in **Appendix Table-6.2.8**, however, passenger vehicles with a 2.45-kN wheel load have an impact of less than 1/160,000 those of large vehicles with a 49-kN wheel load. Since the impact of passenger vehicles are thus very small, the designed daily volume for pavement is sometimes determined by only surveying the traffic volume of large vehicles without counting the number of travelling passenger vehicles.

Appendix Table-6.2.8: Conversion factors for axial loads (weight to wheel loads with respect to 49-kN wheel loads)

Wheel load (kN)	2.45	4.9	9.8	19.6	29.4	39.2	49	98
Conversion factor (weight)	6.25×10^{-6}	0.0001	0.0016	0.0256	0.1296	0.4096	1.0	16

To obtain the number of wheel passes causing fatigue failure, 49-kN equivalent wheel loads (N_{49}) per day and direction is first calculated by converting each wheel load measured on vehicles to the standard load (with respect to 49-kN) in accordance with the biquadratic law expressed in **Appendix Equation-6.2.6**.

$$N_{49}=\sum_{j=1}^{m}\left[\left(\frac{Pj}{49}\right)^{4}\times Nj\right] \qquad \textbf{(Appendix Equation-6.2.6)}$$

Next, the accumulated number of 49-kN equivalent wheel loads (N) during an n-year design period is calculated by using the following equation.

$$N=\sum_{i=1}^{n}(N_{49}\times 365\times ai) \qquad \textbf{(Appendix Equation-6.2.7)},$$

where
- N_{49} : Number of 49-kN equivalent wheel loads per day and direction,
- P_j : Representative value of the wheel load classified as the j-th largest wheel load,
- m : Number of classifications of the magnitude of wheel loads; j = 1 to m,
- N_j : Number of passages of P_j,
- N : Accumulated number of 49-kN equivalent wheel loads during the design period (required number of wheel passes causing fatigue failure),
- n : Design period (year), and
- a_i : Rate of elongation occurring with respect to N_{49} i years later; i = 1 to n.

(4) How to calculate design CBR

The section CBR and the design CBR are calculated on the basis of the result of the preliminary survey. In Japan, the CBR of the subgrade is evaluated in accordance with JIS A 1211. Specifically, a specimen is prepared by using a ϕ15-cm mold and separating it into three layers depending on natural water content under the condition of 67 falls/layer (with a 4.5-kg rammer from a height of 45 cm). A test is performed on the specimen at a penetration speed of 1.0 mm/min after it is immersed in water for four days in consideration of the influence of rainwater, etc.

a. When the subgrade consists of several different layers in the longitudinal direction, the CBR at that point is calculated by applying **Appendix Equation-6.2.4** to the CBR of each layer present between the subgrade surface and the level 1 m under the subgrade surface.

$$CBR_m=\left[\frac{h_1CBR_1^{1/3}+h_2CBR_2^{1/3}+\cdots h_nCBR_n^{1/3}}{h}\right]^3 \qquad \textbf{(Appendix Equation-6.2.8)},$$

where CBR_m : CBR at point m,
- CBR_1, CBR_2, ⋯, CBR_n : CBR of each layer at point m,
- h_1, h_2, ⋯, h_n, : Thickness (cm) of each layer at point m, and
- $h_1 + h_2 + \cdots + h_n = h$ (h= 100).

b. The pavement structure is not changed for a 200-m road traffic in principle, and the construction section is determined in such a manner that the pavement will have a uniform cross section. The CBR of this section is calculated by using **Appendix Equation-6.2.9**. If one CBR_m value is much larger or smaller than another CBR_m value in this section, the section CBR must be calculated by excluding the CBR_m value.

Section CBR = Average CBR_m at each point – Standard deviation of CBR_m at each point (σ_{n-1})
(**Appendix Equation-6.2.9**)

c. The design CBR is determined from the section CBR by referring to **Appendix Table-6.2.9**.

Appendix Table-6.2.9: Relationship between section CBR and design CBR

Section CBR	Design CBR
(2 or greater but less than 3)	(2)
3 or greater but less than 4	3
4 or greater but less than 6	4
6 or greater but less than 8	6
8 or greater but less than 12	8
12 or greater but less than 20	12
20 or greater	20

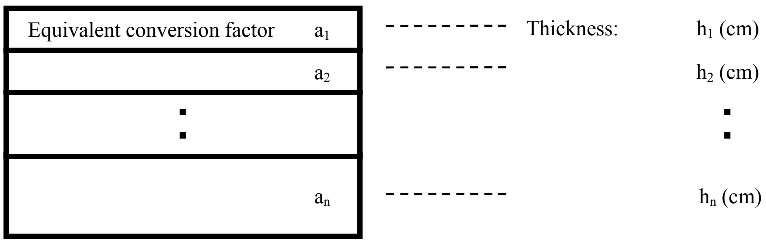
[Note] Values in the parentheses are applied if it is impossible to construct modified subgrade when the design CBR of the existing subgrade is 2 in construction, such as in replacement.

(5) Method for determining pavement structure

The pavement cross section is determined by referring to cross sections that have been used many times with good results, and the equivalent thickness of the determined pavement cross section (T_A') is calculated from the material and thickness of each layer. As shown in **Appendix Equation-6.2.6**, T_A' is the total sum of the product of the equivalent conversion factor corresponding to the material of each layer (ai) and the thickness of the layer (hi).

$$T_A' = \sum_{i=1}^{n} a_i \cdot h_i$$ (**Appendix Equation-6.2.10**),

where T_A' : Equivalent thickness of the determined pavement cross section (cm),
a_i : Equivalent conversion factor corresponding to the material and construction method of each layer (**Appendix Table-6.2.10**),
h_i : Thickness of each layer (cm), and
n : Number of layers.



Appendix Figure-6.2.9: Cross-sectional view of calculated pavement structure

An equivalent conversion factor is the value of a hot asphalt mixture thickness in centimeters that corresponds to 1 cm of the relevant layer of the pavement cross section in strength from the perspective of its material and construction method.

Appendix Table-6.2.10: Equivalent conversion factors corresponding to the materials and construction methods used for each layer

Relevant layer	Material and construction method	Quality standards	Equivalent conversion factor ai
Surface and binder courses	Hot asphalt mixture	Reference value for the Marshall stability test	1.00
Base course	Bituminous stabilization	Hot mixing: Stability of 3.43-kN or higher Cold mixing: Stability of 2.45-kN or higher	0.80 0.55
	Cement and bituminous stabilization	Uniaxial compressive strength (7 days): 1.5 to 2.9 MPa Primary displacement magnitude (7 days): 5 to 30 1/100 cm Residual strength rate (7 days): 65% or higher	0.65
	Cement stabilization	Uniaxial compressive strength (7 days): 2.9 MPa	0.55
	Lime soil stabilization	Uniaxial compressive strength (10 days): 0.98 MPa	0.45
	Crushed stone for mechanical stabilization and mechanically stabilized steel slag	Modified CBR: 80 or more	0.35
	Hydraulic mechanically stabilized steel slag	Modified CBR: 80 or more Uniaxial compressive strength (14 days): 1.2 MPa	0.55
Subbase course	Crusher-run, steel slag, sand, etc.	Modified CBR: 30 or more Modified CBR: 20 or more but less than 30	0.25 0.20
	Cement stabilization	Uniaxial compressive strength (7 days): 0.98 MPa	0.25
	Lime soil stabilization	Uniaxial compressive strength (10 days): 0.7 MPa	0.25

Pavement structure must be determined in such a manner that the calculated T_A' will not be smaller than the required equivalent conversion factor (T_A). In addition, the minimum values of the sum of the thicknesses of surface and binder courses listed in **Appendix Table-6.2.11** and the minimum thicknesses of base course layers listed in **Appendix Tables-6.2.12** and 6.2.13 must be satisfied.

Appendix Table-6.2.11: Minimum values of the sum of the thicknesses of surface and binder courses

Traffic volume class	Designed daily volume for pavement (Unit: vehicles/day per direction)	Minimum value of the sum of the thicknesses of surface and binder courses (cm)
N_7	3,000 or more	20 (15)
N_6	1,000–2,999	15 (10)
N_5	250–999	10 (5)
N_4	100–249	5
N_3	40–99	5
N_2	15–39	4 (3)
N_1	0–14	4 (3)

* The values in the parentheses are the minimum thicknesses that are applied when bituminous stabilization is performed on the base course.

Appendix Table-6.2.12: Minimum thicknesses of base course layers (Designed daily volume for pavement: 40 or more vehicles/day per direction)

Construction method and material	Minimum thickness of one layer
Bituminous stabilization (hot mixing) Other base course materials	Two times the maximum grain size, and 5 cm Three times the maximum grain size, and 10 cm

Appendix Table-6.2.13: Minimum thicknesses of base course layers (Designed daily volume for pavement: Less than 40 vehicles/day per direction)

Construction method and material	Minimum thickness of one layer
Crushed stone for mechanical stabilization and crusher-run	7 cm
Bituminous stabilization (cold mixing)	7 cm
Bituminous stabilization (hot mixing)	5 cm
Cement and bituminous stabilization	7 cm
Cement stabilization	12 cm
Lime soil stabilization	10 cm

(6) Example of pavement structure design

The following is an example of a procedure for determining pavement structure by the T_A method under the road conditions described below.

a. Setting input items

Design CBR and designed daily volume for pavement were obtained as shown in **Appendix Table-6.2.14** by a preliminary survey for determining pavement structure. The design period for pavement is 10 years.

Appendix Table-6.2.14: Example set values for determining pavement structure

Input item	Set value
Design CBR	8
Designed daily volume for pavement	Traffic volume of large vehicles: 1,800 vehicles/day per direction (N_6)
Design period	10 years

Since the actual traffic volume of large vehicles is 1,800 vehicles, the traffic volume class is N_6 (1,000–2,999). From **Appendix Table-6.2.2**, the corresponding number of wheel passes causing fatigue failure (N) is 7,000,000 times/10 years. A reliability of 90% is selected.

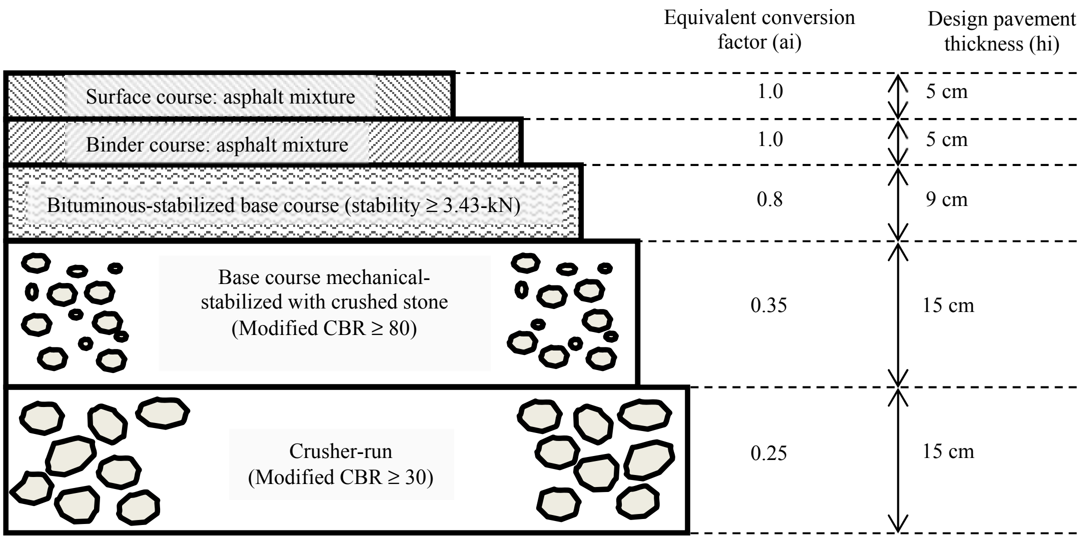
b. Calculating T_A

The value of T_A is calculated by substituting values listed in **Appendix Table-6.2.14** into **Appendix Equation-6.2.1**.

$$T_A = \frac{3.84 \times (7000000)^{0.16}}{(8)^{0.3}} = \frac{3.84 \times 12.5}{1.87} = 25.6 \cong 26$$

c. Structural design

Structural design is performed on the assumption of the pavement cross section illustrated in **Appendix Figure-6.2.10**. This cross section is formed by referring to cross sections that have been used successfully and the minimum values listed in **Appendix Tables-6.2.11 and 6.2.12**.



Appendix Figure-6.2.10: Example of design of pavement cross section

The equivalent conversion factor (T_A') of this pavement cross section is calculated by using **Appendix Equation-6.2.10**.

$$T_A' = 1.0 \times 5 + 1.0 \times 5 + 0.8 \times 9 + 0.35 \times 15 + 0.25 \times 15 = 26.2 > 26\ (T_A)$$

The value of T_A' calculated by using **Appendix Equation-6.2.10** is 26.2 cm, which exceeds 26 cm, the value of T_A calculated by using **Appendix Equation-6.2.1**. Therefore, the above-illustrated pavement structure can be used for the pavement material and pavement thickness of each layer. The actual structural design must be determined from the perspective of economy by comparing several design plans.

[References]

1) Japan Road Association: Pavement Design Handbook, February 2006 edition

2) HRB: The AASHO Road Test, Proc. Conference Held May16–18, 1962. HRB Special Report 73, 1962.

3) HRB: The AASHO Road Test, HRB Special Report 61A–61G, 1961–1962.

4) Japan Road Association: Technical Standards on Pavement Structure and Descriptions of the Standards, July 2001

5) Japan Road Association: Pavement Performance Evaluation Methods—Essential and Principal Performance Indices—, April 2013

6) Japan Road Association: Pavement Performance Evaluation Methods: Separate Volume—Methods for Evaluating Performance Indices Defined as Needed—, February 2006

7) Harumi Takeshita: Applications of Logarithmic Graphs of Asphalt Pavement, Doro (Roads), No. 295, September 1965

8) Yorimasa Abe: Approach to Structural Design of Asphalt Pavement, Asphalt, No. 113, November 1977

Appendix 7: Pavement Structure Evaluation with FWD

1 Overview of FWD

1-1 Outline

FWD (falling weight deflectometer) drops weights onto a loading plate to exert an impact load on a road surface and uses multiple sensors to measure the road surface deflection that occurs in response to the impact load. FWDs are classified into on-board FWDs (**Appendix Photograph-7.1.1**) and towed FWDs (**Appendix Photograph-7.1.2**).

FWD surveys allow the soundness of pavement to be evaluated on the basis of measured pavement deflection. Methods for evaluating the soundness of pavement are roughly classified into the following two types: (1) methods of determining the characteristic values of the layers of pavement by using an empirical formula, etc. and (2) methods of determining elastic moduli of the layers of pavement by performing inverse analysis.

Appendix Photograph-7.1.1: On-board FWD

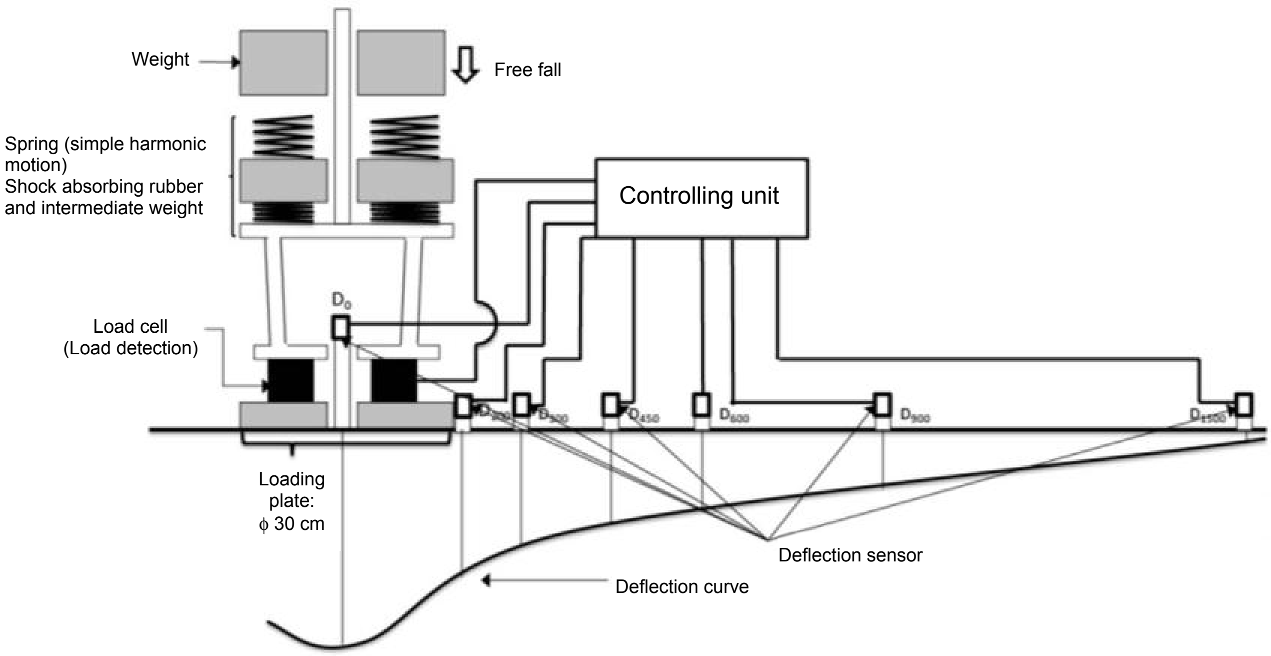
Appendix Photograph-7.1.2: Towed FWD

1-2 Basic structure

FWD consists of weights for exerting an impact load on a road surface and multiple deflection sensors for measuring road surface deflection. Measurement is computer controlled, and the impact load measured with a load cell and the deflection measured with the deflection sensors are recorded.

Appendix Figure-7.1.1 illustrates the basic structure of FWDs.

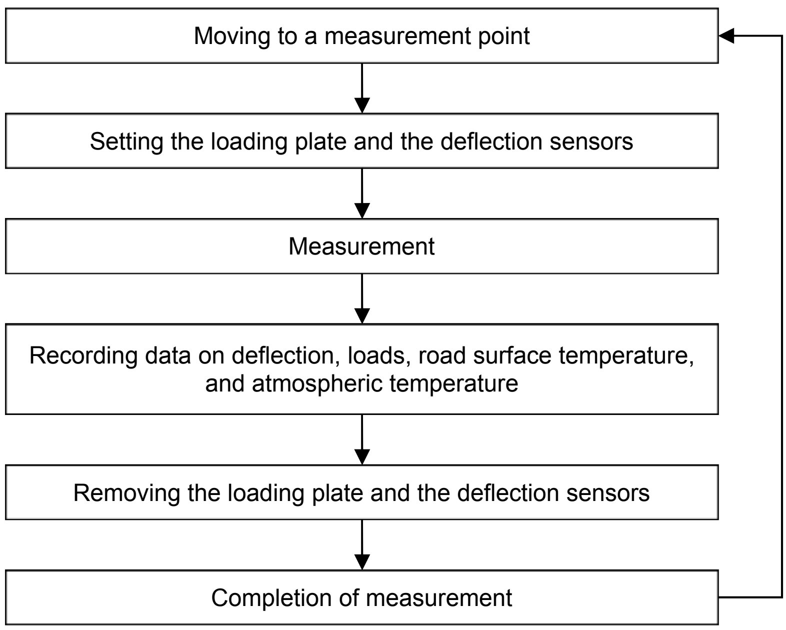
Sensors for measuring deflection are generally located at points 0, 20, 30, 45, 60, 90, and 150 cm away from the center of the loading plate. The deflection at each sensor is expressed with a symbol, such as D_0 and D_{150}.



Appendix Figure-7.1.1: Basic structure of FWDs

1-3 Procedure for measuring deflection

Pavement deflection measurement with FWD is performed in accordance with the workflow shown in **Appendix Figure-7.1.2**. In the measurement, a series of steps are repeated until the necessary amount of data has been obtained. The measuring time per point is 3 to 4 minutes. The series of steps performed after the FWD has moved to a measurement location (setting deflection sensors, dropping weights, measuring deflection, etc.) is automatically performed by computer control.



Appendix Figure-7.1.2: Procedure for measuring deflection with FWD

2 Use of measurement data

2-1 Asphalt pavement

2-1-1 Evaluation using empirical formulae, etc.

(1) Meaning of deflection

Among the amounts of deflection measured at sensor points, D_0, D_{20}, and D_{150} are important values for evaluating the structural soundness of pavement. **Appendix Table-7.2.1** lists the meanings of the measured deflection.

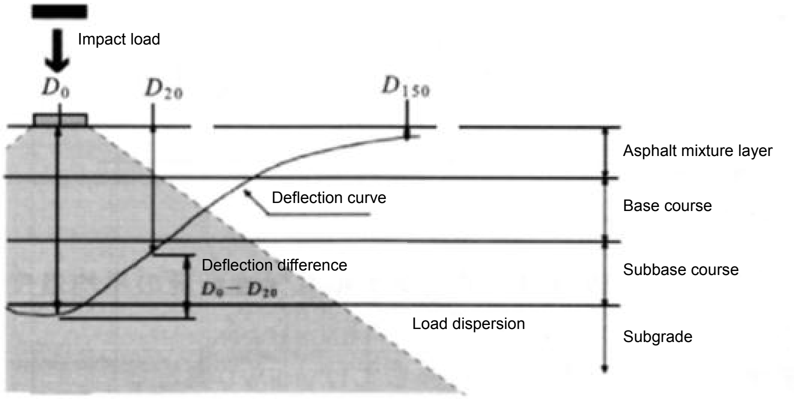
Note that calculation is performed using the deflections measured in response to an impact load of 49-kN.

Appendix Table-7.2.1: Meanings of deflection amounts for asphalt pavement

Deflection	Meaning
D_0	Represents the bearing capacity of the entire pavement including the subgrade. This value is used to determine whether to perform repair.
$D_0 - D_{150}$	Represents the bearing capacity of the pavement portion above the subgrade. Residual equivalent thickness T_{A0} can be determined by the following formula. $T_{A0} = -25.8\log\frac{D_0 - D_{150}}{10^3} + 11.1$, where T_{A0}: Residual equivalent thickness (cm), D_0: Deflection at the center of the loading plate (μm), and D_{150}: Deflection at a point 150 cm away from the center of the loading plate (μm).
$D_0 - D_{20}$	Represents the soundness of the asphalt mixture layer. The elastic modulus (E) of the asphalt mixture layer can be estimated by the following formula. $E = \frac{2352\left(\frac{D_0 - D_{20}}{10^3}\right)^{-1.25}}{h_1}$, where E: Elastic modulus of the asphalt mixture layer (MPa), D_0: Deflection at the center of the loading plate (μm), D_{20}: Deflection at a point 20 cm away from the center of the loading plate (μm), and h_1: Thickness of the asphalt mixture layer (cm).
D_{150}	Represents the bearing capacity of the subgrade. The CBR of the subgrade can be estimated by the following formula. $CBR = \frac{1000}{D_{150}}$, where CBR: CBR of the subgrade (%), and D_{150}: Deflection at a point 150 cm away from the center of the loading plate (μm).

An impact load exerted on the road surface by FWD is propagated in the direction of the pavement depth from the loading point. The load propagates within the pavement while dispersing in the shape of a cone.

Appendix Figure-7.2.1 [1] illustrates the expansion of the range affected by the impact load. According to this figure, D_0 immediately below the loading point, for example, is the sum of the deflection of all the layers. D_{20} is the sum of the deflection of the base course, and D_{150} represents the deflection of the subgrade. D_0 - D_{20} is the deflection obtained by subtracting the deflection of the base course and its lower layers from the deflection of all the layers of the pavement; in other words, it represents the deflection of the asphalt mixture layer. Similarly, D_0 - D_{150} represents the deflection of the portion above the subgrade.



Appendix Figure-7.2.1: Relationship between load dispersion and deflection measured with each sensor created from 1)

Deflection differs depending on exerted loads. Accordingly, deflection corresponding to the standard load (49-kN) is calculated by using **Appendix Equation-7.2.1**.

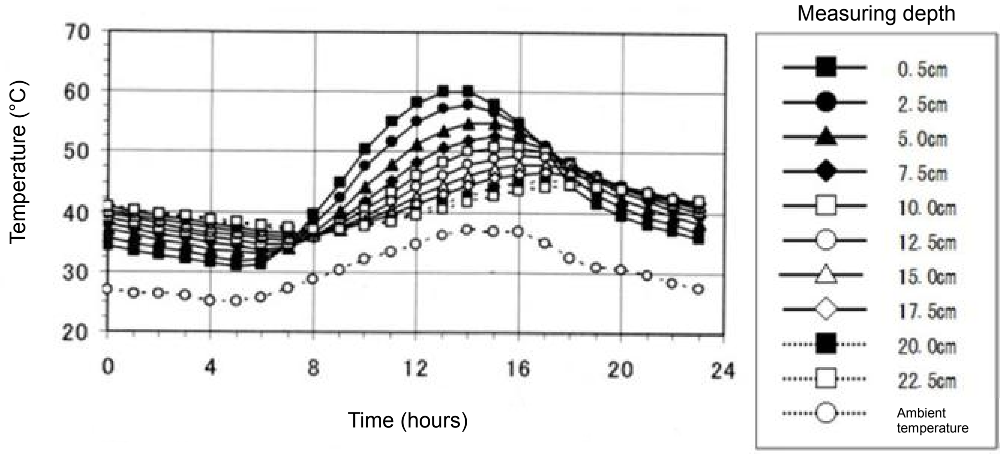
$$D' = D \times 49/L \qquad \text{(Appendix Equation-7.2.1)},$$

where

- D': Deflection corrected with respect to the load (μm),
- D: Measured deflection (μm), and
- L: Load used for the measurement (kN).

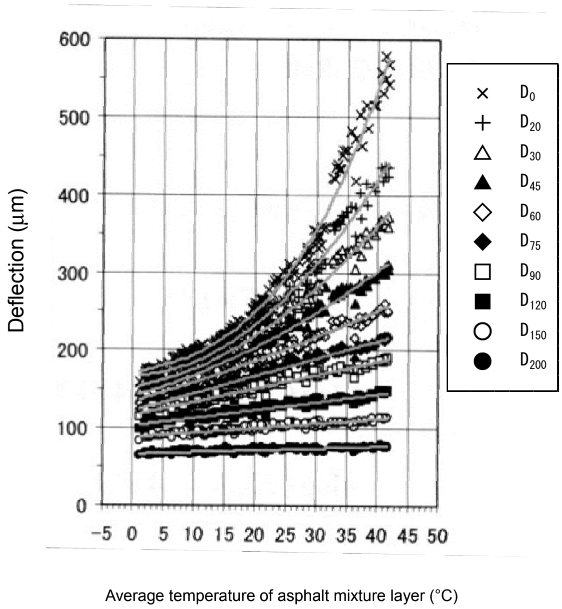
In addition, since the viscosity of asphalt varies with temperature, deflection measured with FWD varies depending on the internal temperature of the asphalt mixture.

Appendix figure-7.2.2 [2] shows examples of temperatures measured for different depths in pavement. The measured temperatures vary more significantly at depths closer to the road surface.



Appendix Figure-7.2.2: Example of variations with time in measured temperatures of asphalt mixture layer created from 2)

Appendix Figure-7.2.3 2) shows the relationship between the average temperature of the asphalt mixture (at the central depth of the total thickness of the entire asphalt mixture layer) and the deflection measured with each sensor. According to this figure, the higher the average temperature of the asphalt mixture layer is, the larger the deflection becomes.



(Cross section corresponding to the N_7 traffic volume class)

Appendix Figure-7.2.3: Relationship between the average temperature of the asphalt mixture layer and deflection created from 2)

However, it is difficult to measure the actual temperature at the center of the asphalt mixture layer. Accordingly, it is generally estimated from the road surface temperature and atmospheric temperature by using **Appendix Equation-7.2.2** 3).

$$T(s,t) = aX_1 + bX_2 + cX_3 + dX_4 + e \cdots\cdots\cdots\cdots\cdots\cdots \textbf{(Appendix Equation-7.2.2)},$$

where

s	:	Month of measurement (January to December)
t	:	Time of measurement (0 to 23)
$T(s,t)$	:	Average temperature (°C) of the asphalt mixture layer at the time of measurement t in month of measurement s,
X_1	:	Road surface temperature (°C) at time of measurement t,
X_2	:	Atmospheric temperature (°C) at time of measurement t,
X_3	:	Difference in atmospheric temperature between time of measurement t and one hour before that time (Atmospheric temperature at time of measurement t − atmospheric temperature one hour before that time) (°C),
X_4	:	Thickness of the asphalt mixture layer (mm), and
a, b, c, d, and e	:	Coefficients (appropriately selected depending on month of measurement s and time of measurement t from **Appendix Table-7.2.2**: Coefficients of the equation for estimating the average temperature).

Appendix Table-7.2.2: Coefficients of the equation for estimating the average temperature (1)

		1.2375	−0.2685	−0.2690	0.0116	−0.2212
		1.2629	−0.2994	−0.0478	0.0117	−0.0732
		1.2595	−0.2908	−0.7146	0.0116	−0.3993
		1.2592	−0.2759	−0.7653	0.0115	−0.6395
		1.2433	−0.2648	−0.5780	0.0116	−0.4333
		1.2608	−0.2815	−0.7614	0.0112	−0.5136
		1.1711	−0.1593	0.3865	0.0085	−1.0930
		1.0330	0.0263	−0.5407	0.0025	−1.2285
		0.8001	0.2069	−0.9800	−0.0078	1.5376
		0.6403	0.3208	−0.6732	−0.0190	4.1809
		0.6217	0.3370	−1.0757	−0.0281	5.7264
		0.6226	0.3448	−0.8740	−0.0366	6.2460
		0.6580	0.2865	−0.7868	−0.0412	7.0546
		0.6985	0.2387	−0.9674	−0.0400	6.8828
		0.7378	0.1522	−1.0176	−0.0361	7.4001
		0.7858	0.1046	−1.3063	−0.0284	6.4054
		0.8291	0.0758	−1.2144	−0.0188	4.7661
		0.8980	−0.0105	−0.9727	−0.0090	3.9349
		1.1638	−0.2566	−0.0779	0.0006	1.7316
		1.2131	−0.2960	−0.3626	0.0076	0.8320
		1.2479	−0.3175	−0.3083	0.0103	0.3514
		1.2513	−0.3045	−0.1176	0.0115	0.1394
		1.1865	−0.2376	−0.5532	0.0124	0.2068
		1.1855	−0.2313	−0.2841	0.0127	0.2705
		1.2304	−0.2120	−0.2032	0.0127	−1.2084
		1.2196	−0.2061	−0.3113	0.0128	−1.0822
		1.2288	−0.2159	−0.1546	0.0128	−1.0362
		1.2068	−0.1820	−0.5659	0.0129	−1.2903
		1.2125	−0.2079	−0.5260	0.0128	−0.8588
		1.2435	−0.2428	−0.4083	0.0128	−0.8665
		1.2047	−0.2246	−0.1170	0.0116	−0.2828
		1.0776	−0.1246	−0.4721	0.0060	0.7202
		0.9505	−0.0374	−0.9397	−0.0034	2.8357
		0.8156	0.1173	−1.1617	−0.0139	3.8622
		0.7308	0.2749	−1.2133	−0.0241	3.6341
		0.6820	0.3230	−0.7474	−0.0312	4.1286
		0.6883	0.3291	−0.6740	−0.0351	3.9968
		0.6885	0.3160	−0.5370	−0.0358	4.5618
		0.7114	0.3049	−1.0742	−0.0295	4.0252
		0.7454	0.2496	−1.0923	−0.0198	3.4521
		0.8632	0.0779	−0.7145	−0.0086	3.0423
		0.9677	−0.0340	−0.4156	0.0005	2.3717
		1.0756	−0.1115	−0.4684	0.0071	0.5320
		1.1841	−0.1668	0.2207	0.0107	−0.7112
		1.1548	−0.1432	−0.3579	0.0121	−0.9070
		1.1914	−0.1752	−0.2048	0.0126	−1.1091
		1.1968	−0.1814	−0.1693	0.0129	−1.1133
		1.1874	−0.1568	−0.1254	0.0131	−1.3265

* "0:00" indicates the time between 0:00 and 00:59.

Appendix Table-7.2.2: Coefficients of the equation for estimating the average temperature (2)

		1.0670	−0.1161	−0.1846	0.0119	0.1960
		1.0163	−0.0832	−0.2212	0.0122	0.3293
		1.0827	−0.1302	−0.0487	0.0125	0.1636
		1.0655	−0.1159	−0.0309	0.0127	0.1839
		1.0685	−0.1156	−0.1101	0.0127	0.1083
		1.0724	−0.1205	−0.1145	0.0128	0.0992
		1.0684	−0.1164	−0.1142	0.0128	0.1029
		1.0513	−0.1116	0.0798	0.0123	0.1234
		0.9908	−0.0555	−0.0093	0.0072	−0.1204
		0.9036	0.0107	−0.2611	−0.0046	0.5880
		0.7494	0.2079	−0.4131	−0.0155	1.4858
		0.6882	0.2861	−0.4165	−0.0242	2.1644
		0.7395	0.2428	−0.4229	−0.0295	2.1187
		0.7849	0.2080	−0.5443	−0.0287	1.9315
		0.7747	0.2107	−0.7453	−0.0232	2.1209
		0.9088	0.0740	−0.5525	−0.0147	1.0449
		1.0457	−0.0861	−0.6002	−0.0036	0.3607
		1.1448	−0.1865	−0.1882	0.0043	0.3370
		1.1538	−0.2081	−0.2452	0.0076	0.2548
		1.1448	−0.1865	−0.1882	0.0043	0.3370
		1.1188	−0.1693	−0.1067	0.0102	0.3090
		1.1018	−0.1557	0.0143	0.0109	0.3850
		1.0846	−0.1414	−0.1048	0.0116	0.3071
		1.0739	−0.1276	−0.2113	0.0119	0.1810
		1.1731	−0.2414	−0.1185	0.0124	0.0262
		1.1511	−0.2236	−0.2093	0.0129	0.0444
		1.0955	−0.1736	−0.2867	0.0132	0.1439
		1.1346	−0.2096	0.0362	0.0135	0.1221
		1.1145	−0.1851	0.0554	0.0137	0.1344
		1.0811	−0.1491	−0.0808	0.0138	0.1245
		1.0668	−0.1425	−0.0766	0.0136	0.1204
		0.9327	−0.0432	−0.1693	0.0110	0.4536
		0.8257	0.0287	−0.4668	0.0006	1.5892
		0.7177	0.1941	−0.6840	−0.0128	2.8159
		0.6260	0.3018	−0.8020	−0.0253	4.3852
		0.6184	0.3548	−0.6589	−0.0352	4.7341
		0.6354	0.3412	−0.5334	−0.0408	5.0886
		0.7098	0.2418	−0.6026	−0.0413	4.7949
		0.7667	0.1330	−1.0321	−0.0359	4.9380
		0.7761	0.1742	−0.8532	−0.0258	3.6538
		0.9294	−0.0467	−0.5696	−0.0139	2.5616
		1.0403	−0.1344	−0.3699	−0.0013	1.1781
		1.1616	−0.2367	−0.1833	0.0064	0.3624
		1.1591	−0.2242	−0.3069	0.0095	0.0502
		1.0939	−0.1252	−0.3587	0.0109	−0.0131
		1.1449	−0.1883	−0.3512	0.0118	−0.1458
		1.1245	−0.1589	−0.4911	0.0122	−0.2729
		1.1148	−0.1670	−0.1672	0.0127	0.0590

* "0:00" indicates the time between 0:00 and 00:59.

Temperature correction for deflection is performed on D_0 and D_{20}, which are affected by the asphalt mixture layer. In the temperature correction, deflection is converted to deflection corresponding to 20°C by using **Appendix Equation-7.2.3**.

$D'' = CF \times D'$ (**Appendix Equation-7.2.3**),

$\log CF_0 = (-4.914 \times 10^{-5} \times H_{as} + 2 \times 10^{-4}) \times (T - 20)$, and

$\log CF_{20} = (-4.829 \times 10^{-5} \times H_{as} + 2 \times 10^{-4}) \times (T - 20)$, where

D'': Deflection obtained by temperature correction (μm),
CF_0: Temperature correction factor of D_0,
CF_{20}: Temperature correction factor of D_{20},
H_{as}: Thickness of the asphalt mixture layer (mm), and
T: Average temperature of the asphalt mixture layer in measurement (°C).

(2) Example of pavement evaluation directly from deflection

Deflection (D_0), which is measured with FWD (loading plate: ϕ30 cm; exerted load: 49-kN) at the point immediately below the loading point, represents the bearing capacity of the entire pavement including the subgrade. In Japan, the necessity of repair is judged by comparing measured deflection D_0 with the allowable deflection shown as a guide in **Appendix Table-7.2.3**.

Appendix Table-7.2.3: Example of allowable deflection as a guide for each traffic volume class

Traffic volume class	N_3	N_4	N_5	N_6	N_7
D_0 (mm)	1.3	0.9	0.6	0.4	0.3

* Listed on p. 41 of the main text.

Structural evaluation as shown by **Appendix Table-7.2.4** has also been proposed. In this evaluation, the structure of asphalt pavement in service is evaluated by using the deflection measured with each FWD sensor [4]. For the boundary values used for the structural evaluation, see References [5].

Appendix Table-7.2.4: Structural evaluation using the deflection of asphalt pavement in service [4]

D_0	D_{150}	D_0-D_{20}	D_0-D_{150}	
good	good	good	good	
good	good	poor	good	
good	poor	good	good	
poor	poor	good	good	
good	good	good	poor	
good	poor	good	poor	
poor	poor	good	poor	
poor	good	poor	poor	
poor	poor	poor	poor	

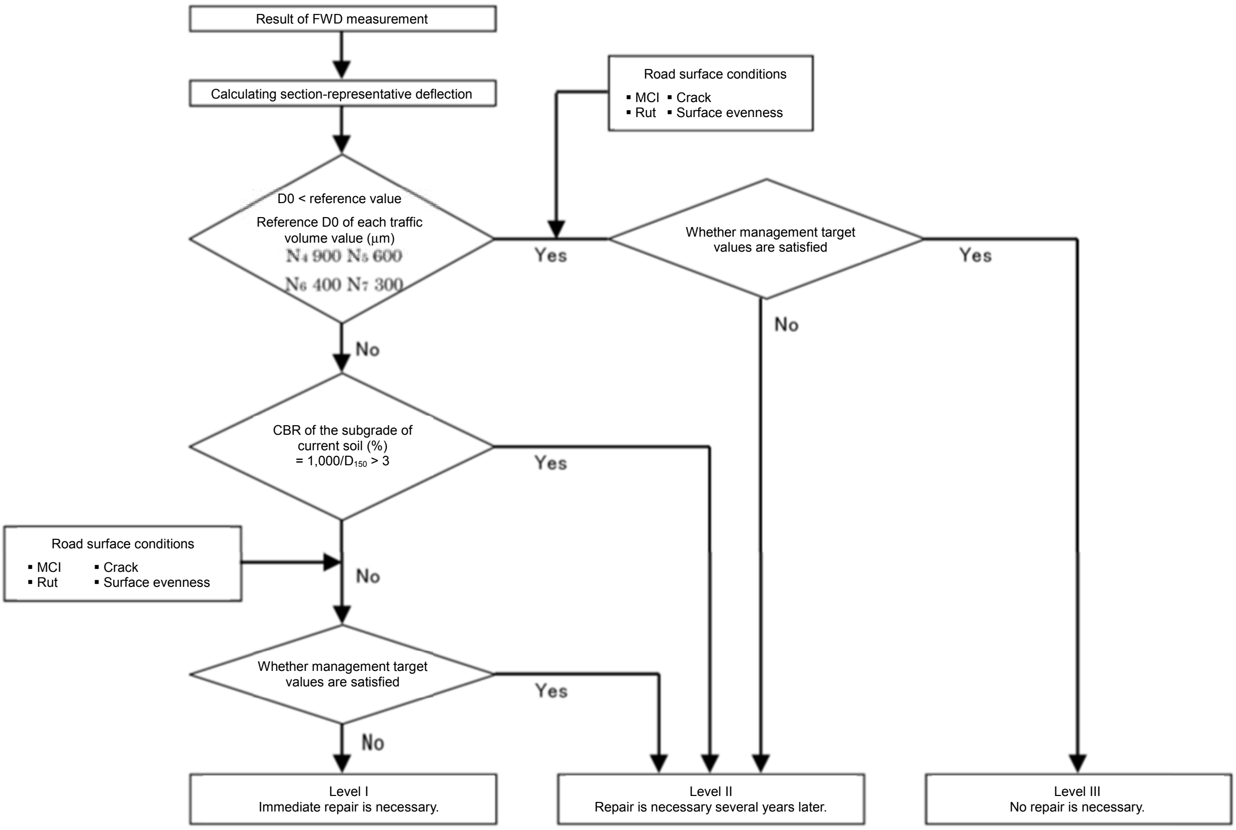
(3) Example of workflow for determining repair timing

To determine a repair timing, the relevant pavement network must be surveyed over a wide area. In the survey, measurement is performed at 50 to 100 m intervals, and the representative deflection value is determined for an evaluation section by using **Appendix Equation-7.2.4**.

Representative deflection value for evaluation section (μm) = average deflection - standard deviation of deflection

(**Appendix Equation-7.2.4**)

The repair timing is determined by evaluating the calculated deflection in accordance with the workflow illustrated in **Appendix Figure-7.2.5** [6].



Appendix Figure-7.2.5: Example of evaluation for determining a repair timing [6]

2-1-2 Evaluation using inverse analysis

When the structure and thickness of each pavement layer are known, its elastic modulus can be estimated from measured deflection. This estimation is generally performed by using an inverse-analysis program.

Inverse analysis estimates the elastic modulus, etc. of each pavement layer from impact loads, deflection, the thickness of each pavement layer, and Poisson's ratio of each pavement layer. For asphalt mixture layers, temperature correction for the elastic modulus obtained by inverse analysis is performed by using **Appendix Equation-7.2.5** [7].

$$E_{as(20)} = E_{as(z)} \times 10^{-0.0184(20-T\mathrm{avg}(z))}$$ (**Appendix Equation-7.2.5**),

where

$E_{as(20)}$: Elastic modulus of the asphalt mixture layer at standard temperature (20°C) (MPa),

$E_{as(z)}$: Elastic modulus of the asphalt mixture layer at $T_{avg(z)}$°C (MPa), and

$T_{avg(z)}$: Average temperature of the asphalt mixture layer in FWD measurement (°C).

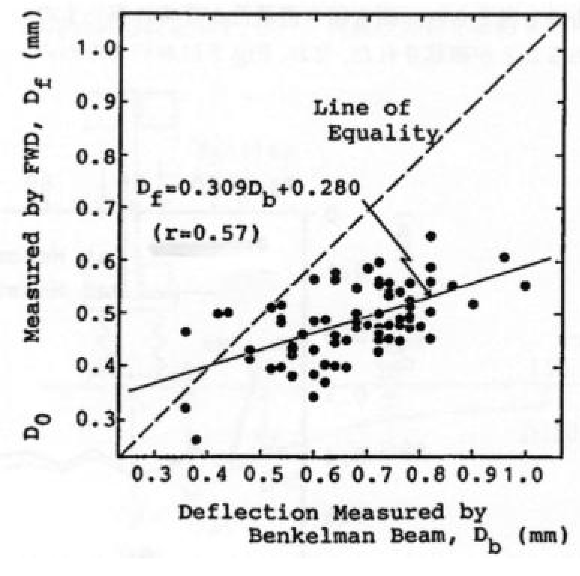
The soundness of each layer can be diagnosed by comparing its elastic modulus determined by inverse analysis with the typical elastic moduli of pavement materials. Appendix Table-7.2.5 [8] lists examples of typical elastic moduli of pavement materials.

Appendix Table-7.2.5: Examples of elastic moduli of materials use for pavement layers [8]

Material	Elastic modulus (MPa)
Asphalt mixture	600 to 12,000
Cement-stabilized mixture	1,000 to 15,000
Gravel material	100 to 600

2-1-3 Comparison between measurement by the Benkelman beam test and measurement with FWD

In addition to FWD, the Benkelman beam test is available for pavement deflection measurement. **Appendix Figure-7.2.6** [9] illustrates the relationship between the deflection measured by the Benkelman beam test and that measured with FWD.



Appendix Figure-7.2.6: Relationship between the deflection measured by the Benkelman beam test and that measured with FWD [9]

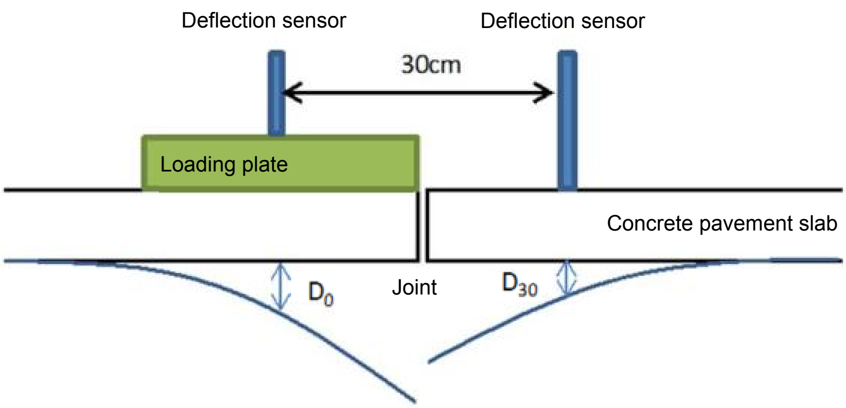
2.2 Concrete pavement

Concrete pavement is evaluated mainly by using the values of D_0 and D_{30}. **Appendix Table-7.2.6** describes the meanings of the deflection measured at the sensor points corresponding to D_0 and D_{30}.

To measure load transfer rates, the loading plate must be placed in such a manner that the distance of its end from the relevant joint will not exceed 2 cm, as illustrated in **Appendix Figure-7.2.7**.

Appendix Table-7.2.6: Meanings of the deflection of concrete pavement

<table>
<tr><th>Deflection</th><th>Meaning</th></tr>
<tr><td>D_0</td><td>Used to evaluate the load distribution capacity of concrete slabs, the bearing capacity of the base course, the presence of cavities, etc.</td></tr>
<tr><td>D_{30}</td><td>Used to evaluate the load transfer rate. The load transfer rate is calculated by using the following equation:
$$\text{Load transfer rate (\%)} = \frac{D_{30}}{\frac{D_0+D_{30}}{2}},$$
where
D_0: Deflection at the center of the loading plate (μm), and
D_{30}: Deflection at a point 30 cm away from the center of the loading plate (μm).
The following table lists the criteria for judging the load transfer rate.
<table>
<tr><th>Load transfer rate (%)</th><th>Judgment</th></tr>
<tr><td>80–100</td><td>Accepted</td></tr>
<tr><td>65–79</td><td>Insufficient</td></tr>
<tr><td>0–64</td><td>Rejected</td></tr>
</table>
</td></tr>
</table>



Appendix Figure-7.2.7: Locations of the loading plate and sensors in measurement of a load transfer rate (when the relevant sensor is located 30 cm away from the center of the loading plate)

[References]

1) Teruhiko Maruyama, Kenji Himeno, and Masanori Hayashi: Structural Evaluation of Pavement Using the Deflection Evaluation Index, Hoso (Pavement), Vol. 24-9, pp. 3-8, 1988

2) Shinya Hayashi, Shigeo Higashi, Toshihiro Kanai, and Toshiyuki Okabe: Development of Temperature Correction System for Deflection by FWD, Journal of JSCE, Vol. 2, pp. 95-104, 1997

3) Japan Road Association: Pavement Performance Evaluation Methods —Essential and Principal Performance Indices—, April 2013

4) Nagato Abe, Teruhiko Maruyama, Kenji Himeno, and Masanori Hayashi: Structural Evaluation of Pavement Using the Deflection Evaluation Index, Journal of JSCE, No. 460, V-18, pp. 41-48, 1993

5) Teruhiko Maruyama, Nagato Abe, Yoshio Saika, and Kenji Himeno: Development of structural evaluation and rehabilitation design system for pavement using FWD, Journal of JSCE, No. 484, V-22, pp. 61-68, 1994

6) Road Management Technology Center: For Effective Use of FWD, 2005

7) Yuichi Ikeda, Takuya Ikeda, and Satoshi Taniguchi: Data on Inverse Analysis of FWD-measured Deflection and Discussion on a Temperature Correction Formula, the 54th Annual Academic Lecture of JSCE, V-196, pp. 392-393, 1999

8) Japan Road Association: Pavement Design Handbook, 2006

9) Teruhiko Maruyama, Iwao Goto, Nagato Abe, Kenji Himeno, Raizou Tsuchiya, and Masanori Hayashi: Nondestructive pavement testing by the falling weight deflectometer, Bulletin of Nagaoka University of Technology, No. 10, pp. 119-127, 1988

Appendix 8: Measures against Flow Rutting

1 Flow rutting

Flow rutting is characterized by settlement in the vehicle-running pavement portions and rising in their surroundings (portions in the middle of lanes and portions near road shoulders).

Flow rutting will often occur soon after opening to traffic if asphalt mixture or asphalt is not appropriately selected for the climate and traffic conditions or if the asphalt mixture is poor in quality.

In particular, flow rutting tends to occur under conditions such as high road surface temperature, heavy traffic loads, low traffic speed, and the concentration of the passage of running vehicles on certain portions of the surface.

Flow rutting is also called rutting due to the plastic deformation of an asphalt mixture layer. Plastic deformation resistance is expressed by the number of wheel passes causing plastic deformation.

In technical standards in Japan, the number of wheel passes causing plastic deformation is defined as the number of 49-kN wheel loads that are repeatedly exerted on a paved road surface at a surface course temperature of 60°C until the paved road surface develops a 1-mm downward displacement. It is specified separately for each section in which the pavement surface course is made of the same material with the same thickness.

Therefore, an asphalt mixture whose number of wheel passes causing plastic deformation is large is resistant to plastic deformation, and is capable of suppressing flow rutting.

2 Testing methods for evaluation

Appendix Table-8.2.1 lists typical laboratory tests for evaluating resistance to flow rutting.

In Japan, the wheel tracking test has been used since around 1975 as an laboratory test for evaluating the number of wheel passes causing plastic deformation in asphalt mixture.

The following sections outline the wheel tracking test.

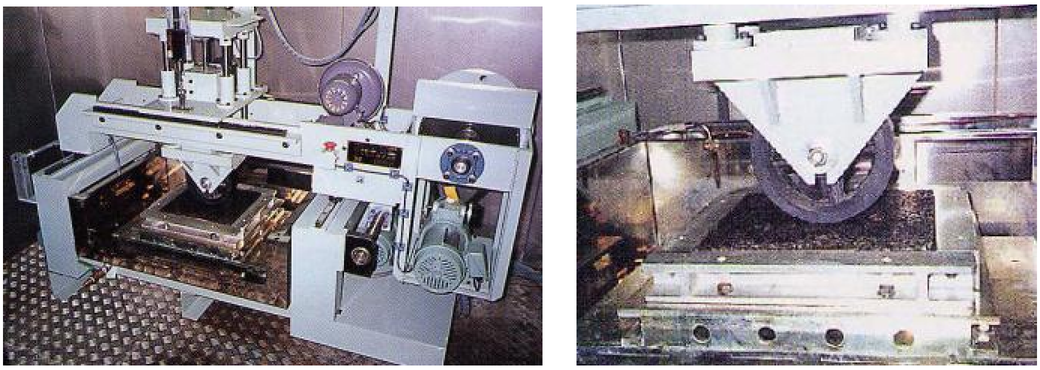
Appendix Table-8.2.1: In-door evaluation tests (flow rutting resistance and plastic deformation resistance)

Test name	Test target item
Wheel tracking test	Dynamic stability
Dynamic triaxial compression test	Dynamic modulus, static creep, and residual deformation
Asphalt pavement analyzer	Rut depth
Superpave shear tester	Evaluation of shear resistance (static, dynamic, and repeated shear)

2-1 Wheel tracking tester

Appendix Photograph-8.2.1 shows a wheel tracking tester.

A wheel tracking tester produces plastic deformation in a specimen by repeatedly exerting a linear reciprocating wheel load on it.



Appendix Photograph-8.2.1: Wheel tracking tester

2-2 Test conditions

Appendix Table-8.2.2 lists typical test conditions.

The contact pressure of the test wheel and the test temperature for the test conditions are determined appropriately for Japan.

Contact pressure: Although the contact pressure corresponding to 49-kN, the wheel load of an actual vehicle, is 0.59 MPa, 0.63 MPa is used for the following reasons.

a. Conventionally, 0.63 MPa has been used as the pressure for the test, and the relationship between the results obtained from such tests and rut depths on actual roads has been clarified.

b. Since this contact pressure (0.63 MPa) is larger than the contact pressure corresponding to the 49-kN wheel load (0.59 MPa), such tests produce results on the safe side.

Test temperature: 60°C (with consideration given to the maximum road surface temperature)

2-3 Organizing the test results

Appendix Figure-8.2.1 shows a test result.

The test result is expressed as dynamic stability (DS) by using **Appendix Equation-8.2.1**.

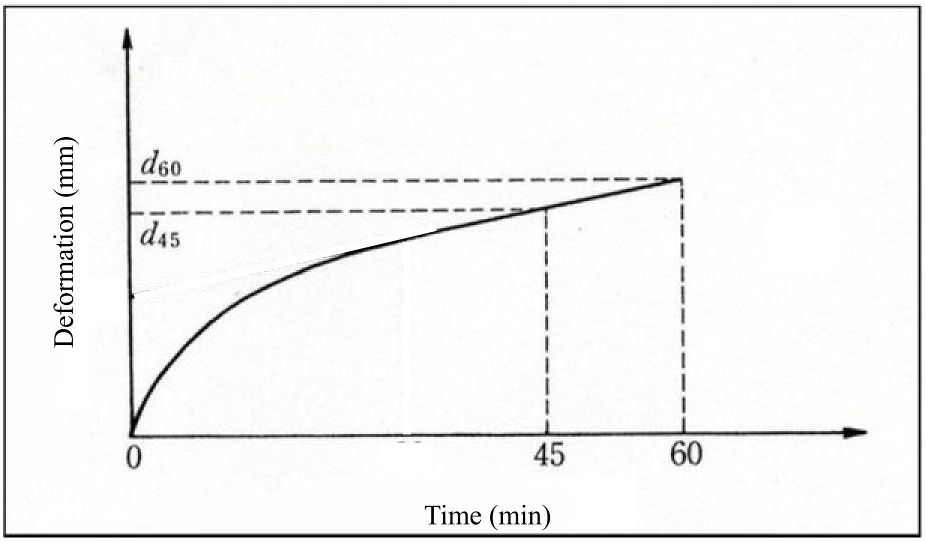
The dynamic stability obtained under the test conditions is regarded as the number of wheel passes causing plastic deformation.

$DS = 42 \times (60 - 45)/(d_{60} - d_{45})$ ························(**Appendix Equation-8.2.1**),

where DS: Dynamic stability (times/mm),
d_{60}: Deformation in a test time of 60 minutes (mm), and
d_{45}: Deformation in a test time of 45 minutes (mm).
Deformation must be measured down to the nearest 1/100 mm.

Appendix Table-8.2.2: Test conditions

Item		Standards and conditions
Test specimen	Size	Length × width × thickness = 300 × 300 × 50 mm
	Compaction degree of mixture	100%
Running test wheel	Shape and dimensions	Solid tire 200 mm in diameter, 50 mm in width, and 15 mm in rubber thickness
	Rubber hardness	Rubber hardness at 20°C: 84 ± 4 Rubber hardness at 60°C: 78 ± 2 (Measured with a JIS K 6253 durometer.)
Test conditions	Contact pressure of test wheel	Contact pressure at 60°C: 0.63 MPa (Test wheel load: 686 ± 10 N)
	Running speed of test wheel	42 ± 1 times/min.
	Running distance of test wheel	230 ± 10 mm
	Test temperature	60°C ± 0.5°C
	Testing time	60min.



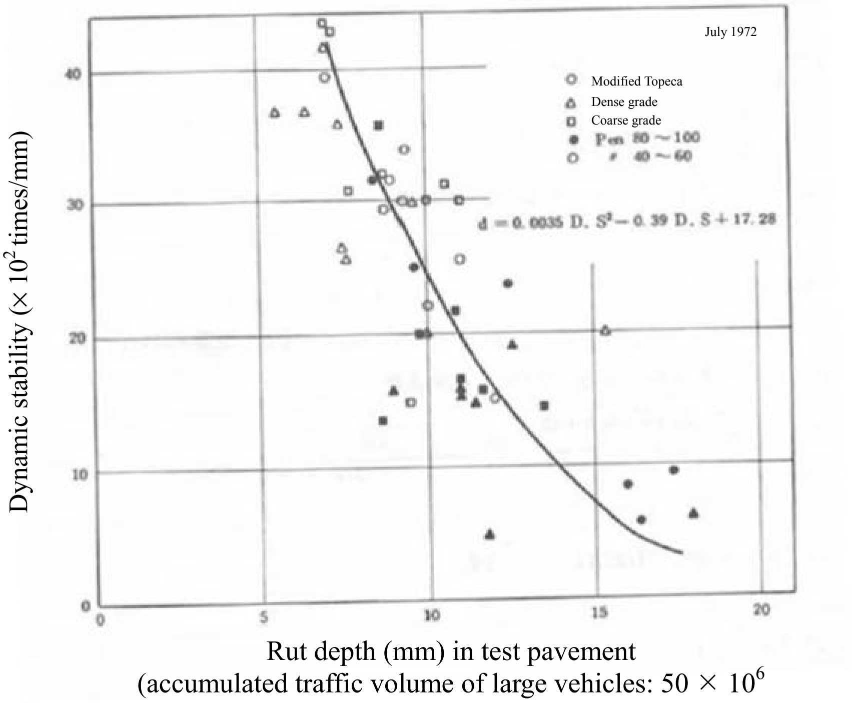
Appendix Figure-8.2.1: Test result (time-deformation curve)

2-4 Relationship between dynamic stability and rut depth

Appendix Figure-8.2.2 shows an example of a survey result of the relationship between rut depths on actual roads and the dynamic stability of the mixtures used for the roads.

According to this result, rut depths are smaller in pavement constructed of a mixture with higher dynamic stability.

The data were collected in 1972. However, various organizations, such as the national government, municipal governments, and expressway companies, have performed similar data collections and concluded that the dynamic stability obtained by the wheel tracking test is valid as an index for evaluating plastic deformation resistance.



Appendix Figure-8.2.2: Relationship between dynamic stability and rut depth created from 1)

2-5 Reference value of the number of wheel passes causing plastic deformation

In Japan, the number of wheel passes causing plastic deformation is set to a value greater than or equal to the corresponding value shown in **Appendix Table-8.2.3**.

Appendix Table-8.2.3: Reference values for the number of wheel passes causing plastic deformation

Classification	Designed daily volume for pavement (Vehicles/day per direction)	Number of wheel passes causing plastic deformation (Times/mm)
Type 1, Type 2, Type 3 Classes 1 & 2, and Type 4 Class 1	3,000 or more	3,000
	0–2,999	1,500
Other		500

It is expected that rutting will occur at an early stage in service if the reference values are applied in countries where a wheel load heavier than the design standard wheel load in Japan (49-kN) is used, or in warmer areas (countries in which road surface temperature becomes higher, and countries that have a long hot season). Therefore, the appropriate reference values for the number of wheel passes causing plastic deformation must be determined for target areas by dynamic stability measurement under test conditions suitable for the environmental conditions, field surveys, etc.

3 Factors affecting rutting

Factors affecting rutting are roughly classified into the following three types: factors due to the characteristics of asphalt mixtures, such as materials and mix design; factors due to external forces exerted on mixtures, such as ambient temperature and traffic loads; and factors due to pavement structure.

3-1 Factors due to the characteristics of asphalt mixtures

Factors of this type are mainly the materials used in the asphalt mixtures and the mix design. These include the following.

These items will be detailed in "4. Concrete examples of rutting-prevention measures."

a. Asphalt

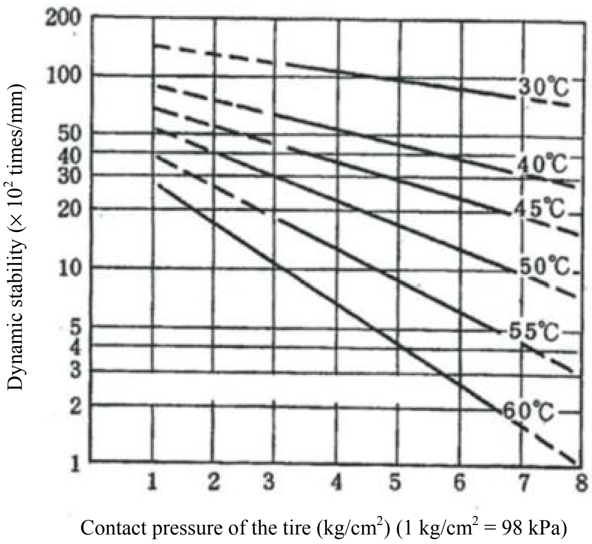
b. The characteristics and shapes of aggregates

c. Mix design

3-2 Factors due to external forces exerted on mixtures, such as ambient temperature and traffic loads

Appendix Figure-8.3.1 shows changes in dynamic stability depending on differences in test temperature (ambient temperature) and in the contact pressure of the test wheel (traffic situation).

Dynamic stability becomes lower at a higher test temperature or under a higher contact pressure. The degree of change is considerably large.



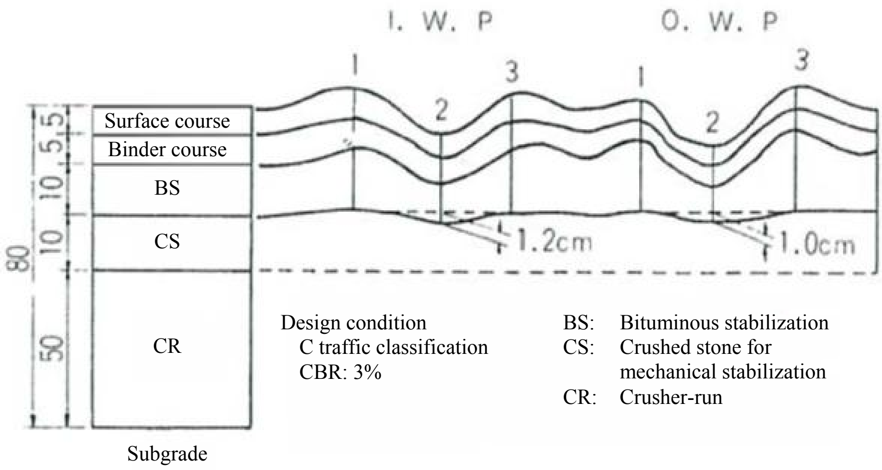
Appendix Figure-8.3.1: Change in dynamic stability depending on difference in the contact pressure of the test wheel and difference in temperature[2)]

3-2 Factors due to pavement structure

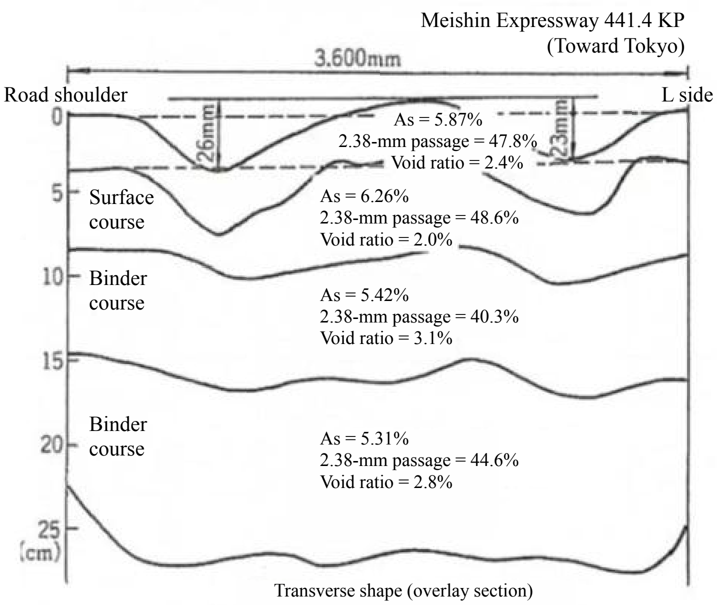
The pavement for roads with large traffic volume of large vehicles is generally designed on the basis of a pavement cross section consisting of multiple asphalt mixture layers.

Appendix Figure-8.3.2 was drawn by measuring the longitudinal and transverse deformation of each layer on an excavated portion that had developed rutting on such a road. The rutting has not only reached the surface course, but also the binder course and the bituminous stabilized layer.

In road sections with large traffic volume of large vehicles, therefore, asphalt mixtures with high plastic deformation resistance must be used not only for their surface course but also their lower layers.



Appendix Figure-8.3.2: Transverse view of an excavation cross section of a road with heavy traffic (1) [3)]



Appendix Figure-8.3.2: Transverse view of an excavation cross section of an expressway with heavy traffic (2)[4)]

4 Concrete examples of rutting-prevention measures

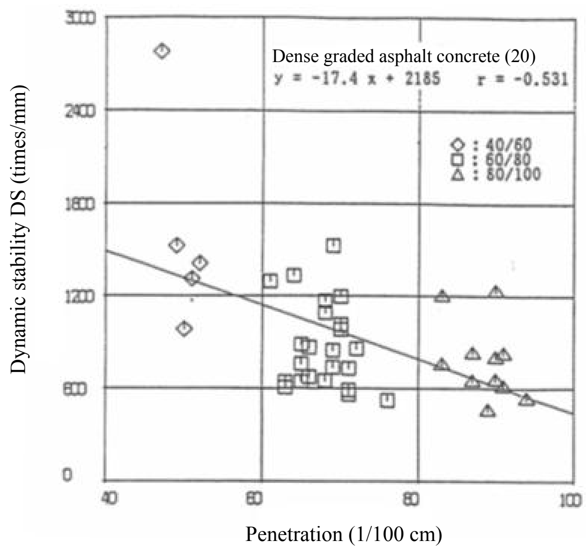
The following sections describe a method considering materials and mixing design, as a rutting-prevention measure for asphalt mixtures.

After a rutting-prevention measure is implemented, it is desirable to perform the wheel tracking test to check its effectiveness.

4-1 Asphalt

(1) Straight asphalt

When straight asphalt is to be used, asphalt with small penetration tends to produce high dynamic stability (does not develop rutting easily) as seen in **Appendix Figure-8.4.1**. However, since the use of asphalt with small penetration tends to lead to low cracking resistance, such asphalt is not often used in Japan.

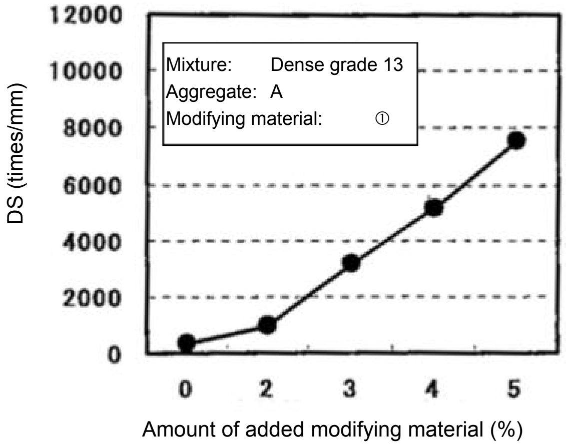


Appendix Figure-8.4.1: Relationship between penetration and dynamic stability [5)]

(2) Modified asphalt

Appendix Figure-8.4.2 shows how dynamic stability changes when a modifying material is added to straight asphalt 60/80. The modifying material used is SBS (styrene-butadiene-styrene block copolymer). The graph shows that addition of the modifying material improves dynamic stability.

Various materials have been used as modifying materials in Japan. At present, the use of SBS-added modified asphalt has become mainstream for several reasons: for example, its cracking resistance does not degrade when its dynamic stability is enhanced; the handling of this modified asphalt is easy.



Appendix Figure-8.4.2: Relationship between the amount of modifying material added and dynamic stability [6)]

4-2 Aggregate and filler

Aggregates used for asphalt mixtures are roughly classified into two types: coarse aggregate (captured with 2.36 mm sieves) and fine aggregate (passing through 2.36 mm sieves but captured with 75 µm sieves). Fine-grained fractions passing through 75 µm sieves are called filler.

(1) Coarse aggregate

Crushed stone produced by mechanically crushing raw stone and crushed gravel produced by crushing cobblestone or gravel are used as coarse aggregate.

Since crushed stone holds moderate roughness on its surface and has an irregular rough shape, it tends to deliver higher rutting resistance than crushed gravel does.

(2) Fine aggregate

Materials, such as natural sand (sea sand, river sand, and mountain sand), artificial sand, and screenings, are used as fine aggregate.

Since the grading and other properties of natural sand tend to differ from place to place, sufficient surveys are necessary. In addition, insufficient angularity may lead to rutting when only natural sand is used; in such a case, artificial sand or screenings is used in combination with natural sand as a rutting-prevention measure.

(3) Filler

Materials such as stone dust produced by crushing limestone or another type of stone, slaked lime, cement, and recovered dust from asphalt plants, are used as fillers.

Using too much recovered dust tends to degrade plastic deformation resistance. Accordingly, it is best to keep it from exceeding 30% of the filler material passing through a 75-µm sieve.

4-3 Mixing

Methods, such as the Marshall method and the Superpave method, are used to perform the mixing design of asphalt mixtures.

This section describes a rutting-prevention measure implemented by the Marshall method.

(1) Aggregate grading

The target aggregate grading is adjusted to be lower than the median within the grading range. In particular, the percentage by mass of aggregate passing through 2.36 mm and 75 μm sieves must be reduced.

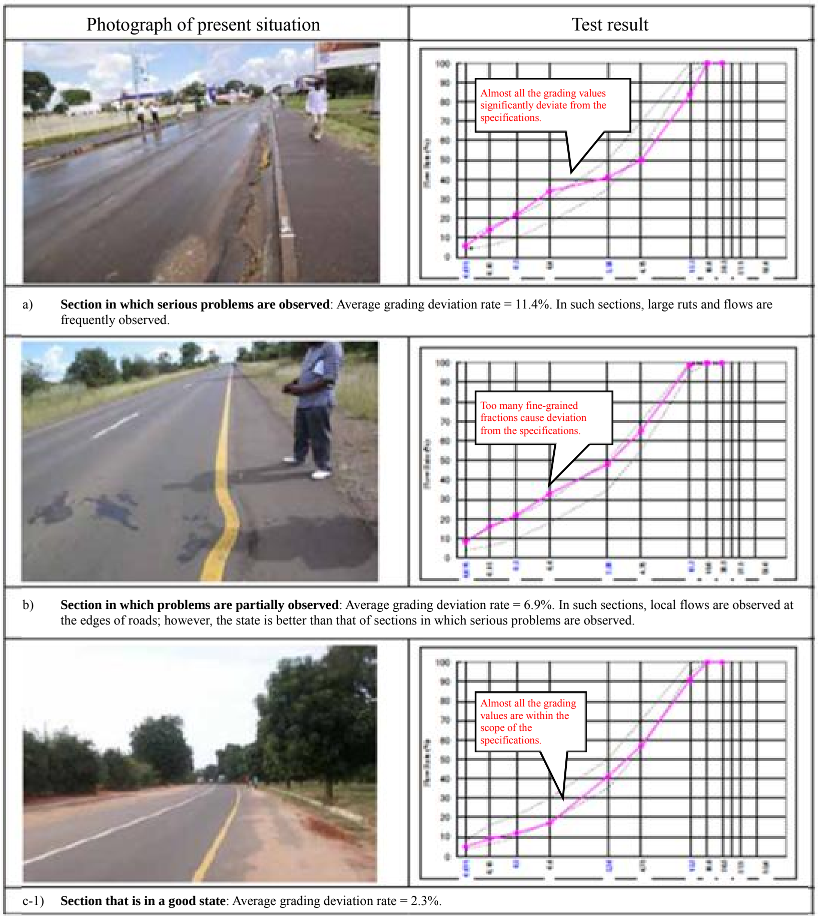
(2) Asphalt content

Asphalt content is adjusted to be less than or equal to the median within the common range.

5 Quality control

As described in the above, the target mixing-design quality of asphalt mixtures can be achieved on site by securely performing the in-plant management of properties such as aggregate grading and asphalt content, and the on-site management of properties such as degree of compaction.

Appendix Figure-8.5.1 shows an overseas case example of the results of a grain size distribution survey on cores collected from portions that developed flow rutting. The results show that the aggregate grading measured in the portions deviates from the grading range.



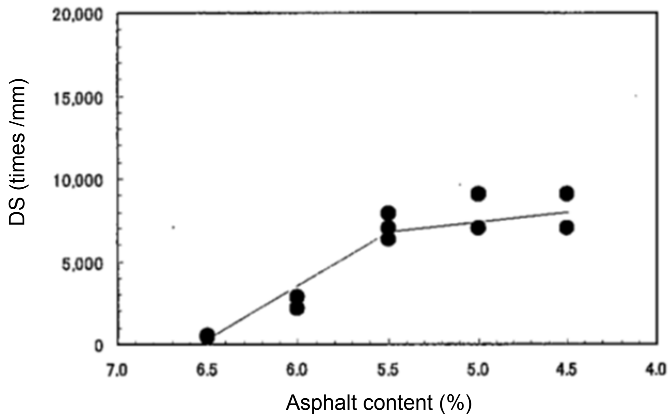
a) **Section in which serious problems are observed**: Average grading deviation rate = 11.4%. In such sections, large ruts and flows are frequently observed.

b) **Section in which problems are partially observed**: Average grading deviation rate = 6.9%. In such sections, local flows are observed at the edges of roads; however, the state is better than that of sections in which serious problems are observed.

c-1) **Section that is in a good state**: Average grading deviation rate = 2.3%.

Appendix Figure-8.5.1: Grain size distribution in cores collected from the site and road conditions

Appendix Figure-8.5.2 shows the change in dynamic stability as the values of asphalt content change; the given values of asphalt content are the optimum asphalt content (OAC) of 5.5%, OAC ± 0.5%, and OAC ± 1.0%. When asphalt content is larger than the OAC, dynamic stability is significantly degraded. When asphalt content is less than the OAC, dynamic stability tends to increase slightly. However, small asphalt content, which leads to degradation in cracking resistance, is not always desired.

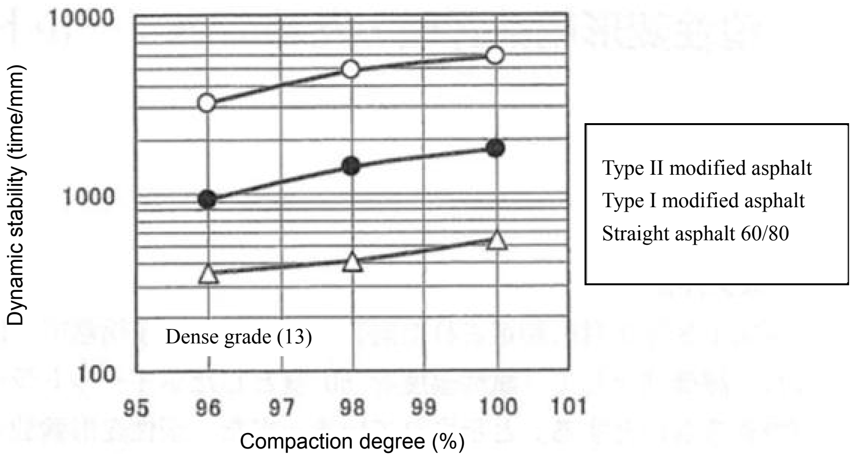


Appendix Figure-8.5.2: Relationship between asphalt content and dynamic stability[6)]

Appendix Figure-8.5.3 shows the change in dynamic stability depending on differences in the compaction degrees of test specimens.

The smaller the compaction degree is, the lower the dynamic stability becomes.

This fact suggests that pavement finished at a low compaction degree on site tends to develop rutting.



Appendix Figure-8.5.3: Change in dynamic stability depending on differences in the compaction degrees of test specimens [created from 7)]

Appendix Table-8.5.1 lists specific methods for checking the management items for asphalt mixture production.

In everyday process checking, management points specified for facilities and production processes in voluntary work standards are checked by visual inspection before the start of work or during work.

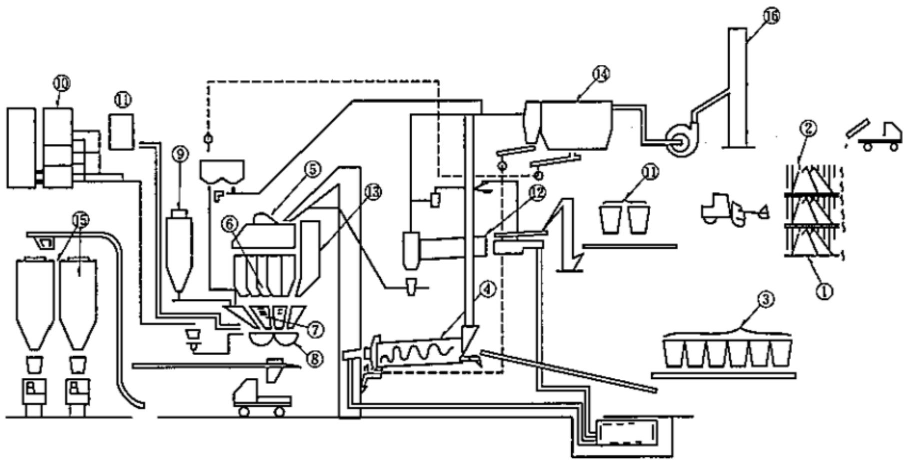
If a value measured by a quality check test deviates from the corresponding management limit, or if values measured by a quality check test tend to appear on one side, the test frequency must immediately be increased to check for abnormality, and necessary measures must be implemented.

In particular, variations in aggregate grading at receipt or warehousing have significant impacts on hot bin grading. Accordingly, careful grading management is required for each aggregate material.

Appendix Figure-8.5.4 lists examples of points to be checked at asphalt plants. Perform daily checks by referring to the check points.

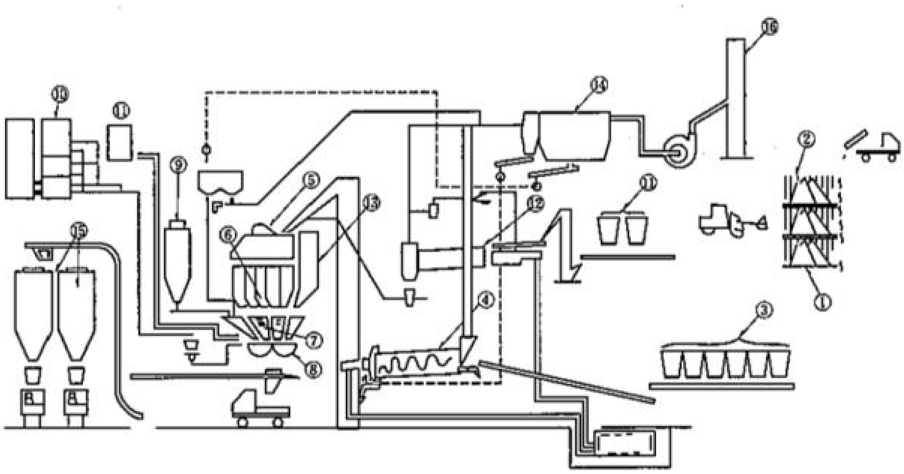
Appendix Table-8.5.1: Examples of concrete methods for checking management items

	Management item	Daily process checks	Quality verification tests
New aggregate	Grading	・ Received materials (Visual check using standard materials) ・ Gate opening ・ Feeder settings Flow rate and clogging (Visual check of cold bins)	Sieving test Check the variations and tendencies of each material If variations are detected (Rechecking raw materials) If grading is different from the planned composite grading (Materials, flow rate, and clogging) If the mixing rate is changed (Change of discharge rate)
	Water content	Water content (Visual check)	Water content test Checking variations in composite water content ratio in aggregate (Relationships to production quantity and fuel consumption)
Mixture	Grading	Hot bin grading (Visual check using standard grading) Mixture grading (Visual check at discharge and measured values)	Sieving test Checking the variations and tendencies of grading in each bin Printed record or sampling test Checking the variations and tendencies of mixture grading If variations are detected (Rechecking for carryover, sieve clogging, sieve breakage, and partition wall breakage and rechecking discharge rate and raw materials)
	Asphalt content	Asphalt content (Visual check at discharge and measured values)	Printed record or sampling test Checking variations in asphalt content If variations are detected (Check the aggregate batchers and their settings)
	Mixing property	Mixed state (Visual check at discharge)	Checking for uneven mixing If uneven mixing is detected (Check the mixing time and temperature)
	Asphalt content	Storage temperature	Checking fluctuations in storage temperature (Check the temperature controller)
	Hot aggregate	Temperature for heating aggregate (Observation of autographic recording)	Checking settings for heating aggregate (Water content ratio in aggregate and relationship between aggregate heating temperature and burner adjustment)
	Temperature	Mixtures at discharge (Visual observation of mixed state and smoke)	Temperature measurement Checking fluctuations in mixture temperature If fluctuations are detected (Relationship between aggregate heating temperature and burner adjustment) (Check the thermometer installed at each portion)



No.	Location to be checked	Check item	Case examples of inspection and maintenance
①	Aggregate storage area	Quality (separation) Stockpile Mixing Water content in sand	Are materials in accordance with the specifications? Are appropriate quantities for production stored? Have materials gotten mixed together? Is it too wet?
②	Recycled aggregate storage area	Quality and quantity Stockpile Solidification state	Are materials in accordance with the specifications? Are appropriate quantities for production stored? Have the materials solidified?
③	Cold bin	Settings for discharge rate Accumulation level in bins	Has the outlet of the aggregate supply feeder become smaller than designed due to clogging with a foreign matter, etc. or growth of aggregate deposition? Has aggregate spilled by the meandering motion or inappropriate position of the belt of the belt conveyer? Is it normal?
④	Dryer	Feeding rate Burning conditions Heating temperature	Is it appropriate? Is the burning at the burner normal? Is a vane in the drum significantly deformed or worn?
⑤	Vibration sieve	Sieving capacity Breakage Carryover	Does the screen vibrate normally? Has a material with unnecessary grading been mixed in? Has clogging developed in the wire net of the screen?
⑥	Hot bin	Bin balance Hot-aggregate grading Temperature	Is the bin leveler operating normally? Has a hole been made in the hot bin partition wall? Is the overflow chute clogged? Has leakage developed due to abrasion, etc. at the bin gate? Is it normal?
⑦	Aggregate batcher	Grading Measuring state	Does the measuring balance for each material indicate correct values? Has a hole, abrasion, or leakage been detected in the aggregate weighing tank?

Appendix Figure-8.5.4: Examples of points to be checked in asphalt plants (1)



No.	Location to be checked	Check item	Case examples of inspection and maintenance
⑧	Mixer	Loading state Mixing state	Is it normal? Is the mixer arm, a mixer vane, or a mixer liner significantly worn or deformed? Has leakage of a material or a mixture developed at the mixer gate?
⑨	Stone dust silo	Stockpile Supply state	Is an appropriate quantity for production stored? Has leakage from the stone dust storage and supply units developed? Has leakage developed at the gate of the stone dust weighing tank?
⑩	Asphalt tank	Temperature Stockpile	Are the heating and heat-insulating units for the asphalt tank, pipelines, weighing tank, and pumps operating normally? Has asphalt leakage or clogging developed in the asphalt storage and supply units?
⑪	Recycled-aggregate cold bin	Settings for discharge rate Solidification state Accumulation level in stock bin	Is the material discharge detector of the recycled aggregate supply feeder operating normally? Does the weighing balance of the conveyer scale indicate correct values? Has clogging developed due to solidification, deposition, etc. in the recycled aggregate supply feeder? Is it appropriate?
⑫	Recycling dryer	Feeding rate Burning situation Heating temperature Situation of deposition on the inner walls of the drum	Is it appropriate? Is it normal? Is it normal? Has a large amount of asphalt mortar content been deposited on a vane or inner wall of the drum?
⑬	Hot-aggregate storage bin	Stockpile Temperature Supply situation	Is it appropriate? Is the specified temperature maintained? Has clogging developed in the hot aggregate storage?
⑭	Bag filter	Situation of dust recovery Emission gas temperature (Differential pressure manometer)	Has clogging or breakage developed in the filter cloth of the bag filter? (Is the differential pressure in the bag filter normal?) Has dust clogging or leakage developed in the dust supply unit? Has a hole been made due to corrosion of the bag filter can? Has dust accumulated in the bag house dust bunker? Has a large amount of asphalt mortar content accumulated in the temporary dust collector and the emission gas flue (when recycling is performed)? Do the air-exhausting units deliver normal performance (abrasion of the impellers, holes on the casing, etc.)? Have holes formed in the emission gas flue?
⑮	Mixture silo	Stockpile Storage time Temperature	Is it appropriate? Is it appropriate? Is the specified temperature maintained?
⑯	Smoke stack	Color of smoke	Is it normal?

Appendix Figure-8.5.4: Examples of points to be checked in asphalt plants (2)

[References]

1) Pavement Research Laboratory of the Public Works Research Institute, the Ministry of Construction: Study on the Mixing Design and Materials of Asphalt Mixtures by Using Makuhari Test Pavement and Laboratory Test, Document of Public Works Research Institute, March 1974

2) Koji Nogami and Ippei Kojima: Wheel Tracking Test, Asphalt, vol. 29, No. 147, 1986

3) Susumu Watanabe: Test Pavement on a Road with Very Heavy Traffic Volume with Rutting-prevention Measures Implemented, Doro Kensetsu (Road Construction), November 1984

4) Yasuo Mori, Kazuo Kaneda, and Masamichi Niidome: Pavement Layer Structure and Flow Rutting, Hoso (Pavement), February 1990

5) Pavement Research Laboratory of the Public Works Research Institute, the Ministry of Construction: Result of Survey on Properties of Straight Asphalt (Second Method), Document of Public Works Research Institute, No. 2685, December 1988

6) Pavement Research Laboratory of the Public Works Research Institute, the Ministry of Land, Infrastructure, Transport and Tourism: Development of a New Method for Evaluating Flow Resistance of Asphalt Mixtures, Document of Public Works Research Institute, No. 3802, January 2001

7) Tsuyoshi Terada and Masahide Ito: Discussion on Wheel Tracking Test Conditions for Evaluating the Number of Wheel Passes causing Plastic Deformation, Paper of the 25th Japan Road Conference, November 2003

Appendix 9: Measures against Overloaded Vehicles

Pavement is a structure constructed on a subgrade and consisting of a surface course, a binder course, and a base course (or a concrete slab and a base course). These layers play the following structural roles: the surface course directly supports wheel loads and transfers them to its lower layers while dispersing them; the binder course disperses the received wheel loads uniformly onto the base course (the concrete slab supports the received wheel loads and disperses them onto the base course); the base course, which provides a homogeneous supporting base for the surface and binder courses, transfers the wheel loads from its upper layers to the subgrade while dispersing them.

Thus, each pavement layer supports wheel loads and transfers them to its lower layers while dispersing them. Pavement thereby protects the subgrade below. This fact makes us understand anew that wheel loads directly affect structural pavement design. If actual wheel loads are larger than postulated, the progress of damage to the pavement will be accelerated.

This appendix describes the legal grounds for the magnitude of the wheel load specified in structural pavement design and activities to comply with the wheel load.

1 Design wheel load on pavement

Article 30 of the Road Act (Law No. 180 of 1952) stipulates a provision regarding standards on road structure as follows.

(Standards on road structure)

Article 30: (1) For technical standards on the structure of national expressways and national roads, the following matters shall be stipulated by government ordinances.

- (i) Matters related to types of vehicles using the road
- (ii) Road width
- (iii) Construction gauge
- (iv) Road alignment
- (v) Sight distance
- (vi) Gradient
- (vii) Road surface
- (viii) Drainage facilities
- (ix) Intersections and junctions
- (x) Turnout
- (xi) Pedestrian bridges, fences, and other facilities for ensuring safe traffic
- (xii) Necessary strength that bridges and other major structures stipulated by a government ordinance are required to have for supporting vehicle loads
- (xiii) Matters necessary for the structure of national expressways and national roads other than the matters listed in each of the preceding items

(2) Technical standards (limited to matters related to those listed in Items (i), (iii), and (xii) of the preceding paragraph) on the structure of prefectural roads and municipal roads shall be stipulated by government ordinances.

(3) Other than the matters stipulated in the preceding paragraph, technical standards on the structure of prefectural roads and municipal roads shall be stipulated by ordinances of local public bodies, which are the road administrators of said roads, with consideration given to standards stipulated by government ordinances.

Technical standards on pavement have been stipulated as follows in accordance with these provisions in Paragraphs (1) and (2) of Article 30 of the Road Act by the Government Ordinance on Road Design Standards (Government Ordinance No. 320 of 1970).

(Pavement)

Article 23 (1) Pavement shall be laid on roadways, central strips (excluding median strips), road shoulders connected to roadways, bicycle tracks, etc., and sidewalks. However, this need not apply when there is some special reason, such as very small traffic volume.

(2) Pavement on roadways and marginal strips shall be designed by using 49-kN as the standard vehicle wheel load to have structure in conformity with the standards stipulated by ordinances of the Ministry of Land, Infrastructure, Transport and Tourism so that safe and smooth vehicle traffic can be ensured by considering designed daily volume, the weights of vehicles, the state of the subgrade, the situation of climate, and other conditions. However, this need not apply when there is some special reason, such as small vehicle traffic volume.

(3) Pavement on Type 4 roads (excluding tunnels) shall be designed to have a structure that, if necessary, allows rainwater to flow smoothly through road surfaces and is capable of reducing road traffic noise, with consideration given to the conditions of the areas in which said roads are located, land use in areas along said roads, and vehicle traffic. However, this need not apply when there are uncontrollable circumstances for some special reason, such as road structure and climate.

As seen in Paragraph (2) of Article 23 of the Government Ordinance on Road Design Standards, it is stipulated that the vehicle wheel load used for pavement design be 49-kN.

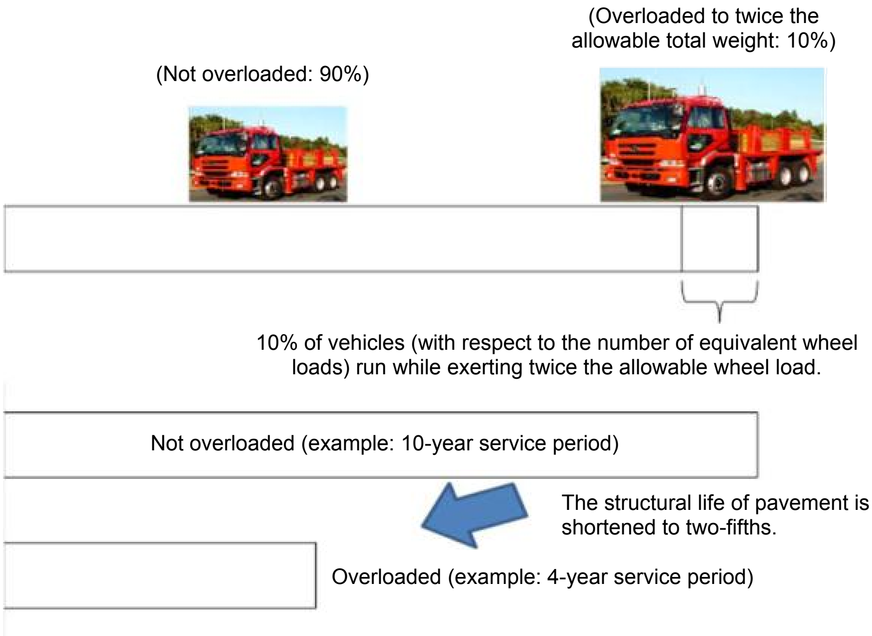
This is in accordance with both the safety standards on road trucking vehicles based on the Road Trucking Vehicle Act (Law No. 185 of 1951), which stipulates standards on road-running vehicles, and the maximum vehicle wheel load of 5 t specified by the Vehicles Regulations Order (Government Ordinance No. 265 of 1961), which stipulates limits to maintain road structure based on the Road Act and prevent danger to traffic.

Actual vehicle traffic consists of small to large vehicles of various types in different traffic volumes. Accordingly, structural pavement design (by an empirical design method) is basically performed by using traffic volume corresponding to the 49-kN equivalent wheel load. This traffic volume is obtained by converting the daily traffic volume of large vehicles (in each direction).

2 Adverse impacts of overloads to pavement

As described in the previous section, structural pavement design is performed basically by converting wheel loads to 49-kN equivalent wheel loads. Actual wheel loads are converted to 49-kN equivalent wheel loads by using a biquadratic law. According to this law, damage from traffic loads to pavement exponentially increases in proportion to the biquadrate of the ratio between the wheel load and the standard load (49-kN in this case). This law was derived from actual data on asphalt pavement on the basis of the result of the AASHO Road Test [1).

For example, one wheel exerting a 98-kN wheel load, which is twice the allowable wheel load of 49-kN, causes $2^4 = 16$ times the damage to pavement, compared with one wheel exerting a 49-kN wheel load. This fact means that even if only 10% (with respect to the number of equivalent wheel loads) of vehicles running on a road are in an overloaded state exerting twice the allowable wheel load, the structural life of the pavement will be shortened to two-fifths (**Appendix Figure-9.2.1**). Although road bridges are different structures (it is thought that impacts on their degradation are proportional to the 12th power of exerted weight), the Ministry of Land, Infrastructure, Transport and Tourism also considers that 0.3% of large vehicles illegally exceed the allowable weight, producing about 90% of the impacts of all traffic on road bridge degradation [2]. The Ministry is implementing measures to make the traffic of large vehicles more appropriate.



Appendix Figure-9.2.1: Example of calculation of impacts of overloading on service period

3 Penal regulations on overload

Regulations on overload have been enforced from a long time ago mainly from the perspective of preventing severe accidents caused by vehicle damage (ruptured axle (hub), etc.). Now public concern is also intensifying from the perspective of measures to be implemented on old roads.

Measures to be enforced not only to deal with drivers of overloaded vehicles but also the operators of the transport businesses and transport contractors are being stipulated.

(1) Road Traffic Act

1) Drivers

For overloaded driving, penalty points will be assigned, and payment of a fine is required, as specified in the driving license system. For loads twice the legal limit or greater, penal servitude up to six months or a fine of up to 100,000 yen will be incurred. Drivers are also required to produce a vehicle inspection certificate, to undergo weight measurement, and to take emergency measures if found to be overloaded (unloading on the spot and driving with police guidance).

2) Business operators

If a user of a vehicle orders or permits a vehicle to be overloaded in the course of business operations, the public safety commission will declare that that user is not allowed to drive or cause a person to drive a vehicle for a period not exceeding three months. A violation of this order will result in the user being subject to up to three months of penal servitude or a fine of up to 50,000 yen. Ordering or permitting a vehicle to be overloaded will result in the user being subject to up to six months of penal servitude or a fine of up to 100,000 yen.

3) Transport contractors, etc.

Transport contractors, etc. are prohibited from selling or consigning embarkation loads when they know that the loads will lead to overload for the relevant driver. If it is judged that transport contractors, etc. who have violated this prohibition may repeatedly require overloaded vehicles, a police chief will issue an "order to prevent recurrence." In addition, a violation of this order will result in the violator being subject to up to six months of penal servitude or a fine of up to 100,000 yen.

(2) Trucking Business Act (Law No. 83 of 1989)

The Trucking Business Act aims to realize appropriate and rational trucking business operations.

1) Trucking business operators

Vehicle usage will be suspended for a minimum of 10 days depending on the degree of overload. Suspension of vehicle use will be imposed even for a first violation if overloaded transport is found. Stricter penalties, such as much longer suspension of vehicle use and revocation of transport business license, will be imposed for repeated violations.

2) Transport contractors

When suspension of vehicle use described in 1) is imposed, a written request for cooperation in preventing the recurrence of overloaded transport will also be issued to the relevant transport contractor. In addition, a warning notice will be issued to transport contractors who have received written requests for cooperation two times within three years. If a transport contractor makes a request that cannot be achieved without overloading a vehicle, or intentionally requests overloaded transport, the Minister of Land, Infrastructure and Transportation will advise the relevant transport contractor to implement recurrence prevention measures.

(3) Road Act

1) Drivers and business operators

The Road Act stipulates that vehicles whose width, weight, height, length, or minimum turning radius exceeds the corresponding maximum limit stipulated in the Government Order on Road Design Standards must not be driven on roads. A violator of this stipulation will be subjected to a fine of up to one million yen (this also applies to persons who drive a vehicle in violation of the conditions for permission to drive a special vehicle).

Other penalties are also imposed in cases where the traffic permission certificate for the special vehicle is not carried by the driver and on persons who violate an order issued by a road administrator, etc., such as revocation of permission to drive.

4 Actions taken for overload prevention

(1) Permanent control base (roadside)

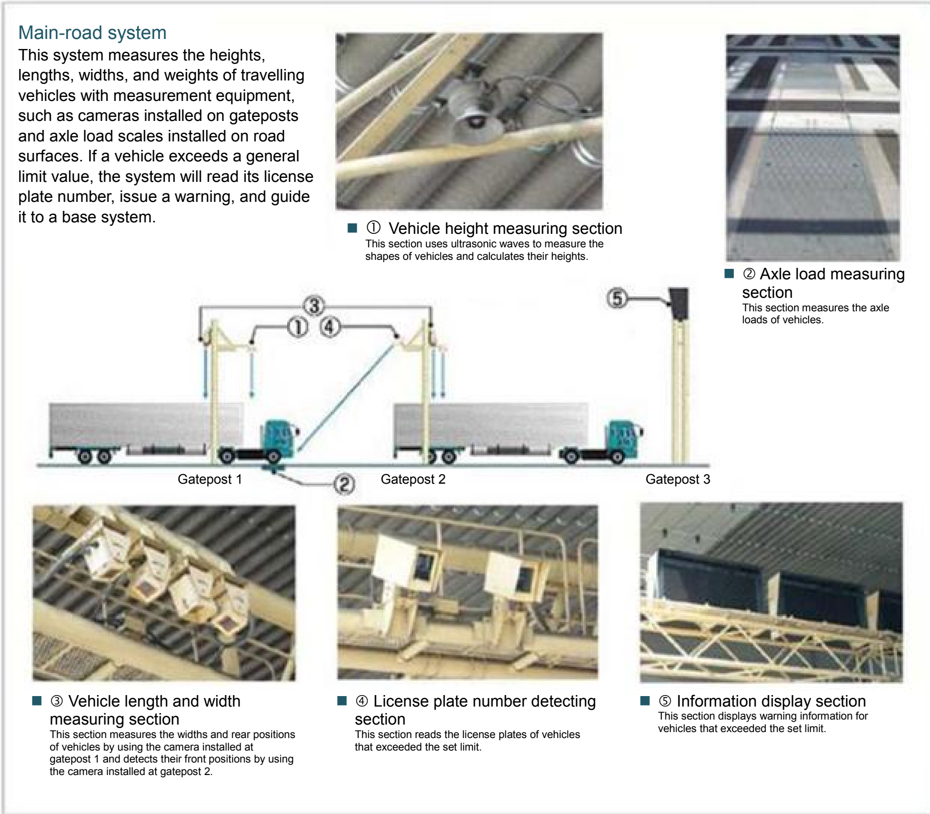
Special control bases (example: **Appendix Photograph-9.4.1**) are constructed on the sides of trunk roads, and road administrators and the police watch for vehicles violating laws, in cooperation when necessary.

Appendix Photograph-9.4.1: Special control base [3)]

(2) Permanent control base (overhead)

Automatic special-vehicle measurement systems (example: **Appendix Photograph-9.4.2** and **Appendix Figure-9.4.1**) are installed over the roadways of trunk roads to implement measures such as displaying license plate numbers and warning messages to violators on electronic message boards.

Appendix Photograph-9.4.2: Installed automatic special-vehicle measurement system [4)]



Appendix Figure-9.4.1: Vehicle measurement system [4)]

(3) Control at toll booth entrances in accordance with the Vehicles Regulations Order

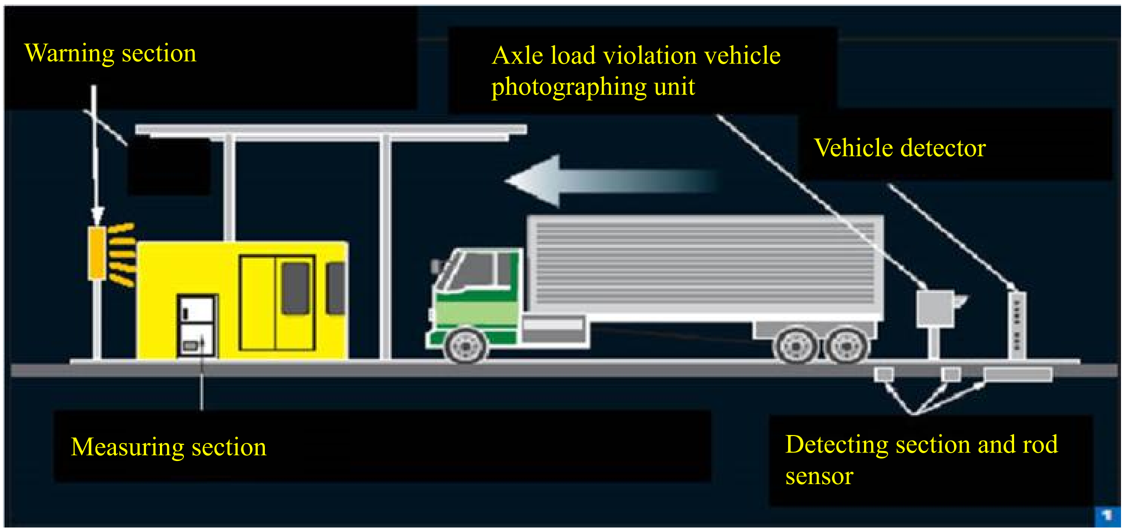
Teams for enforcing controls in accordance with the Vehicles Regulations Order are deployed at interchange entrances, guiding vehicles to a weighing area to perform measurement with a truck scale or some other measuring instrument (example: **Appendix Photograph-9.4.3**). They implement measures for vehicles in violation of laws, such as load reduction and orders for the vehicle to exit the expressway, which include U-turns or exit from a specified interchange (example: **Appendix Figure-9.4.2**).

Appendix Photograph-9.4.3:
Measurement of total weight after guiding a vehicle from a toll booth to a measurement area [5)]

Appendix Figure-9.4.2: Examples of measures implemented on a violator [5)]

(4) Warning issued at toll booths

Axle loads are automatically measured when vehicles pass through expressway toll booths, and a warning will be issued to overloaded vehicles (example: **Appendix Figure-9.4.3**).



Appendix Figure-9.4.3: Vehicle weight measuring system[6)]

(5) Overload prevention measures, etc. implemented by the government offices concerned and public works

The overloading problem can be traced back to a problem with frequent severe traffic accidents caused by large cargo trucks, such as dump trucks, in around 1965 (**Appendix Table-9.4.1**). Measures to prevent overloading have gradually been enhanced since then, not only by imposing legal regulation and control on drivers, business operators, etc., but also by regulating orders for public works operated by the national government, etc. and providing guidance for relevant organizations. At present, overload prevention measures are stated in specifications as part of contract documents for public works to eliminate illegal dump trucks from public works.

"Regarding Present Measures to Prevent Illegal Overload Traffic"

(Agreement among the government offices concerned on August 29, 1981)

- Thorough guidance on prevention of illegal overload traffic
- Thorough guidance on prevention of illegal alteration of article loading units, such as installation of additional frames
- Strengthening of control of illegal overload traffic

"Regarding Elimination of Dump Trucks with Additional Frames, etc."

(Agreement among the government offices concerned on March 19, 1986)

- Thorough guidance for the business operators concerned, etc.
- Strengthening of control of vehicles with additional frames, etc.

During this period, the Road Traffic Act was revised mainly to strengthen penalties for driving overloaded vehicles and the accountability of transport contractors, vehicle users, etc. who encourage such driving.

"Procedures for Overload Prevention Measures on Dump Trucks in Works Implemented by the National Government"

(Gi-Cho-Hatsu No. 161 and Ei-Kan-Hatsu No. 32 of the Ministry of Construction)

- Implementation of thorough site inspection and reading of items on overloading during on-site explanation
- Check of descriptions in the construction plan and instructions in everyday supervisory activities

"Regarding Measures to Prevent Illegal Overloaded Traffic"

(Agreement among the government offices concerned on April 8, 1994)

- Thorough guidance to and supervision of the business operators concerned
- Strengthening, etc. of control of illegal overloaded traffic
- Overload prevention measures, etc. on orders for public works
- Establishment of a cooperative system among the agencies and organizations concerned

Appendix Table-9.4.1: Overview of the Occurrence of Severe Accidents caused by Overload in Those Days created from 7)

No.	Prefecture	Accident name	Time and date of occurrence	Overview of accident	Remarks
1	Shizuoka	Accident with multiple human casualties caused by the so-called "fade phenomenon" that occurred in a large trailer	3:05 p.m. on Monday, August 1, 1988	A large trailer (maximum payload: 31.5 tons) was travelling on a long downward slope with 45.5-ton steel products loaded on it. Frequent use of its foot brake caused the so-called "fade phenomenon," resulting in loss of braking capability. To prevent collision into the rear end of a passenger vehicle waiting for a traffic light, the driver intentionally overturned the trailer. However, loaded steel products fell directly onto the passenger vehicle.	Fatalities: 3 persons Seriously injured: 2 persons
2	Shizuoka	Accident with multiple human casualties caused by the so-called "fade phenomenon" that occurred in a large trailer	6:20 a.m. on Saturday, June 15, 1991	A large trailer (maximum payload: 24 tons) was travelling on a long downward slope with 40.6-ton steel products loaded on it. Frequent use of its foot brake caused the so-called "fade phenomenon," resulting in loss of braking capability. The trailer collided into the rear end of a passenger vehicle ahead of it. It did not stop there, but collided with five more passenger vehicles waiting for a traffic light one after another at the second and third spots at a location about 1.9 km away. The passenger vehicles burst into flame.	Fatalities: 8 persons Seriously injured: 1 person Slightly injured: 1 person
3	Kyoto	Accident with multiple human casualties at the Oka railway crossing of the Fukuchiyama line	8:16 a.m. on Tuesday, June 25, 1991	A large truck (maximum payload: 8.75 tons) with 19.6-ton construction equipment (power shovel) loaded on it got stuck in the Oka railway crossing of the JR-West Fukuchiyama line. A three-car train collided with the truck.	Slightly injured: 308 persons Train service suspension: 40 trains Affected: About 4,500 persons
4	Nagano	Accident with multiple human casualties caused by runaway of a large trailer	10:40 p.m. on Tuesday, March 17, 1992	A large trailer (maximum payload: 36 tons) was running on a long downward slope with 48-ton steel-plate coils loaded on it. The driver was aware of a brake failure but continued driving. As a result, the trailer lost control and collided with 10 vehicles running in the opposite and same directions, finally irrupting into a gas station.	Fatalities: 3 persons Seriously injured: 1 person Slightly injured: 3 person
5	Chiba	Accident with multiple human casualties at the Osuga railway crossing of the Narita line	4:06 p.m. on Monday, September 14, 1992	A large dump truck (maximum payload: 8.75 tons) loaded with 37-ton of mountain sand was travelling on a downward slope at a speed of about 40 km/h. Near the Osuga railway crossing of the JR Narita line, the vehicle had too much momentum due to being overloaded and lost its braking ability. As a result, the dump truck almost collided with two vehicles waiting for the crossing gate to open. In order to pass through the crossing before an approaching train, it changed to the right lane and entered the crossing while accelerating. However, it collided with the approaching four-car train.	Fatalities: 1 person Seriously injured: 1 person Slightly injured: 64 persons Train service suspension: 32 trains Affected: About 5,300 persons
6	Tokyo	Multiple fatal accidents involving eight vehicles near the Gokokuji ramp of Metropolitan Expressway 5	About 7:40 p.m. on Sunday, May 9, 1993	A large trailer (maximum payload: 12.7 tons) with 46 rolls of paper (595 kg per roll and about 27.4 tons in total; overweight by approx. 110%) loaded on it was travelling on the Metropolitan Expressway at a speed of about 90 km/h. It came into contact with a median strip due to a steering mistake and dropped all the rolls of paper onto the road. The rolls collided with seven vehicles travelling on inbound lanes, and the driver left the scene and fled.	Fatalities: 4 persons Seriously and slightly injured: 4 persons

(6) Implementation of overload prevention measures and their effectiveness

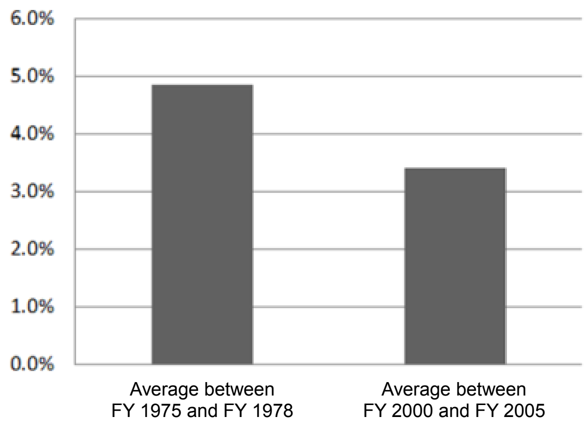
Various types of overload prevention measures have been implemented as described above, and the number of cases of overloading is decreasing as a result. Appendix Figure-9.4.2 shows the change in the number of overloaded vehicle cases in recent years. The measures are steadily being implemented. According to the result of vehicle weight surveys conducted by the former Ministry of Construction (the present Ministry of Land, Infrastructure, Transport and Tourism), the proportion of the number of wheel loads exceeding 49-kN on heavy traffic routes (traffic volume class: N_7) of national roads directly controlled by the national government decreased from 4.9% to 3.4% from the period between 1975 and 1978 to the period between 2000 and 2005[8)] (**Appendix Figure-9.4.4**).

Since the traffic volume of large vehicles is almost constantly increasing (**Appendix Figure-9.4.5**), the measures have also been continuously implemented in recent years [9)] (example: **Appendix Figure-9.4.6**).

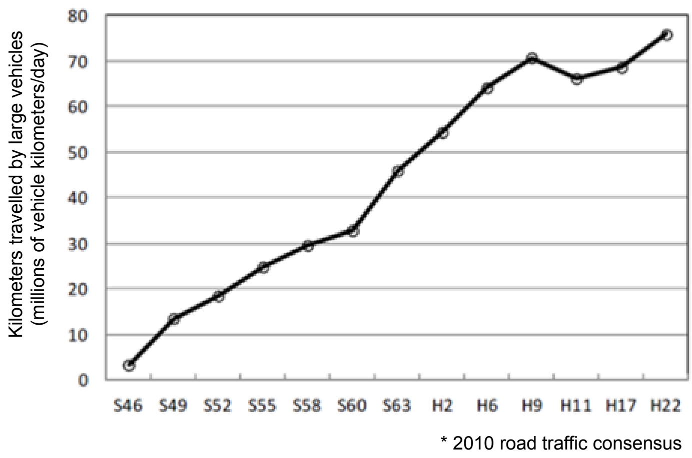
Appendix Table-9.4.2: Change in the number of overloaded vehicles created from 7) and 10)

	8,833,472	120,306	1.4	
	10,158,709	115,272	1.1	−4.2
	11,836,250	126,853	1.1	10.0
	12,470,100	130,394	1.0	2.8
	12,119,233	118,805	1.0	−8.9
	10,910,767	68,040	0.6	−42.7
	11,642,059	90,621	0.8	33.2
	11,687,758	90,356	0.8	−0.3
	12,307,752	97,228	0.8	7.6
	13,154,814	96,863	0.7	−0.4
	13,735,091	103,233	0.8	6.6
	13,684,112	106,756	0.8	3.4
	13,188,225	101,576	0.8	−4.9
	12,725,577	99,512	0.8	−2.0
	10,954,897	97,199	0.9	−2.3
	8,474,055	89,368	1.1	−8.1
	9,040,369	83,192	0.9	−6.9
	9,264,940	77,453	0.8	−6.9
	8,846,233	77,793	0.9	0.4
	8,600,922	91,613	1.1	17.8
	8,061,550	84,760	1.1	−7.5
	7,785,557	54,155	0.7	−36.1
	8,055,213	57,959	0.7	7.0
	8,298,676	50,168	0.6	−13.4
	8,304,115	39,739	0.5	−20.8
	8,278,415	34,272	0.4	−13.8
	7,273,422	29,674	0.4	−13.4
	7,181,868	23,362	0.3	−21.3
	7,188,014	23,359	0.3	0.0
	7,473,925	22,691	0.3	−2.9
	7,807,751	18,923	0.2	−16.6
	8,233,990	15,819	0.2	−16.4
	6,986,838	13,926	0.2	−12.0
	7,795,543	14,510	0.2	4.2
	7,526,529	12,514	0.2	−13.8
	7,657,690	11,487	0.2	−8.2
	7,368,109	18,185	0.2	58.3
	7,191,467	17,650	0.2	−2.9
	7,145,961	15,827	0.2	−10.3
	6,811,383	13,455	0.2	−15.0
	6,442,921	11,998	0.2	−10.8

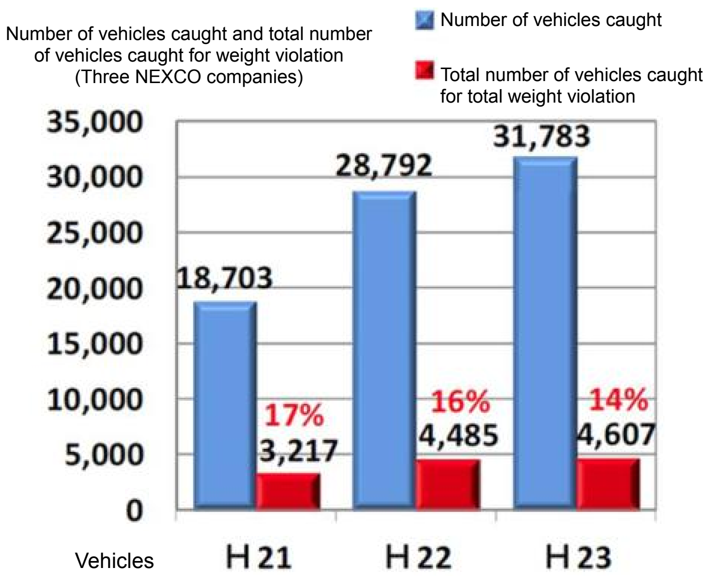
Proportion of the number of wheel loads exceeding 49-kN (average)



Appendix Figure-9.4.4: Change in the proportion of the number of wheel loads exceeding 49-kN on national roads directly controlled by the national government (traffic volume class: N_7) created from 8)



Appendix Figure-9.4.5: Change in the number·kilometers travelled by large vehicles [9)]



Appendix Figure-9.4.6: Change in the number of vehicles caught at toll gates of three NEXCO companies [9)]

(7) Activities that have been implemented as measures for old roads in recent years

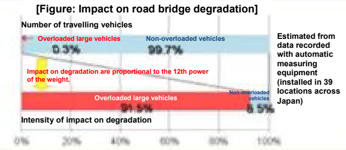
Social concern about overloaded large vehicles has been growing from the perspective of measures to be implemented on old roads. In addition, there is a need to realize efficient and prompt physical distribution through various approaches, such as using larger vehicles, enhancing load factors, and speeding up permission procedures. To satisfy such requirements, various measures have been adopted to revise permission standards for large vehicles, to simplify permission procedures for appropriate users, to impose severe punishments on malicious violators, and to regulate the traffic of large vehicles appropriately (**Appendix Figure-9.4.7**).

Policies on regulating the traffic of large vehicles appropriately as measures to be implemented for old roads

Background

1. **Of large vehicles, 0.3% illegally exceed the allowable weight***, producing **about 90% of the impact of all traffic** on road bridge degradation. A small part of the violating vehicles is the principal factor in road degradation. * Violating vehicles that exceed a total vehicle weight of 20 tons

   → **The impact of a vehicle with an axle load of 20 tons on a road bridge is equivalent to that of 4,000 vehicles with an axle load of 10 tons.**
2. It is desired to realize efficient and prompt physical distribution through various approaches such as larger vehicles, enhancing load factors, and speeding up permission procedures.



Basic policy

Large vehicle traffic is appropriately regulated by revising permission standards for large vehicles, simplifying permission procedures for appropriate users, and **imposing severe punishments on malicious violators**.

Specific activities

Revising standards for traffic permission and improving the permission review procedure

(1) Unifying permission standards on semi-trailer coupling vehicles, such as van type vehicles
- Relaxing the restriction on the driving axle load of semi-trailers, such as vans, to 11.5 tons, which is equivalent to that on international marine containers [Implemented in FY 2014]

(2) Revising permission standards on transport of 45-foot containers, etc.
- Relaxing the restriction on the vehicle lengths of vehicles for loading 45-foot containers and semi-trailers, such as vans [Implemented in FY 2014]

(3) Shortening the period for permission
a. Promoting the construction of a database of information on principal roads [Continuously implemented]
b. Improving the online traffic-permission application system and promoting the spread of its use [Continuously implemented]
c. Expanding the range of roads to which large vehicles are to be guided and implementing collective review by the national government [Commenced on October 27, 2014]
d. Consolidating review systems related to traffic permission [Prepared for stepwise implementation]

(4) Simplifying permission procedures for appropriate users
a. Extending the permission period (two years at present) for persons with no violation record [Prepared for implementation in FY 2015]
b. Operating traffic permission by traffic route tracking based on ITS technology [Prepared for implementation in FY 2016]

Strengthening violation control and guidance to violators

(1) Implementing thorough control on illegally-overloading large vehicles
a. Installing additional automatic measuring equipment [Implemented in FY 2014]
b. Implementing control in cooperation among road administrators, such as collective control by drawing cordon lines on an expressway and a general road that are travelling in parallel, and installing automatic measuring equipment [Continuously implemented]

(2) Stricter instruction of violators
a. Summoning violators to a National Highway Office to provide corrective instruction and indicting habitual violators (an indictment will be made as of the fourth order for action or the fifth instruction for corrective actions) [Implemented in FY 2013]
b. Immediately indicting malicious violators caught by field control overloading the standard load by two times or more [In effect as of February 23, 2015]
c. Implementing report collection and on-the-spot inspections on violators in accordance with the revised Road Act, and indicting violators if they refuse report collection and on-the-spot inspections [In effect as of May 30, 2014]

(3) Establishing cooperative systems with related organizations
a. Establishing a liaison committee for promoting appropriate road use in cooperation with the Ministry of Land, Infrastructure, Transport and Tourism (Road Bureau and Road Transport Bureau), the National Police Agency, expressway companies, Japan Trucking Association, etc. and implementing educational activities for road users including transport contractors and sharing information on violators, etc. [Implemented in FY 2013]
b. The Ministry of Land, Infrastructure, Transport and Tourism directs Japan Expressway Holding and Debt Repayment Agency and six expressway companies to consider strengthening control and instruction, etc. of violators. [Implemented in FY 2014]
c. Implementing administrative disposition, etc. on violating transport business operators in accordance with the Trucking Business Act in cooperation with the Road Transport Bureau and considering measures to provide corrective instruction, etc. for the relevant transport contractors [In effect as of March 1, 2015]

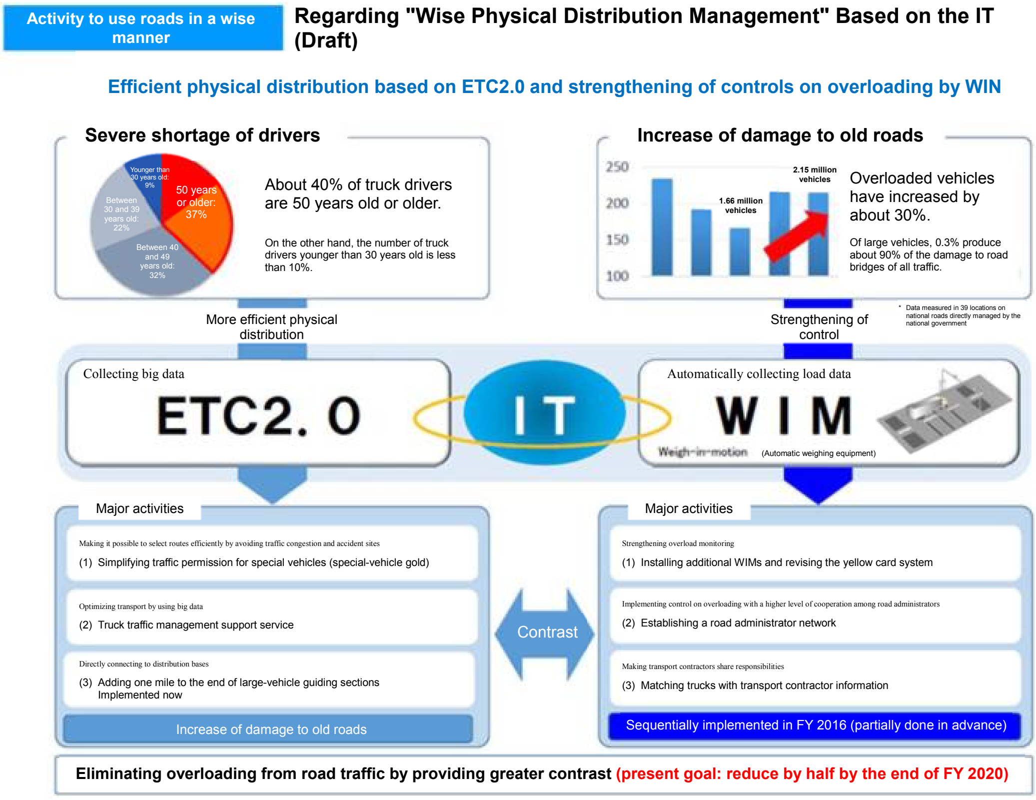
Effects of the implementation of the policy

- **Extension of the life of road structures**
- **Realization of efficient and prompt physical distribution**
- **Prevention of dangerous traffic**

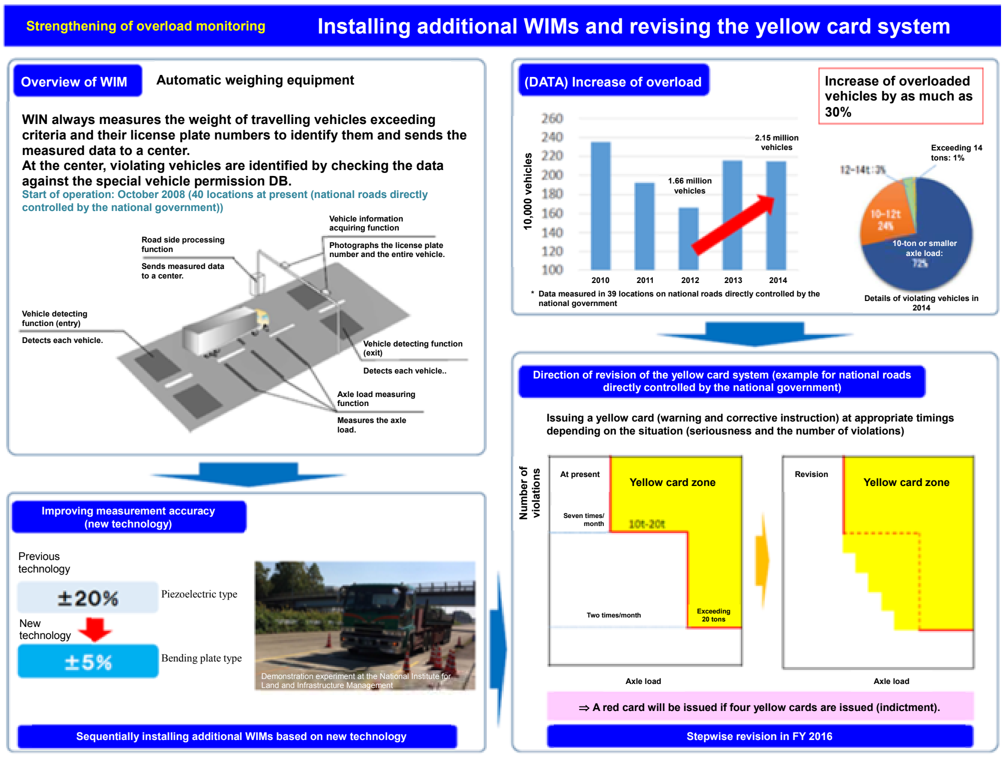
Appendix Figure-9.4.7: Policies on regulating the traffic of large vehicles appropriately as measures to be implemented for old roads [11)]

(8) Direction of measures to be implemented in the future

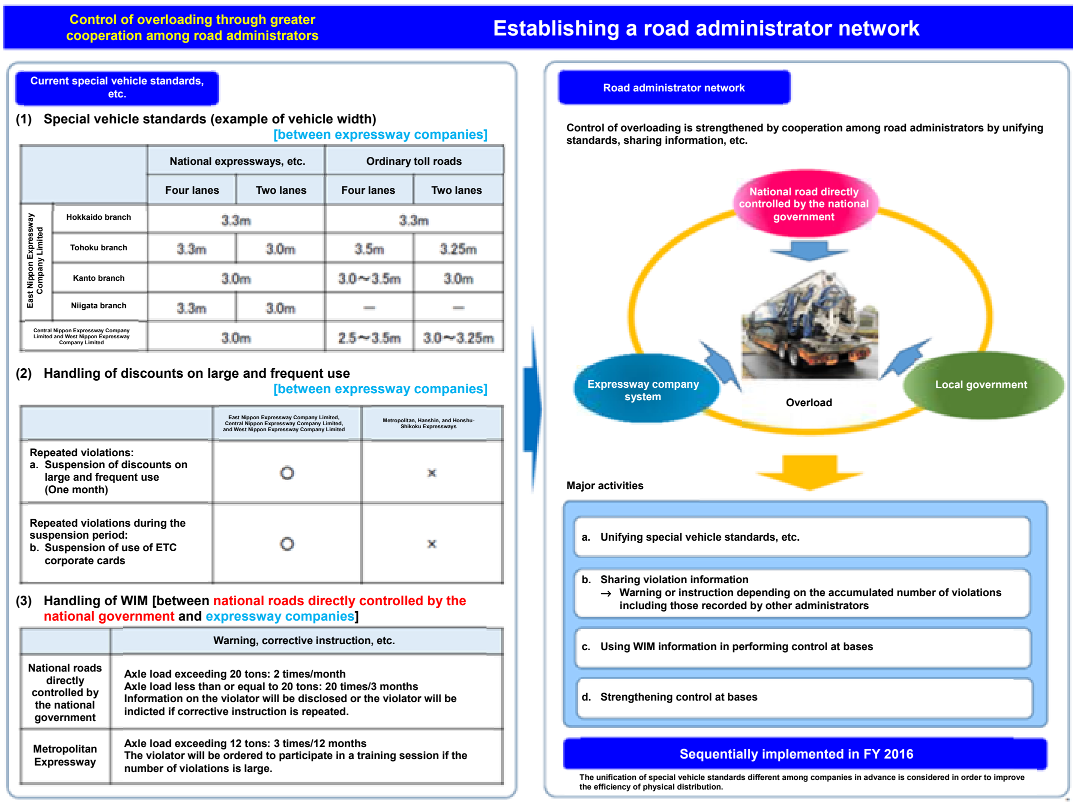
A deliberative council of the national government has proposed "Wise Physical Distribution Management Based on IT (Draft)" as measures to use roads in a wise manner, as part of their discussion on the basic direction, etc. of the physical distribution policy for the future [9]. The measures listed are various types of supports using ETC2.0 for physical distribution, overload monitoring with additionally installed automatic weighing equipment (WIM: weigh-in-motion), control of overloading through cooperation among road administrators, and implementation of measures to make transport contractors share responsibilities (**Appendix Figures-9.4.8** to **9.4.11**).



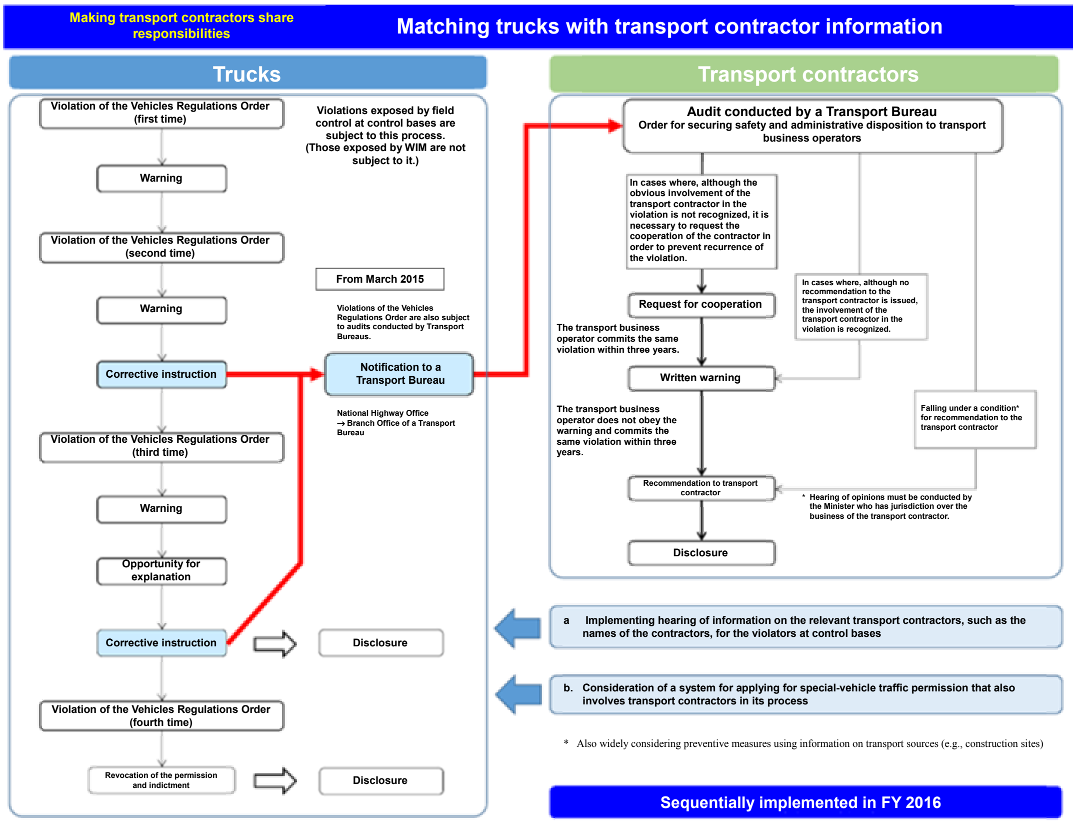
Appendix Figure-9.4.8: "Wise Physical Distribution Management" Based on IT (Draft) [12]



Appendix Figure-9.4.9: Installation of additional WIMs and revision of the yellow card system [12)]



Appendix Figure-9.4.10: Establishment of road administrator network for strengthening control of overloading [12)]



Appendix Figure-9.4.11: Measure to match trucks with transport contractor information to strengthen control of overloading [12)]

[References]

1) Japan Cement Technology Association: AASHO Road Test, 1966

2) Ministry of Land, Infrastructure, Transport and Tourism website: http://www.mlit.go.jp/common/001085051.pdf (confirmed on December 22, 2015)

3) Kanto Regional Development Bureau, etc.: A special-vehicle control base will be opened in a location along ordinary national road 51 in Narita city, Document for a press conference on May 15, 2007

4) Website of the Hyogo Highway Office, Kinki Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism: https://www.kkr.mlit.go.jp/hyogo/introduction/jigyou/jigyo/route43/index2.html (confirmed on December 22, 2015)

5) Central Nippon Expressway Company Limited: Strengthening of Control of Violating Vehicles due to Overloading or Other Violations, Regular press conference, Document 4, April 23, 2015

6) Techno Hanshin Corporation website: http://www.techno-hs.co.jp/service.html (confirmed on December 22, 2015)

7) Toshio Shimizu: Present situation of overloaded driving and measures against it, Road Administration Seminar, May 1994

8) Naotoshi Watanabe, Tadashi Inoue, and Kazuyuki Kubo: Analysis of Result of Vehicle Weight Survey, the 62nd Annual Academic Lecture of JSCE, 5-089, September 2007

9) Technical Review Committee on the Ideal Long-term Maintenance and Update of Expressway Property: Report of Technical Review Committee on the Ideal Long-term Maintenance and Update of Expressway Property, January 2014

10) Cabinet Office: White Paper on Traffic Safety (1997 edition) to (2015 edition), http://www8.cao.go.jp/koutu/taisaku/h09-hakusho/haku9700.htm (confirmed on January 27, 2016)

11) Road Bureau and Road Transport Bureau, Ministry of Land, Infrastructure, Transport and Tourism: Preparation of Related Ministerial Ordinances, etc. on Revision, etc. of Permission Standards for Large Vehicles, Document for a press conference on March 31, 2015, Reference material (policy on appropriate standardization)

12) Document 4 of the 11th Physical Distribution Subcommittee, Basic Policy Section, Road Working Group, Social Infrastructure Development Council, Ministry of Land, Infrastructure, Transport and Tourism: Wise Physical Distribution Management Based on IT (Draft)

Appendix 10: Damage that Frequently Occurs in Other Countries

—Pavement damage that occurs due to underground water or water in base courses mainly in tropical countries and examples of measures against it—

Importance of drainage from the base course and subgrade of pavement

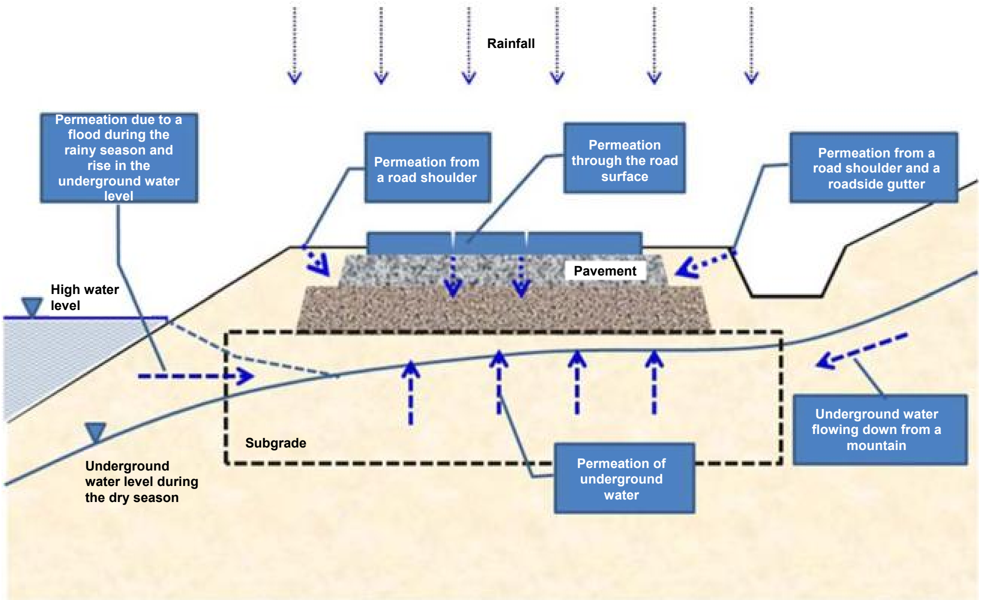
Appropriate water treatment for pavement will extend its life economically. In particular, surface courses constructed using double bituminous surface treatment (DBST), asphalt pavement that is not very thick, and the joints and shoulders of concrete paved roads tend to be affected by water permeating into the relevant base courses or subgrades. DBST in and of itself cannot completely prevent water on the road surface from permeating into the base course and then the subgrade. Even asphalt pavement, if it is thin, may allow water on the road surface to permeate through cracks, etc. Therefore, it is essential to perform maintenance work, such as sealing. Draining permeating water must also be considered at the design stage. In addition, it should be noted that actions for maintenance and management may be difficult without implementing structural measures even after the completion of construction.

1 Basics of water and the bearing capacity of base courses and subgrades

a. Water permeating into a subgrade and pavement through various routes

As illustrated in **Appendix Figure-10.1.1**, water permeates into pavement through various routes.

Permeating water causes various types of problems. Since some of them may lead to severe damage, careful consideration and measures are necessary. Therefore, maintenance and management must be implemented on the basis of correct understanding of these permeation routes.

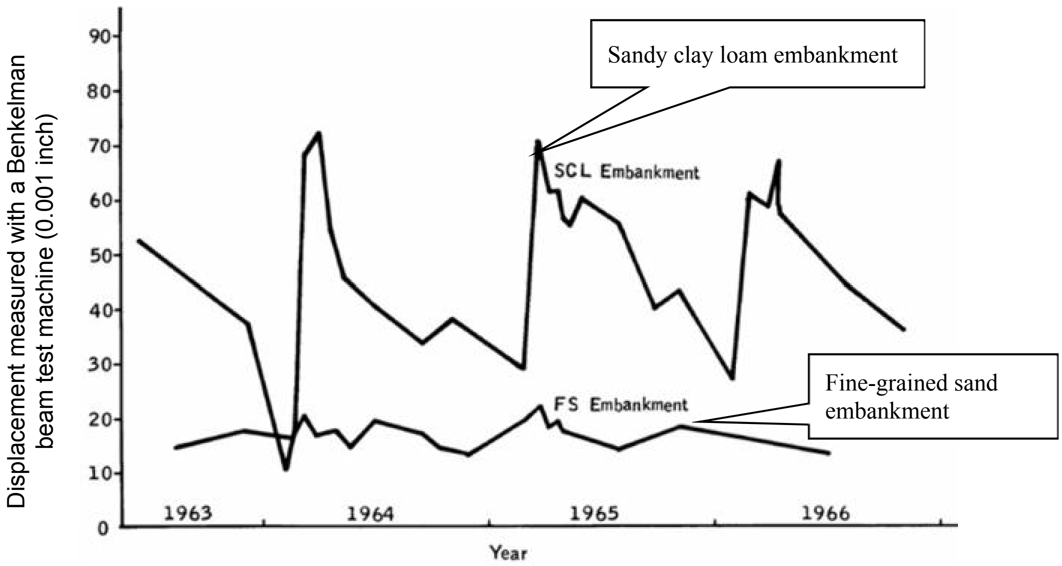


Appendix Figure-10.1.1: Water permeating into pavement through various routes

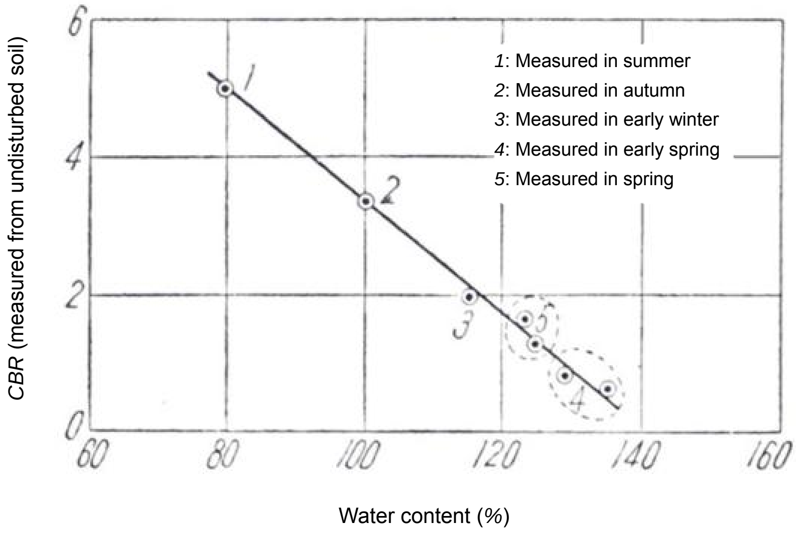
b. The connection between water content and change in CBR

If water permeates into clay or silty soil, it will easily deform because the water acts as a lubricant and, taking a subgrade as an example, it would rapidly lose its bearing capacity. If the subgrade absorbs so much water that it loses its bearing capacity, the deflection of the subgrade surface or some other deformation will occur, leading to the deformation of the base course on it. This damage will further expand into cracking in the asphalt mixture layer and potholes.

CBR is used as an index of bearing capacity. It has been reported that the CBR value changes with water content in the ground that varies depending on seasonal rainfall, snowmelt, and the freezing and thawing of subsoil (**Appendix Figure-10.1.2**). According to one report, the field CBR of a subgrade fluctuates from its minimum to a value of five times or more of the minimum in a certain cold region (**Appendix Figure-10.1.3**).



Appendix Figure-10.1.2: Seasonal change in displacement measured with a Benkelman beam test machine (Minnesota, the United States) 1)



Appendix Figure-10.1.3: Seasonal change in CBR value (using undisturbed specimens) 2)

Some regions in tropical countries are stricken by floods one after another for several months. In such regions, the increase in water content in subgrades and base courses due to inundation leads to a decrease in their bearing capacity. Therefore, the heights of subgrade surfaces must be carefully determined in the road design phase.

In cold regions, once water content in a base course or a subgrade starts to freeze, a high underground water level will supply water from the lower layers of the road due to the capillary effect. As a result, the base course and the subgrade expand as the ice grows, undergoing a phenomenon called frost heave. When the formed ice thaws, the subgrade and the base course will significantly lose their bearing capacity, and the relevant pavement will suffer fatal damage.

c. Damage and degradation in bearing capacity due to pumping

In concrete pavement, slabs make relatively large movements particularly at joints and the edges of shoulders. As a result, pumping will occur if the relevant base course contains water. Also in asphalt pavement, pumping will occur if water permeates through cracks reaching the base course surface to saturation.

Appendix Photograph-10.1.1:
Asphalt pavement in which pumping occurred due to water in the base course and subgrade

Pumping occurs as follows. If a grain base course, such as a macadam base course, contains a large amount of water, an incompressible fluid, the water will gather at the edges of shoulders and the joints of concrete pavement, or the cracks of asphalt pavement, etc. in response to the deformation of part of the base course due to a downward stress, producing a high pressure. This pressure will cause the water to flow fast, resulting in pumping. If pumping occurs, a large force and fast flow will be generated in some areas in accordance with Pascal's principle, which will carry out base course material (particularly the fine-grained fraction). As a result, the bearing capacity of the pavement will be lost, and the surface course will be deformed and damaged. Aggregates in the base course will be subjected to a force developed in the presence of water and scrape against one another which degrades and damages them.

2 Considerations for measures against base course drainage described on the basis of 3)

(1) Various types of water permeating into pavement and measures against permeation

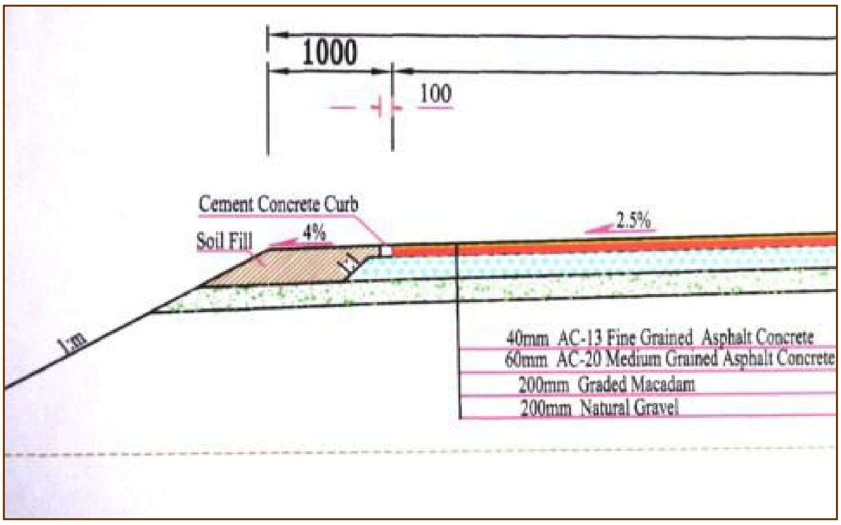
Water permeates into pavement through various routes as described above.

The first point to consider is the prevention of rainwater and other surface water from permeating into the base course and subgrade.

Accordingly, measures must be implemented to prevent roadside gutters from being filled with earth and sand and to maintain the water-tightness of the pavement surface. Therefore, it is essential to seal cracks and patch potholes in maintenance and management work.

The second point to consider is the removal of water permeating into pavement, particularly into the base course, as quickly as possible. To achieve such water removal, the water permeability of the base course must be ensured so that water will be guided to a slope face, etc. In cut cross sections, underground water may permeate into the subgrade and then the base course. In cases where such permeation is expected, sufficiently deep roadside gutters must be constructed and, if the pressure of seepage water is judged to be high, covered conduits must be constructed to drain water to the outside of the road.

Appendix Figure-10.2.1 shows an example of design for base course drainage. Similar base course drainage is adopted in many countries. In this design, one layer of the base course, for example, the subbase course, is made of a material in a specific level (e.g., 10^{-3} cm/sec) or a higher level and is extended to a slope face. As the coefficient of permeability for macadam base courses, 10^{-3} cm/sec or higher can be generally ensured with crusher-run (fine-grained fraction of 0.075 mm or smaller: 5% or lower) but cannot be ensured with crushed stone for mechanical stabilization. Accordingly, when crushed stone for mechanical stabilization is used for the upper base course, the subbase course must be made of a material with high water permeability, or the construction of a drainage layer must be considered as a special measure.



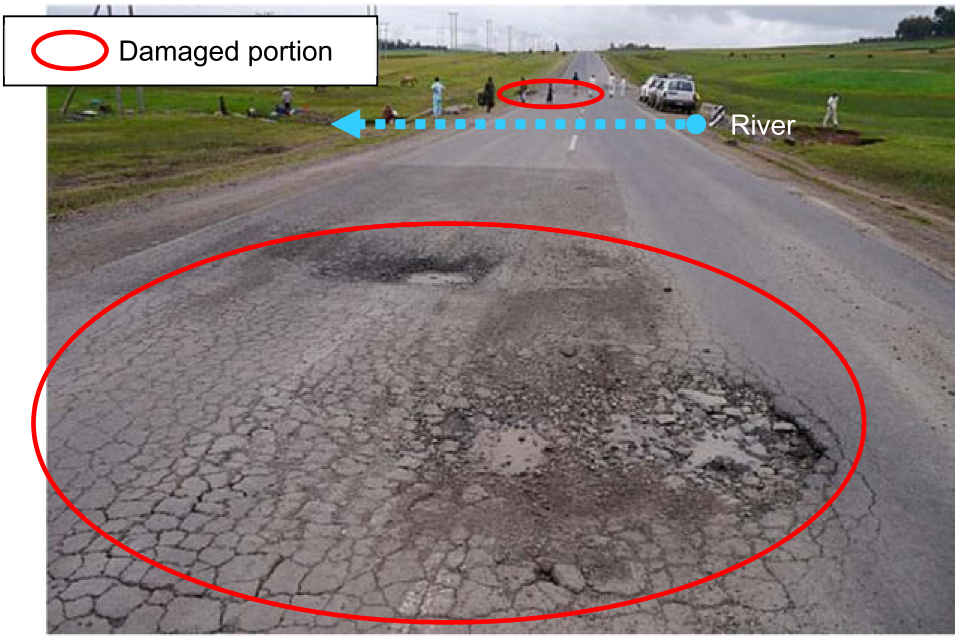
Appendix Figure-10.2.1: Design with a subbase course extended to a slope face (an expressway in Ethiopia)

For concrete pavement, thorough drainage must be implemented to prevent water from accumulating in the base course by sealing shoulders and joints to prevent water permeation, taking water permeability into consideration when designing the base-course material, and using longitudinal subdrainage in shoulders.

Measures against frost heave in cold regions and methods for analyzing its mechanism are unnecessary and omitted in this document.

(2) Damage in sag portions and measures against sag

In sag portions on roads, surface water flowing through roadside gutters and water flowing through the base course gather together. The gathering water saturates in the base course, and as a result, pumping may occur, leading to pavement damage. **Appendix Photograph-10.2.1** shows a typical case of pumping. Pumping is seen in two locations with sag portions. The two locations are in the two sides of a bridge laterally crossing the road. Part of the drainage from the base course and subgrade is led to the river. This pumping is thought to have been caused by water flowing down through the base course or the high underground water level. As a measure against sag, it is effective to construct sufficiently high embankments to separate the subgrade surface from the underground water level. Construction of appropriate roadside gutters is a basic measure. To ensure reliable performance, however, it is also necessary to consider constructing lateral covered conduits.



Appendix Photograph-10.2.1: Pavement damage from underground water in sag portions

(3) Damage from water from a mountain and measures against it

In the roadside along a mountain on sloped land, the underground water level is high, and pavement tends to be easily damaged (**Appendix Photograph-10.2.2**). In such a case, it is necessary to construct both roadside gutters on the mountain side of the road as well as covered conduits to prevent effects on the pavement by removing the underground water.

The same measures are also necessary for areas connecting cutting portions to embankment portions. Construction of lateral covered conduits is recommended.

Appendix Photograph-10.2.2: Pavement damaged from underground water from a mountain (earth and sand in the roadside gutter must be excavated.)

In addition, if underground water seepage is observed in cutting sections during construction, the water will eventually damage the pavement as it will become confined underground water (**Appendix Photograph-10.2.3**). In such a case, maintenance and management costs will greatly increase unless the problem with underground water is solved by constructing longitudinal covered conduits.

Appendix Photograph-10.2.3: Pavement damaged from confined underground water on a road with canal structure (presented by Metropolitan Expressway Company Limited)

3 Policies on base course and subgrade drainage in the United Kingdom and the United States

A UK pavement guidebook for foreign countries, Overseas Road Note 31 (ORN31) [4)] and US pavement guidebooks, Guide for Design of Pavement Structures 1993 (AASHTO1993) [5)] and Mechanistic-Empirical Pavement Design Guide (AASHTO2004) [6)] describe water in base courses and subgrades as follows.

(1) ORN31 of the United Kingdom

ORN31 presents descriptions based on thorough consideration of damage from the underground water level and water in base courses. Its basic policy is as follows: careful considerations must be given to the maintenance and management of roadside gutters so as to prevent water permeation into pavement; however, since it is difficult to implement maintenance by completely preventing water permeation over a long period of time, pavement should be appropriately designed so that permeating water can be drained. It also states for the same reason that pavement must not be designed to have a structure in which an impermeable material is used for shoulders to prevent base course drainage as if it is located in a gutter. In addition, it explains that the relationship between the subgrade surface and the underground water level is important, and recommends that the subgrade surface be higher than the underground water level. According to ORN31, when a CBR test cannot be implemented, the subgrade CBR can be estimated from the soil quality classification and the underground water level as a simplified subgrade CBR estimation method. It can accordingly be said that importance is placed on water (water content) in subgrades. As seen in **Appendix Table-10.3.1**, pavement design differs as follows. For example, in sandy clay with a plasticity index (PI) of 20, the CBR class is S2 (3–4%) at an underground depth of 50 cm from the subgrade surface but is S3 (5–7%) at an underground depth of 1 m.

Appendix Table-10.3.1: Table for simplified estimation of design subgrade CBR class (S1 to S6) in ORN31

Table 3.2 Estimated design subgrade strength class under sealed roads in the presence of a water table

Depth of water table* from formation level (metres) Depth of underground water level from subgrade surface (m)	Subgrade strength class ** Design CBR class				
	Non-plastic sand	Sandy clay PI=10	Sandy clay PI=20	Silty clay PI=30	Heavy clay PI>40
0.5	S4	S4	S2	S2	S1
1	S5	S4	S3	S2	S1
2	S5	S5	S4	S3	S2
3	S6	S5	S4	S3	S2

* The highest seasonal level attained by the water table should be used.

Notes. 1. Since the strength classes given in Table 3.2 are based on estimated minimum CBR values, wherever possible the CBR should be measured by laboratory testing at the appropriate moisture content.

2. Table 3.2 is not applicable for silt, micaceous, organic or tropically weathered clays. Laboratory CBR tests should be undertaken for these soils.

** CBR classes (S1 to S6) are defined in ORN31 as follows.

Subgrade strength classes

Class	Range (CBR %)
S1	2
S2	3 - 4
S3	5 - 7
S4	8 - 14
S5	15 - 29
S6	30

(2) AASHTO policy of the United States (1993 and 2004 editions)

On the premise that the bearing capacity of pavement varies depending on the length of time for which its base course and subgrade are inundated, AASHTO1993 also requires a correction factor (drainage coefficient: m) determined by the drainage condition corresponding to the design structural index (SN value) to be set within the range of 0.4 to 1.4. AASHTO1993 mainly describes empirical design methods. In 2004, another guide, the Mechanistic-Empirical Pavement Design Guide, was released [7)]. This new guide devotes an entire chapter to base course drainage. It should be noted that the guide states that at present, it is a well-known fact that excessive water content in pavement markedly damages pavement durability against heavy loads, as is the case with the design philosophy on base course drainage described in ORN31 of the United Kingdom. The guide recommends various approaches as drainage measures. For example, preventing water permeation into the pavement structure; using materials that are not affected by water, such as good quality gravel; constructing pavement portions, such as shoulders, as pavement structures that minimize damage from water; and removing water permeating into pavement structures as quickly as possible.

In this construction method, the guide recommends installation standards on facilities for drainage other than surface drainage as listed in **Appendix Table-10.3.2**. The standards depend on regional conditions in the United States. **Appendix Figure-10.3.1** shows an example in the guide for design of a facility for drainage other than surface drainage.

Appendix Table-10.3.2: Necessity of drainage other than surface drainage

Climatic Condition	Greater than 12 million 20-year design lane heavy trucks			Between 2.5 and 12 million 20-year design lane heavy trucks			Less than 2.5 million 20-year design lane heavy trucks		
	$k_{subgrade}$ < 3 m/day	$k_{subgrade}$ 3 to 30 m/day	$k_{subgrade}$ > 30 m/day	$k_{subgrade}$ < 3 m/day	$k_{subgrade}$ 3 to 30 m/day	$k_{subgrade}$ > 30 m/day	$k_{subgrade}$ < 3 m/day	$k_{subgrade}$ 3 to 30 m/day	$k_{subgrade}$ > 30 m/day
Wet-Freeze	R	R	F	R	R	F	F	NR	NR
Wet-No Freeze	R	R	F	R	F	F	F	NR	NR
Dry-Freeze	F	F	NR	F	F	NR	NR	NR	NR
Dry-No Freeze	F	NR	NR	NR	NR	NR	NR	NR	NR

k_subgrade: Coefficient of permeability of subgrade (1 m/day is almost equivalent to 10^{-3} cm/sec.)

R: Some system for drainage other than surface drainage is recommended.

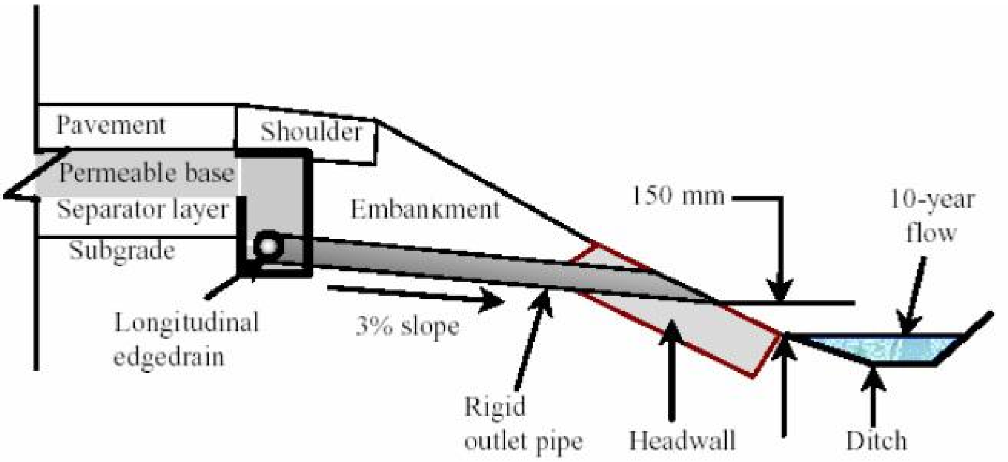
F: Installation of a facility for drainage other than surface drainage must be determined by considering the matters listed below.

(1) Past cases

(2) Cost benefit with consideration also given to other drainage means

(3) Water resistance of materials to be used

NR: A system for drainage other than surface drainage is not required.



Appendix Figure-10.3.1: Example of base course drainage [6)]

According to a teaching material on pavement engineering [8)] in the United States, drainage in paved roads has not been sufficiently considered in the United States. It devotes many of its pages to base-course drainage design. Most interstate highways were constructed in the 1950s and 1960s by laying concrete pavement. To extend the life of the pavement, longitudinal covered conduits are built in their shoulders [9)] to prevent water in their base courses from causing pumping, etc.

[References]

1) C.G. Kruse, Research Project Engineer: Minnesota Highway Department, FLEXIBLE PAVEMENT EVALUATION WITH THE BENKELMAN BEAM, 1968
2) Harumi Takeshita, et al.: Survey and Study on Subgrade and Base Course of Road in Cold Region—Survey Report on National Road 4—, Report of Public Works Research Institute, September 1956
3) Japan International Cooperation Agency (JICA): Handbook on Road Pavement Design in Preliminary Surveys for Cooperation (Draft), April 2015 (released on the JICA website)
4) Transportation Research Laboratory: Overseas Road Note 31, 1993
5) AASHTO Guide for Design of Pavement structures, AASHTO, 1993
6) Mechanistic-Empirical Pavement Design Guide, AASHTO, 2004
7) Subcommittee on Pavement Design, Committee on Pavement Engineering, JSCE: (Feature Article) Mechanistic-Empirical Pavement Design Guide, Asphalt, No. 218, October 2005
8) Yang H. Huang: Pavement Analysis and Design, Prentice Hall, 2003
9) Saburo Matsuno: Damage to Concrete Pavement and Its Performance, Rikoh Tosho, August 2014