20251105

Pavement Failures and Countermeasures

Rutting developed on the steep slope in very hot climate.

These slides will give you the ideas what are the problems and possible solutions which have been developed partly in JICA projects and partly in other projects in the past. Those are fundamentals for engineers who are in charge of road development.

JICA 課題別研修沖縄国際センター Nov. 05, 2025

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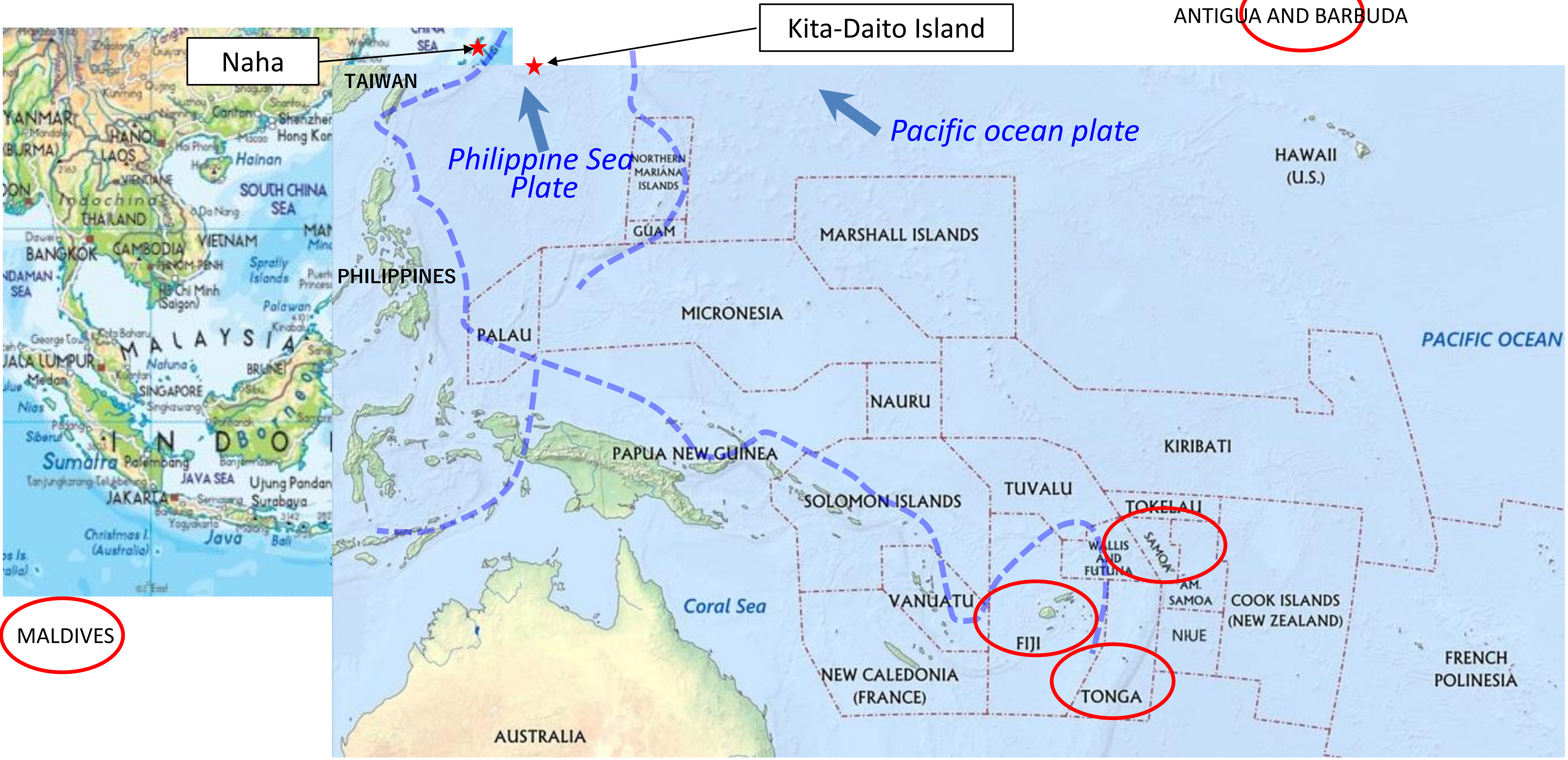


MALDIVES

Pavement Failures and Countermeasures

Table of Contents

Text: ①Japan Road Association, “Maintenance Guidebook of Pavement 2013”, (*CD-ROM provided*)
②JICA, “Road Pavement Handbook for JICA Grant Aid Projects”, 2020
https://libopac.jica.go.jp/images/report/P1000043701.html

1. Pavement design

(1)Role of Pavement

There are two major functions.

1) Surface functions

1.**Smoothness** for Safe & Rapid Traffic
  -Passable all the year round
  -Delete Rutting, Cracks, Roughness

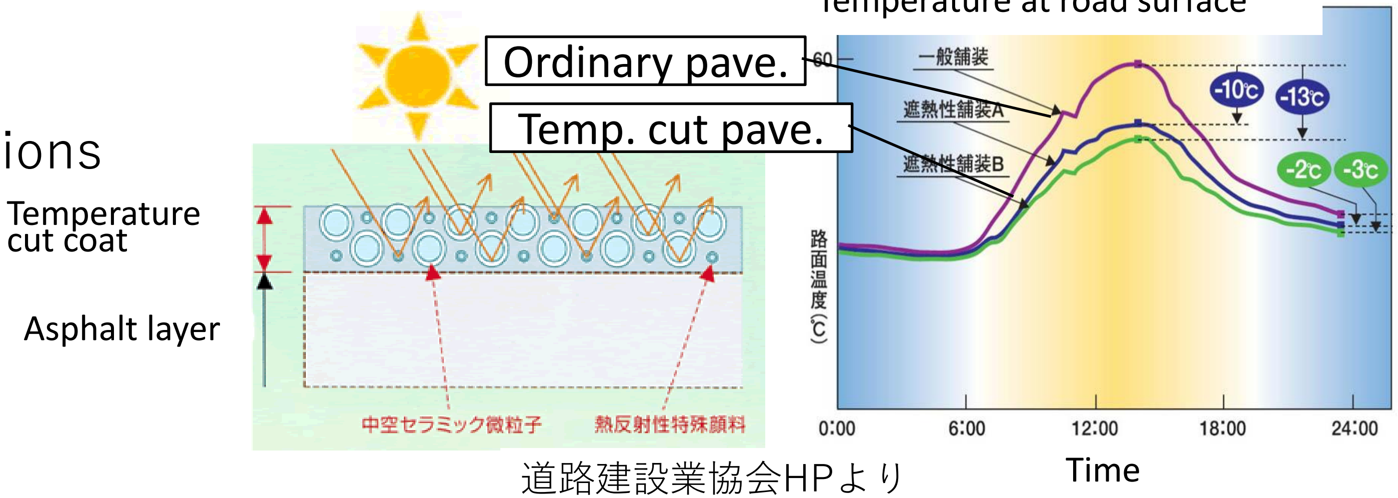
2. **Durability**
  -Against Cracks and Rutting

3. **Safety**
  -Skid resistance
  -No hazardous track

4. **Environmental** Functions
  -Noise,
  -Temperature,
  -Color, etc.

Non-water-proof road (Japan in 1950's)
ワトキンス調査団報告書

★Temperature cut coat pavement



道路建設業協会HPより

2)Load Bearing Function

The load-carrying capacity of flexible pavement is brought about by the load-distributing characteristics of the layered system.

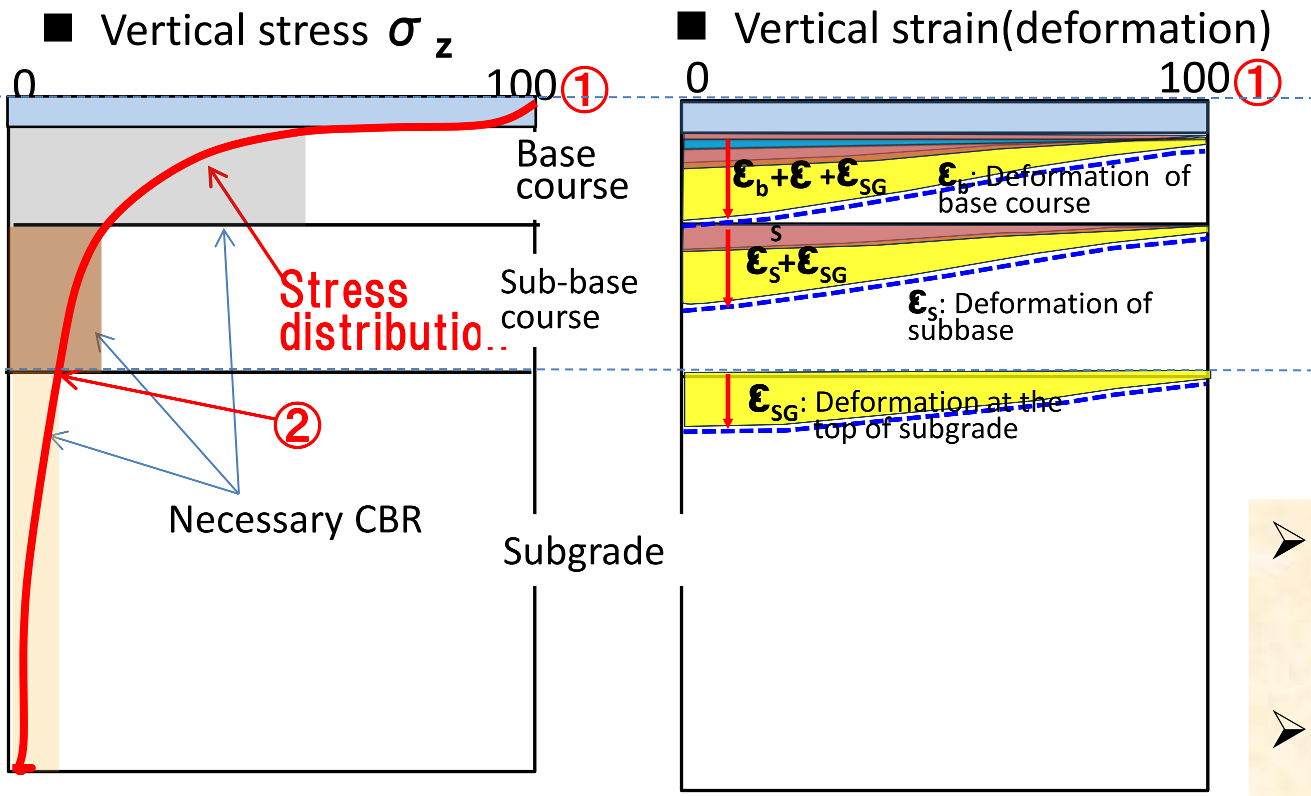
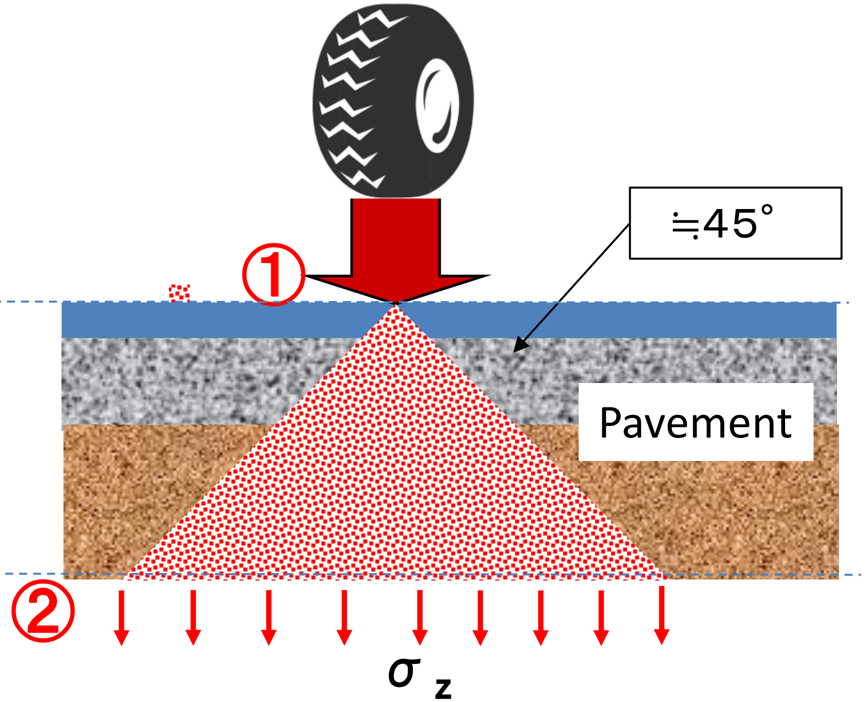


Fig. Stress and strain distribution in the pavement



- Principle of pavement design is to distribute traffic load smaller than the bearing capacity of each layer (CBR).
- At the same time, must be mindful of the significant influence of the subgrade.

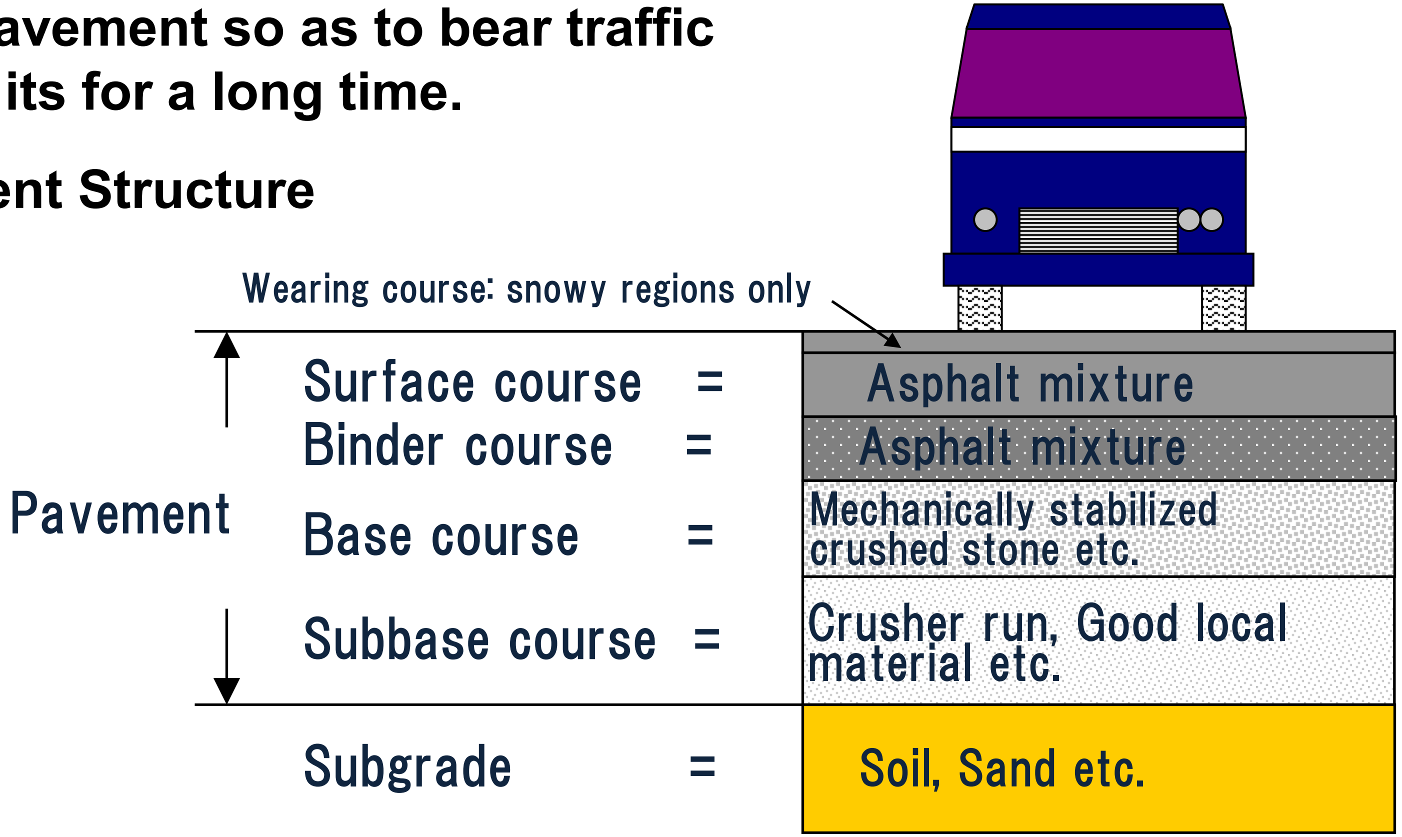
(2) Asphalt Pavement Design

1) Basic design elements and concepts

a. How to design the pavement

We design the pavement so as to bear traffic load and sustain its for a long time.

b. Asphalt Pavement Structure



Slide prepared by PWRI

2) CBR（California Bearing Ratio）test

CBR is used worldwide as a number to evaluate bearing capacity of pavement materials .

■ Definition: Compares the bearing capacity of a material with that of a well-graded crushed stone (standard material).

$$CBR = \frac{p}{p_s} \cdot 100$$

CBR = California Bearing Ratio (%)

P = measured pressure for site soils [N/mm²]

P_s = pressure to achieve equal penetration（25mm) on standard soil [N/mm²]

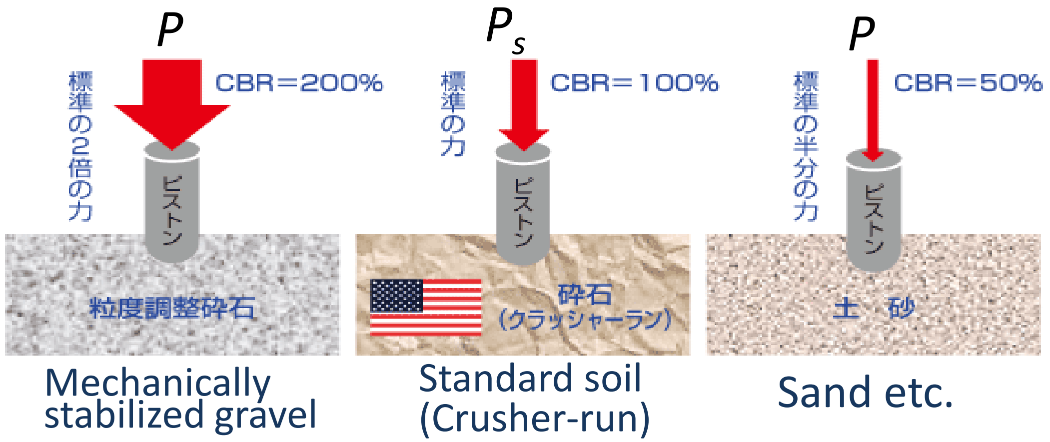


Photo : CBRTest machine
（協）島根県土質技術研究センター浜野浩幹氏

■Equivalent Single Axle Load (ESAL)　等値換算軸数

- $ESAL=\sum_{i=1}^{m} F_i n_i$　　←for all the traffic, for design period

F_i: EALF (Equivalent Axle Load Factor)　for ith-axle group
n_i : Number of passes of the ith-axle load group during the design period
m : number of traffic axle load groups

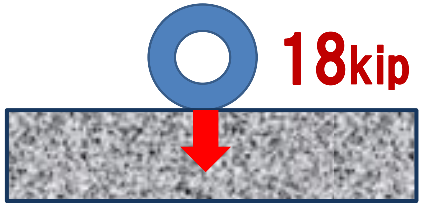
Damage of one truck is that of more than 10,000 passenger cars

- F_x=EALF=$\left(\frac{Lx}{18}\right)^4$　°(1軸毎の等値換算値)

EALF: Damage per pass to a pavement by the axle load (Lx) in question(x axle) relative to the damage per pass of a standard axle load of 18 kip.

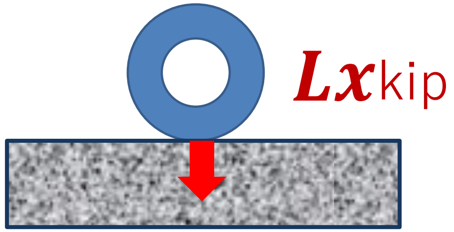
1 kip=4.448kN≃0.454t
18kip=8.17t

Standard axle load: 18kip



EALF = 1.0

X axle's load: Lxkip



$=\left(\frac{Lx}{18}\right)^4$

- The standard wheel load is 49 kN to obtain the Equivalent Wheel Load (ESWL) in Japan.

- **Practical solution**

  Use representative **Vehicle Damage Factor (VDF)** of each vehicle class instead of using Equivalent Axle Load Factor **(EALF)**

ESAL $=\sum_{i=1}^{m} F_i n_i$

i : number of vehicle classes

F_i: **VDF** of class i

n_i: number of vehicles

EALF (Equivalent Axle Load Factor) →

VDF (Vehicle Damage Factor)→

Fig. Example of VDF Calculation

See Text② P1-13

➢ Vehicle Damage Factors(VDF)

Table 2.7 Damage Factors by Country and Route (Reference Values)

Project			Chalinze-Tanga Road	Kilwa Road Widening Plan	Tazara Intersection Improvement	Route 1 Upgrading	George Bush Highway	Ambo-Gode Road	Addis-Tamabel Road
Target country			Tanzania	Tanzania	Tanzania	Ghana	Ghana	Ethiopia	Ethiopia
Road function			Urban trunk	Urban trunk	Urban trunk	Urban trunk	Urban trunk	Regional trunk	Regional trunk
Survey period			2003	2005	2010	2002	2008	2005	2006
Funding			Government	Japanese grant aid	Japanese grant aid	Japanese grant aid	Government	Government	Government
VDF Damage factor	Medium/large buses	BUS	4.00	1.39	0.56	0.86	-	1.14	0.62
	Trucks (2 axles)	MGV	3.00	4.67	0.56	2.17	7.04	0.84	5.27
	Trucks (3 axles)	HGV	14.30	8.84	8.00	4.25	14.19	6.17	3.69
	Trucks (4 axles)	VHGV	14.50	10.84	15.80	3.48	14.78	8.89	9.46
	Trucks (5 axles)					4.62	18.87		12.11
	Trucks (6 axles)					5.05	31.01		14.78

➢ Damage Factors(Continued)

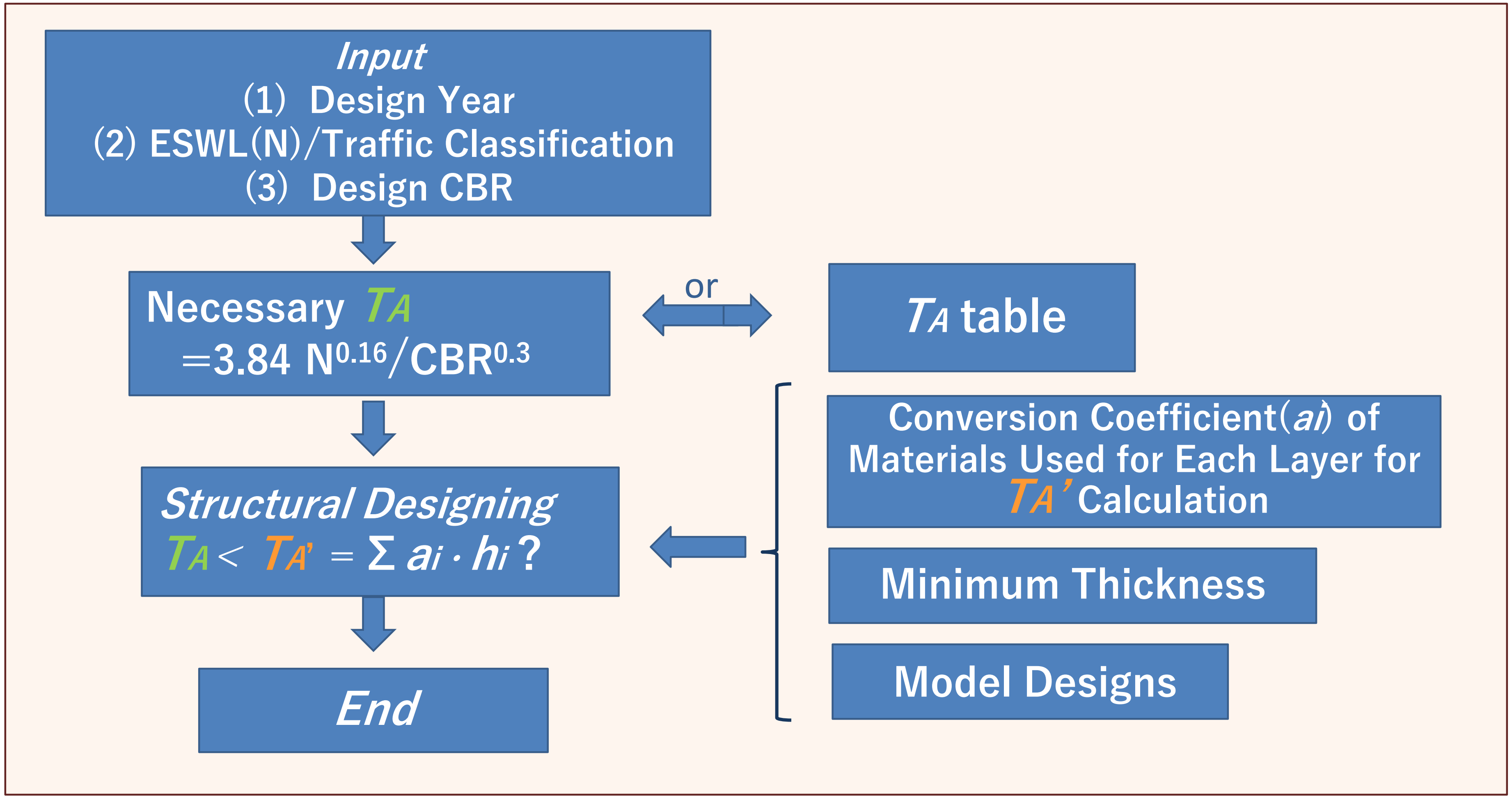
Project			Awash Bridge	4th Trunk Road Upgrading	Monrovia Metropolitan Area Somalia Drive	Lusaka Southern Residential District Improvement	Japan-Cote d'Ivoire Friendship Intersection	Uganda North Gulu Road Upgrading	National Route 9 (Mekong East-West Corridor) Construction
Target country			Ethiopia	Ethiopia	Liberia	Zambia	Cote d'Ivoire	Uganda	Laos
Road function			Regional trunk	Regional trunk	Urban trunk	Urban road	Urban trunk	Provincial urban trunk	Urban trunk
Survey period			2010	2011	2012	2011	2014	2016	2011
Funding			Japanese grant aid	Japanese grant aid	Japanese grant aid	Japanese grant aid	Japanese grant aid	Japanese grant aid	Japanese grant aid
Damage factor	Medium/large buses	BUS	0.14	2.29	1.00	0.46	2.00	0.75	1.01
	Trucks (2 axles)	MGV	6.67	2.76	2.05	0.44	3.50	3.30	0.90
	Trucks (3 axles)	HGV		7.25	4.40	1.00	5.00		2.56
	Trucks (4 axles)	VHGV	11.47	12.26	5.60	3.36	8.00	8.00	3.96
	Trucks (5 axles)								
	Trucks (6 axles)								6.47

Source: Text② JICA, "Road Pavement Handbook for JICA Grant Aid Projects", 2020, P1-13

3) Asphalt Pavement Design : TA Method

■Design process of TA Method

[→Text P246]



- Fatigue equation is based on AASHO field test in 1960's and Japan data.
- Simple procedure; TA is same as SN of AASHTO(1993) but easier to handle.

■ Calculation of *TA*

[→Text P 247、72]

Basic equation (Fatigue equation)

$$T_A = \frac{3.84^{*}\, N^{0.16}}{CBR^{0.3}} \qquad (*90\%\ \text{reliability}) \qquad (1.1)$$

Here in;

TA : **Necessary Equivalent Asphalt Thickness (cm)**
→Minimum requirement for traffic load expressed by ESWL
・・・same as 'SN' of AASHTO design

N : Number of **49kN equivalent single wheel loads** (**ESWL**)
for design period (→ **ESAL=2.25 ESWL, slide #7 : Equivalent Single Axle Load (ESAL)**)

CBR : **Design CBR Value** (subgrade strength)

*3.84 for 90% reliability, 3.43 for 75% and 3.07 for 50% reliability

to the power of 0.3

■ Implication of the formula (ESWL got from T_A & CBR)

The more generous for the thickness, the better.

$$T_A = \frac{3.84\ N^{0.16}}{CBR^{0.3}} \xrightarrow{\text{develop}} N = 0.0002228 \times T_A^{6.25} \times CBR^{1.875}$$

$CBR \rightarrow 2.0CBR$： $T_A \rightarrow 0.81T_A$
$CBR \rightarrow 3.0CBR$： $T_A \rightarrow 0.72T_A$
$CBR \rightarrow 4.0CBR$： $T_A \rightarrow 0.66T_A$

$T_A \rightarrow 1.1\ T_A$ ： $N \rightarrow 1.8N$
$T_A \rightarrow 1.2\ T_A$ ： $N \rightarrow 3.1N$
$T_A \rightarrow 1.5\ T_A$ ： $N \rightarrow 12.6N$
$T_A \rightarrow 2.0T_A$ ： $N \rightarrow 76.1N$

Table1-1: 'N'：Number of 49kN Equivalent Single-Wheel Loads（ESWL）for the design period

($\times 10^6$)

Subgrade CBR	T_A=10	15	20	25	30	35	40	45
3%	0.003	0.039	0.23	0.95	2.98	7.82	18.0	37.6
5	0.008	0.102	0.62	2.4	7.8	20.4	46.9	98.0
7	0.015	0.19	1.16	4.7	14.6	38.3	88.2	184
10	0.03	0.37	2.26	9.1	28.5	74.7	172	359
15	0.06	0.80	4.84	19.5	61.0	159	368	768
20	0.11	1.37	8.29	33.5	104	274	631	1,318

- **Example of necessary equivalent thickness TA for each traffic volume class and various design CBRs**

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 Heavy 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.

Source: Japan Road Association, "Maintenance Guidebook of Pavement 2013"

■ Minimum Thickness

[→Text P 251-253]

Table 1.3 : Min. thickness of Surface & Binder Course

Traffic Classification	One-direction Daily Traffic Volume of Heavy Vehicles (Nhv)	N: ESWL (49kN) (1000/10yers)	Min. A.C. Thickness(cm)
N7(D)	Nhv≥3,000	35,000	20(15)*
N6(C)	3,000> Nhv ≥1,000	7,000	15(10)*
N5(B)	1,000> Nhv ≥250	1,000	10(5)*
N4(A)	250> Nhv ≥100	150	5
N3(L)	100> Nhv ≥40	30	5
N2(L), N1(L)	40> Nhv	1.5～7	4(3)**

* : In case bituminous stabilization or Cement/ bituminous stabilization is adopted for base course.
**: In case heavy vehicles are not anticipated number in parentheses can be applied without treated base course.

(Table 1.4) Min. thickness of base, subbase course

(Nhv ≧40　per day direction)

Treatment/Material	Min. Thickness
Bituminous Stabilized Base (Hot Mixture)	More than Two Times of max. aggregate size and 5cm
Other Base Course	More than Three Times of max. aggregate size and 10cm*

* For Cement stabilized subbase course, 15cm or more will be recommended.

(Table 1.5) Min. thickness of base, subbase course

(40>Nhv　per day,direction)

Treatment/Material	Min. Thickness
Mechanically Stabilized Crushed Stone, Crusher run	7cm
Bituminous Stabilization(Cold Mixture)	7cm
Bituminous Stabilization(Hot Mixture)	5cm
Cement/Bituminous Treated	7cm
Cement Treated	12cm
Lime Treated	10cm

■ Check the pavement design → Calculation of *TA'* (*TA Prime*) [→Text P 250]

Assume pavement design and calculate *TA'*: 'Equivalent Asphalt Thickness' and check if it is larger than Necessary Equivalent Asphalt Thickness （*TA*） value derived from formula 1.1.

$$T_A' = a_1 \times h_1 + \ldots + a_n \times h_n = \sum_1^n ai \times hi \qquad (1.1)$$

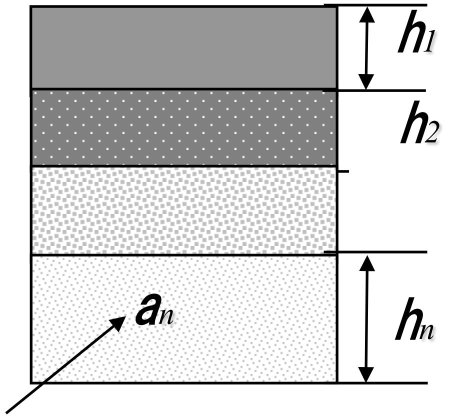
TA': Equivalent Asphalt Thickness (of a trial design)

ai : Equivalent Conversion Factor shown in Table1.6

hi : Thickness of each layer(cm)

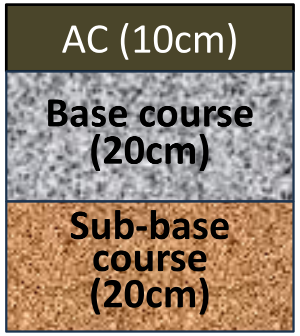
$T_A' \geqq T_A$?

Decided by paving material's strength



➢ Example of TA’ calculation

Sample design
(Thickness)



Design

	Thickness (cm)	Eq. C. F.*	TA value (cm)	
AC Surface	10	1.0	10	
Base C.	20	0.35	7	
Sub-base C.	20	0.25	5	
TA’			22	

* See table 1.6 next page

■Long term behavior of lightly cemented material　（South Africa）

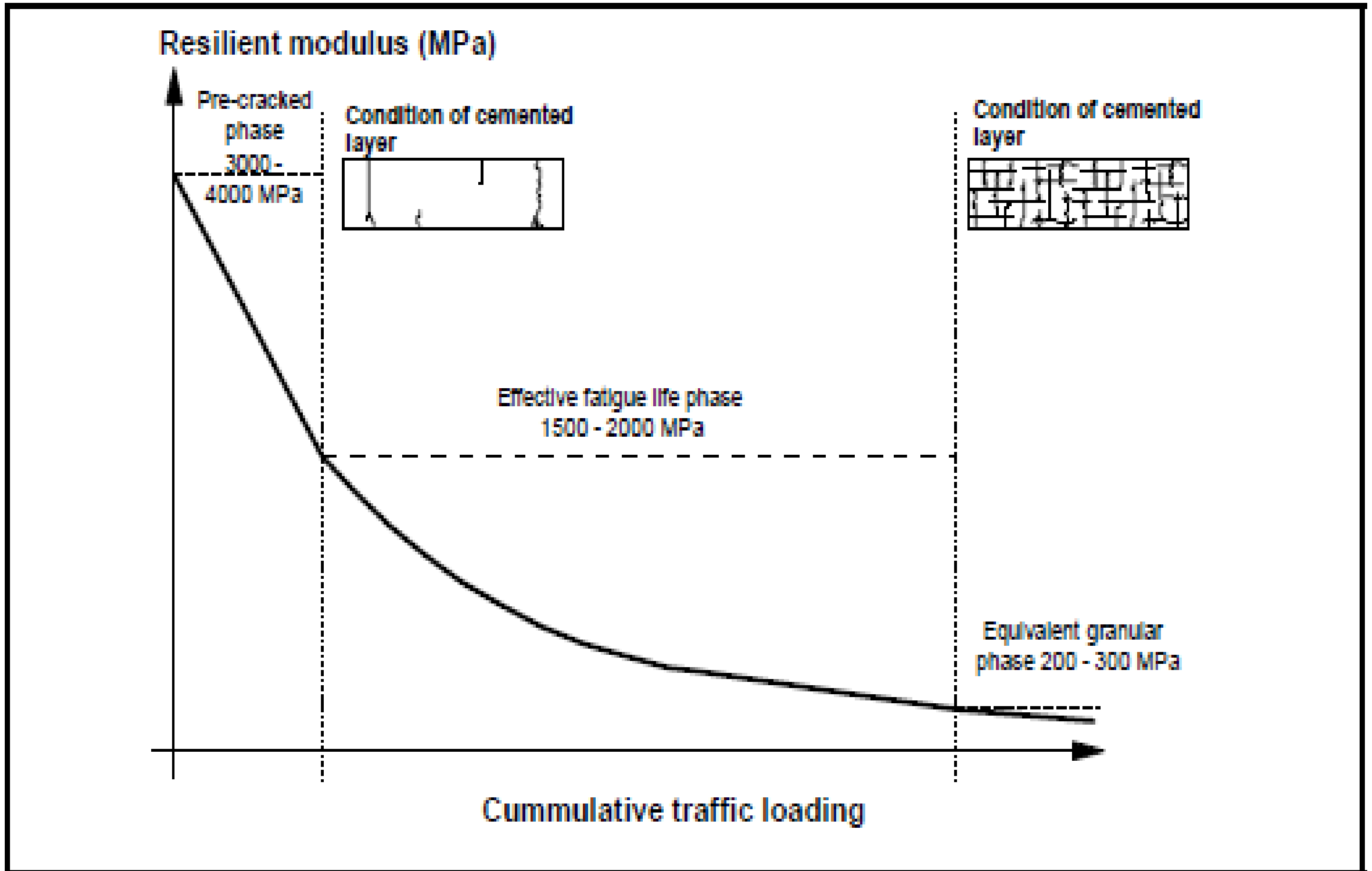


Figure 22: Long-term behaviour of lightly cemented material

- Over time, the cement stabilization layer will return to its original granular state with many cracks(See left Figure).
- In South Africa, cement stabilization is not used for the base course.
- In Japan, in order to use cement stabilization treatment for the base course, the asphalt layer above it must be about 15 cm or more. And the minimum thickness of 20cm is recommendable (Dr. Sadao Nagumo).

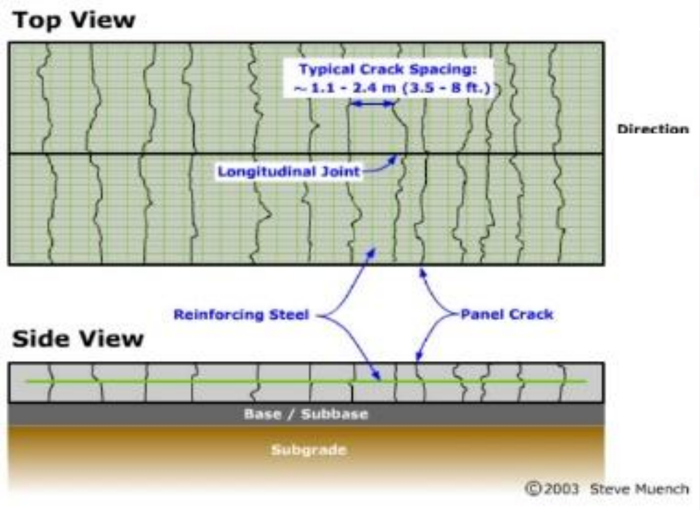
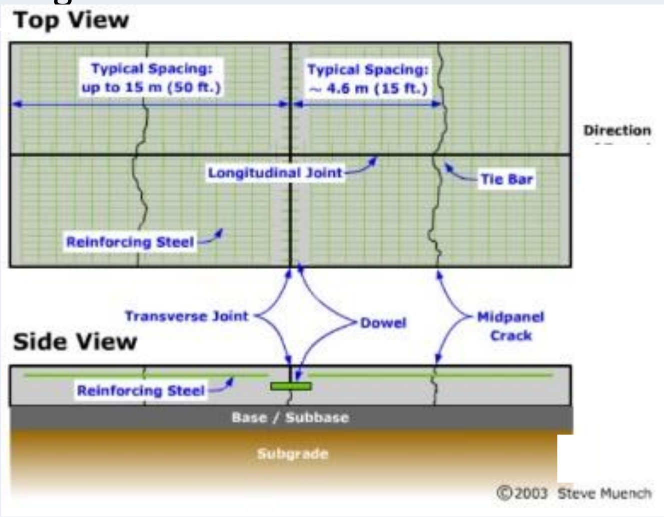
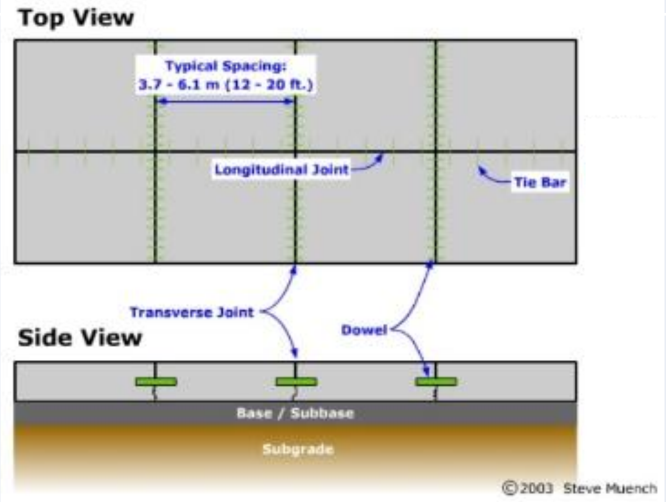
"PAVEMENT ANALYSIS AND DESIGN SOFTWARE (PADS) BASED ON THE SOUTH AFRICAN MECHANISTIC-EMPIRICAL DESIGN METHOD"
H L Theyse and M Muthen

Table 1.6 Equivalent Conversion Factor for New Design [→Text P 251]

Pavement layer	Material/ Treatment	Specifications	Equivalent Conversion Factor (a)
Surface & Binder	Hot Mixture		1.00
Base course	Bituminous Stabilization	Hot-mixed :3.43kN or more Cold-mixed:2.45kN or more	0.80 0.55
	Cement/Bituminous Stabilization	1.5-2.9Mpa (Unconfined Comp. Test:7days) 0.5-3.0(mm)(Displacement at Comp. Test) 65% (Remaining Strength Percent)	0.65
	Cement Stabilization	2.9MPa (Unconfined Comp. Test:7days)	0.55
	Lime Stabilization	0.98MPa (Unconfined Comp. Test:10days)	0.45
	Mechanically Stabilized Crashed Stone/Slag	80% or more (Modified CBR Value)	0.35
	Hydraulic Slag	80% or more (Modified CBR Value) 1.2MPa (Unconfined Comp. Test:14days)	0.55
Subbase course	Crusher-run, slag, sand & etc.	30% or more (Modified CBR Value) 20 to 30% (Modified CBR Value)	0.25 0.20
	Cement Stabilization	0.98MPa(Unconfined Comp. Test:7days)	0.25
	Lime Stabilization	0.7MPa (Unconfined Comp. Test:10days)	0.25

(3) Concrete Pavement Design

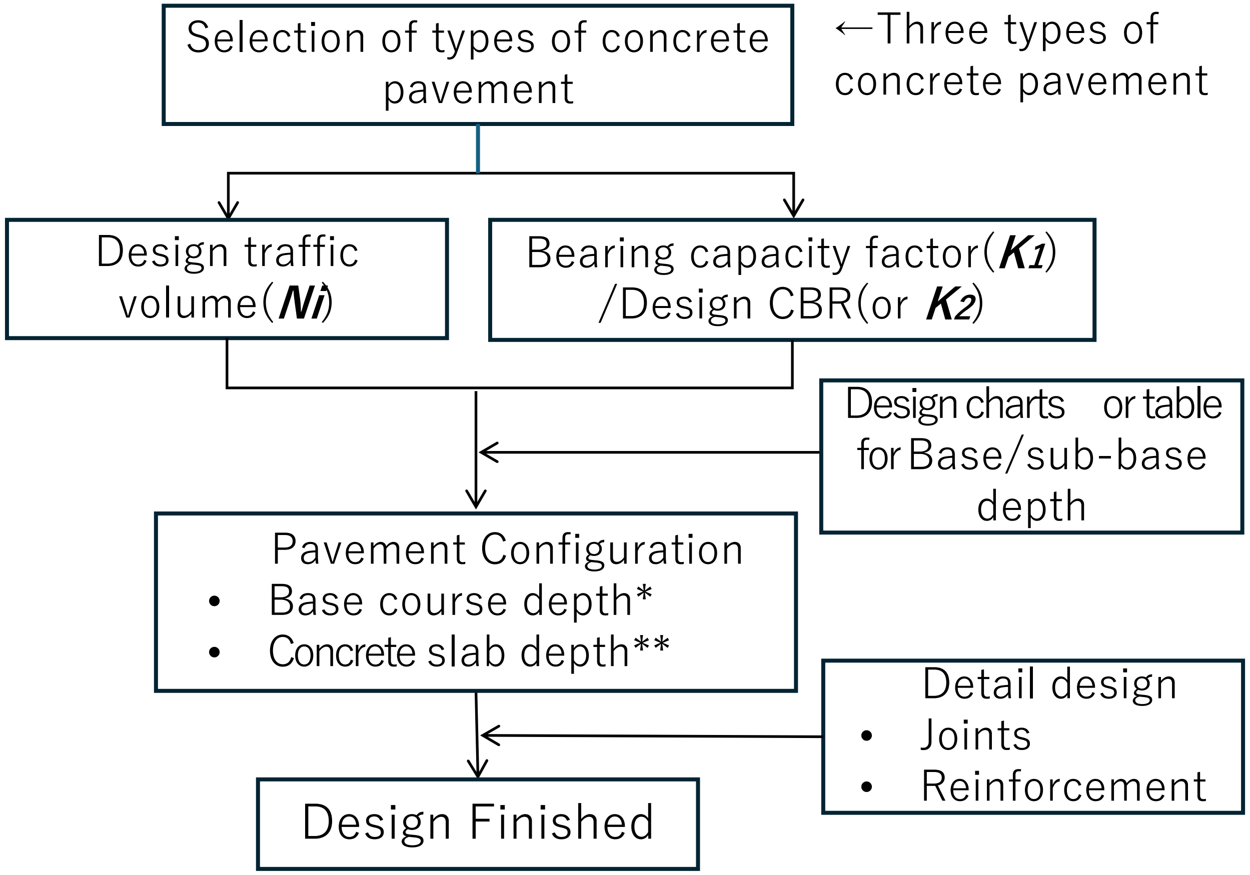
■ Three types of concrete pavement

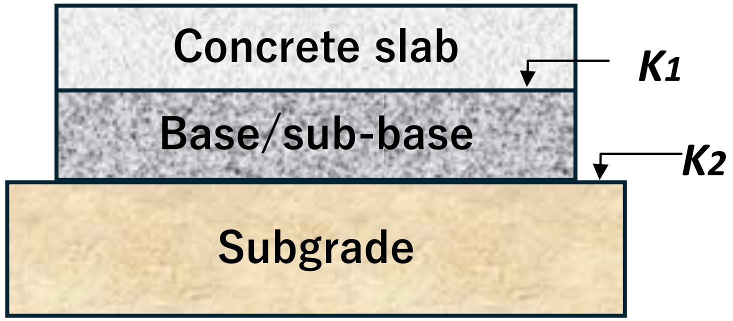
<table>
<tr><th></th><th>CRCP（Continuously Reinforced Cement Pavement)</th><th>JRCP (Jointed Reinforced Concrete Pavement)</th><th>JPCP (Jointed Plain Concrete Pavement)</th></tr>
<tr><td>explanation</td><td>Paving using continuous rebar and omitting the lateral joints. In Japan, it is used for expressway and tunnel paving. It is used for heavy traffic, and it is considered the most economical in LCC (50 years)[1]. The service life is said to be 50 years[2]. Constructed with slipform pavers.</td><td>Pavement with joints using steel wire or rebar. The joint spacing is about 10m. It is widely used in Japan, but its use is diminishing in Europe and the United States. It is not compatible with slipform pavers and the cost is high. Among the three[1], LCC has the lowest rating.</td><td>Pavement with no reinforcement. The joint spacing is about 4.6m. There is no track record in Japan in recent years, but it has been actively used in the United States and Europe in recent years. It is compatible with slipform pavers and is economical. It is said to have a lifespan of 30 years[2].</td></tr>
<tr><td>Overview diagram[1]</td><td>
</td><td>
</td><td>
</td></tr>
</table>

1. Kunhee Choi, “Environmental, Economic, and Social Implications of Highway Concrete Rehabilitation Alternatives”.
2. Indiana DOT, Indiana Design Manua

➢ Experimental-Design Procedure

→日本道路協会:舗装設計便覧pp.147-166





Cross-section of Concrete pavement (JRCP/JPCP)

- MPa./m=N/m^3
- K2=CBR×10

Notes:

- *Base/sub-base depth is given to make the bearing capacity factor(*K1*) of base course more than **200 MPa/m** or **150MPa./m**, in the table → **table 1.**
- **Stipulating flexural strength of concrete **4.4MPa** or **3.9MPa**, pre-calculated numbers are given in the table → **table 2.**

Table 1. Base/Subbase Course Depth (JRCP/JPCP)

Traffic class	P. Design Traffic	Design CBR%	AC layer	Mechanically stabilized agg.*	Crasher run**
N_1~N_4	T＜250	(2)	0	25 (20)	40 (3.0)
		3.	0	20 (15)	25 (20)
		4	0	25 (15)	0
		6	0	20 (15)	0
		8	0	15 (15)	0
		12以上	0	15 (15)	0
N_5	250≦T＜1,000	(2)	0	35 (20)	45 (45)
		3.	0	30 (20)	30 (25)
		4	0	20 (20)	25 (0)
		6	0	25 (15)	0
		8	0	20 (15)	0
		12以上	0	15 (15)	0
N_6,N_7	1,000≦T	(2)	4 (0)	25 (20)	45 (45)
		3.	4 (0)	20 (20)	30 (25)
		4	4 (0)	10 (20)	25 (0)
		6	4 (0)	15 (15)	0
		8	4 (0)	15 (15)	0
		12以上	4 (0)	15 (15)	0

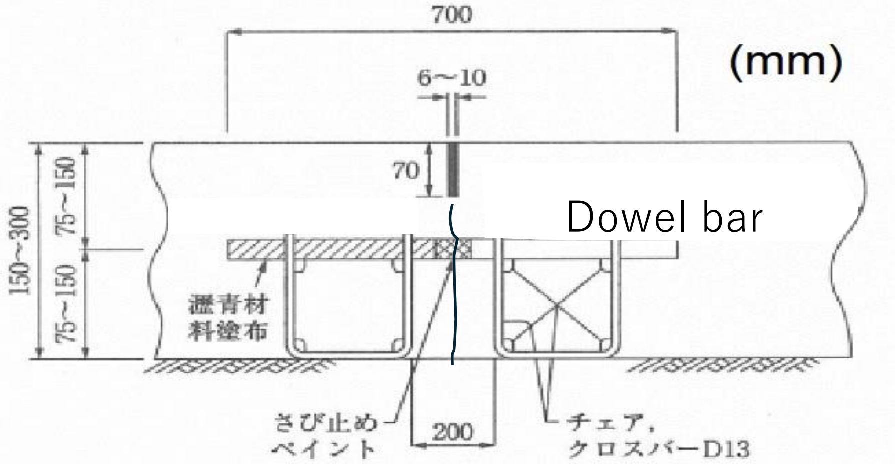
Notes:
* In parenthesis, numbers show the depth of cement-stabilized base course.
** In parenthesis, numbers show the depth in case base course is by cement-stabilization.

Table 2. Concrete Slab Depth (JRCP/JPCP)

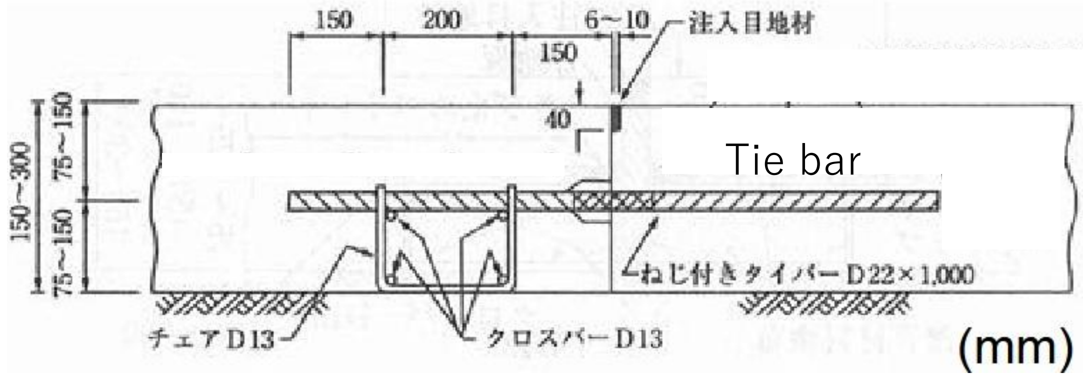
Traffic class	P. Design Traffic (Heavy V. /direction/day)	Concrete slab design			Contraction joint spacing	Use of Dowel bar
		Design Flexural Stg	Slab Depth	Steel mesh		
N_1~N_3	T＜100	4.4MPa (3.9MPa)	15cm (20cm)	Use in principle 3.kg/m^2	・8m Without mesh: 5m	Use in principle
N_4	100≦T＜250	4.4MPa (3.9MPa)	20cm (25cm)			
N_5	250≦T＜1,000	4.4MPa	25cm		10m	
N_6	1,000≦T＜3,000	4.4MPa	28cm			
N_7	3,000≦T	4.4MPa	3.0cm			

Note;
Slab depth in parenthesis shows the case when 3.9MPa is applied for design flexural strength

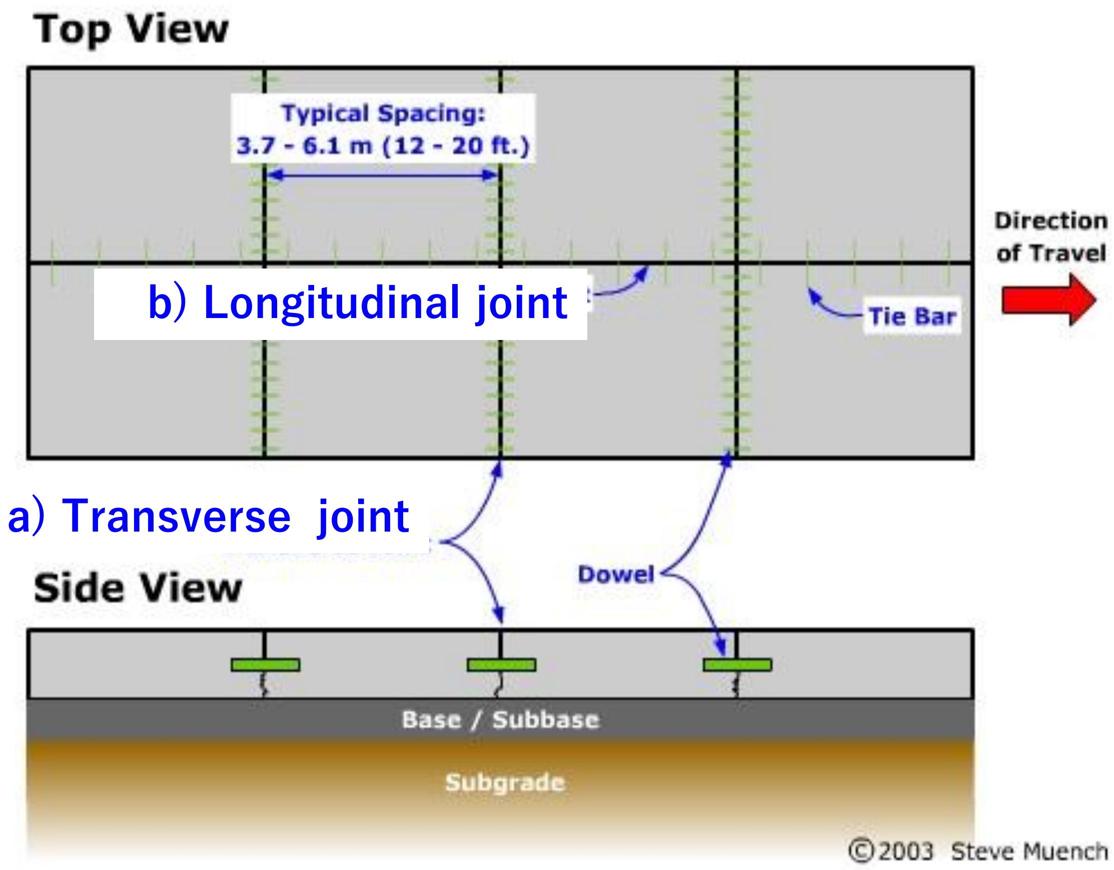
➢ Joints design



a) Transverse joint (Contraction joint)



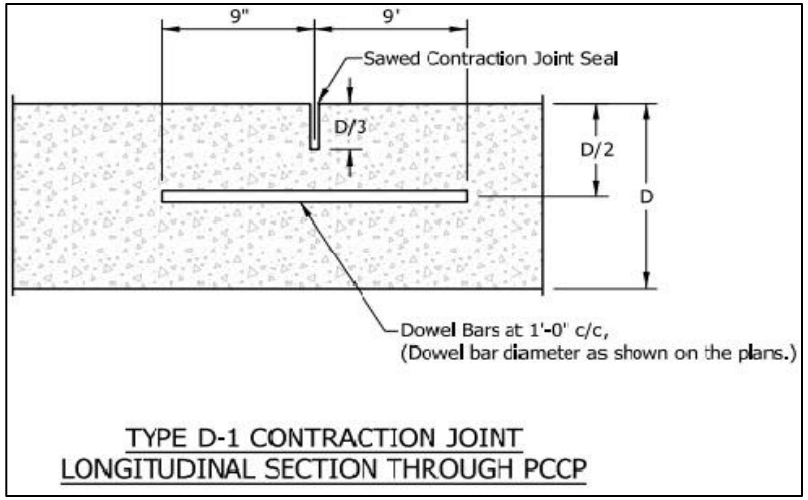
b) Longitudinal joint (Construction joint)



Configuration of joints (JPCP)

➢ **Indiana Concrete Pavement Design**（Chapter 602, **2013 DESIGN MANUAL, Indiana DOT**）

- **コンクリートスラブの下は**
  ３in.(7.5cm)の排水層で#53 (0.75in-1.5in)
  ６in.(15cm)の砂利遮断層＃８
  （2.36mm-9.5mm)
- **縦断排水(Underdrain)の設置**
- **Contraction Joint間隔は15-20フィートで版が薄いほど短くする.**
- **ジョイント(D-1)構造は下図,カッターの厚さ（目地幅）は6mm(1/4" ± 1/16“)**



Source: Indiana Standards Drawings
https://www.in.gov/dot/div/contracts/standards/drawings/sep24/500e/e500%20combined%20pdfs/E503-CCPJ.pdf

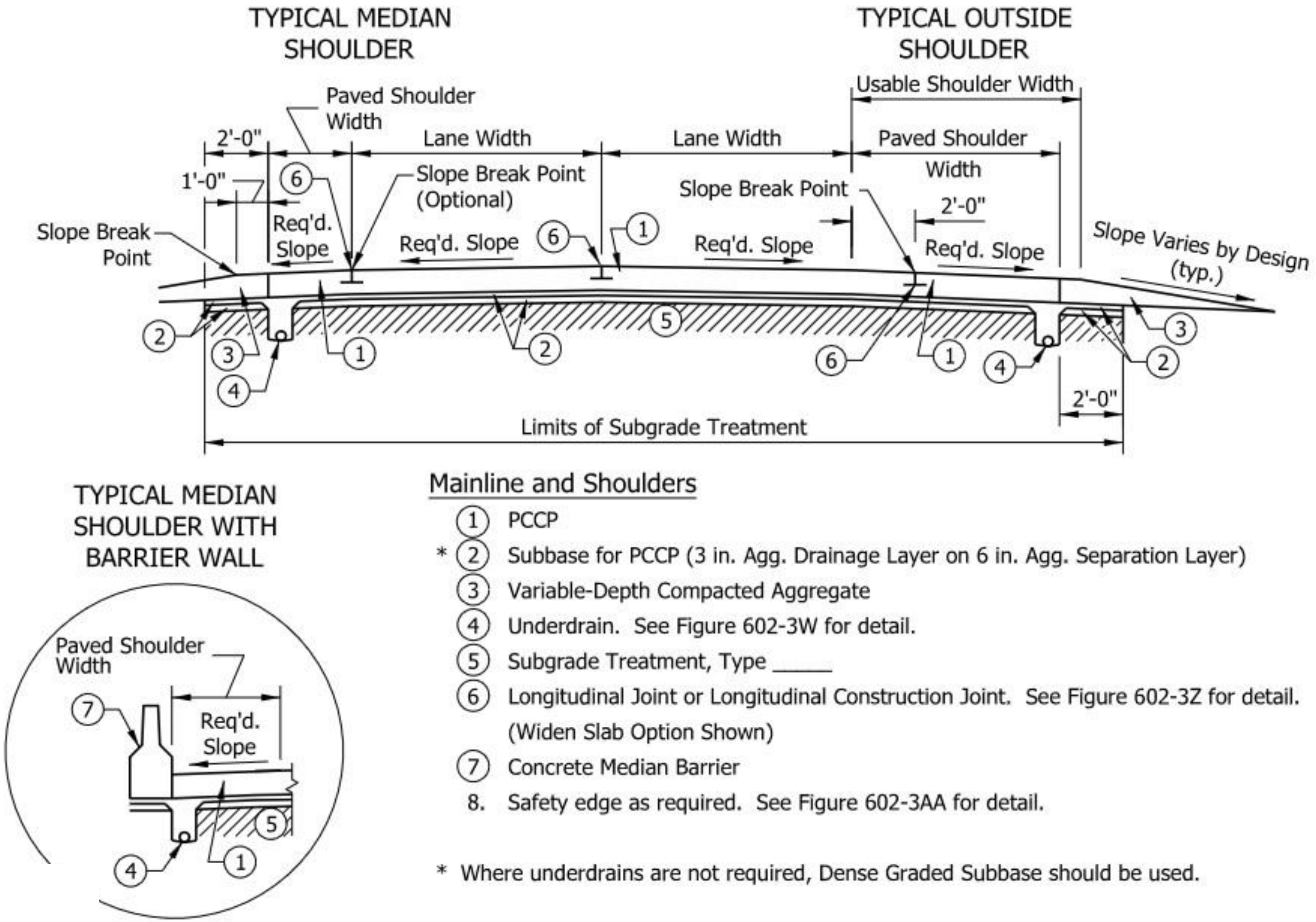
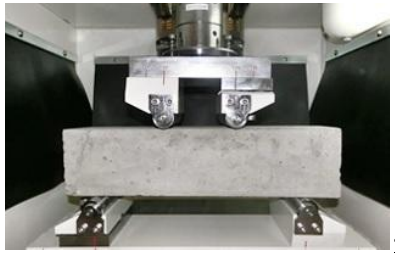


Fig. PCCP Section with PCC Shoulder (Figure 602-3S)

through engineering

(Reference 1) How can we use it for concrete pavement?

1. End objective: Standardization of the design and construction of concrete pavements using CRR as a crude aggregate in the Oceania countries.
2. Unavoidable aggregate test: **Los Angeles abrasion test**(max. abrasion 50%?) , **ASR (Alkali-Silica Reaction) test**
3. Cement concrete strength test: flexural strength (bending strength) test (more than 4.4MPa: design strength)
   a. **Target strength is 4.4+1.65 σ** → Fig. 95percentile reliability (Asumme dispersion coefficient(σ/4,4) to be 0.2, then σ becomes 0.88MPa. for test to get actual standard deviation (σ))
   b. **Try 20~30 tests and get actual standard deviation (σ).**



Test piece size: 10x10x40cm

Source: Marui Co., Ltd. HP.

Fig. Flexural strength test

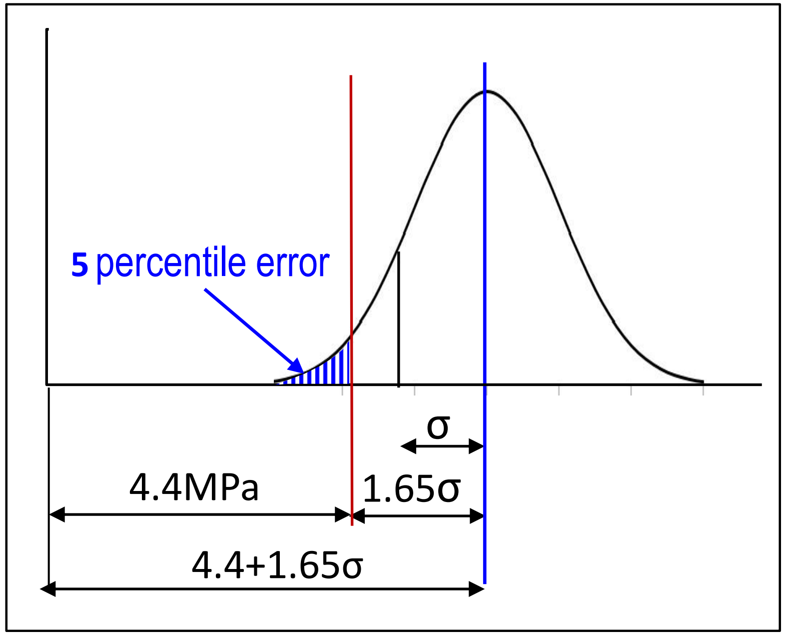
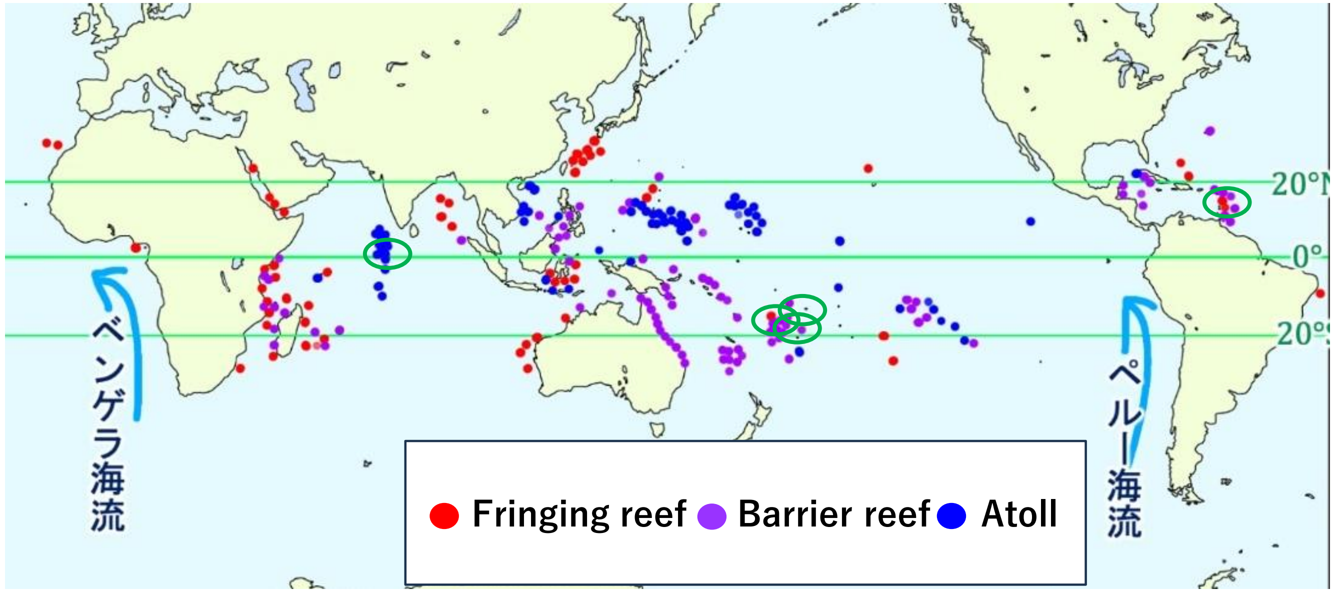


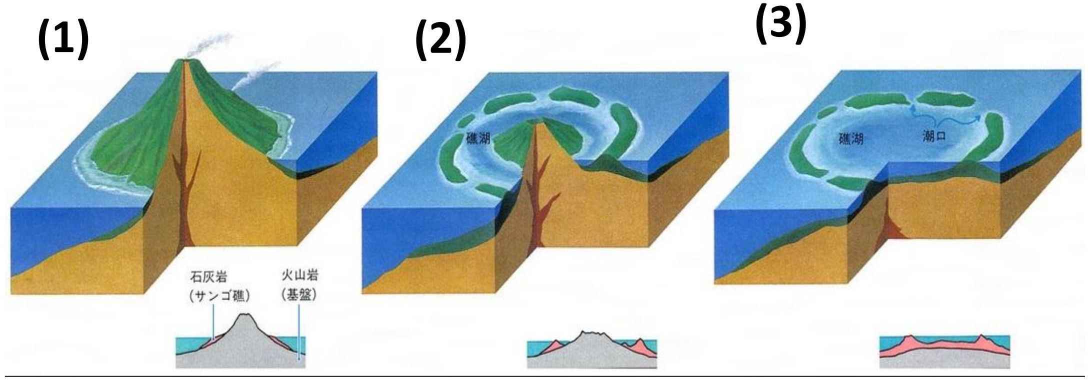
Fig. 95percentile reliability

(Reference2) Coral Reaf Rock Concrete

(1) Utilize Coral Reaf Rock(CRR) for Pavement

- Transition of coral reefs←Darwin





Coral evolution➡

(1)Fringing reef 裾礁　(2)Barrier reef 堡礁　(3) Atoll 環礁

- Coral reefs are currently forming coral limestone (left figure)
- When volcanoes on the Pacific Plate cease their activity, they gradually settle because their specific gravity is heavier than that of seawater. Hence the coral evolves.
- For some reason, the atoll may be uplifted, in which case limestone is present on the land.

➢ An Example of Coral Reaf Rock (CRR)

Kita-Daito Island, like many islands in Okinawa, is made up of CRR, and the island produced phosphate ore until 1950.

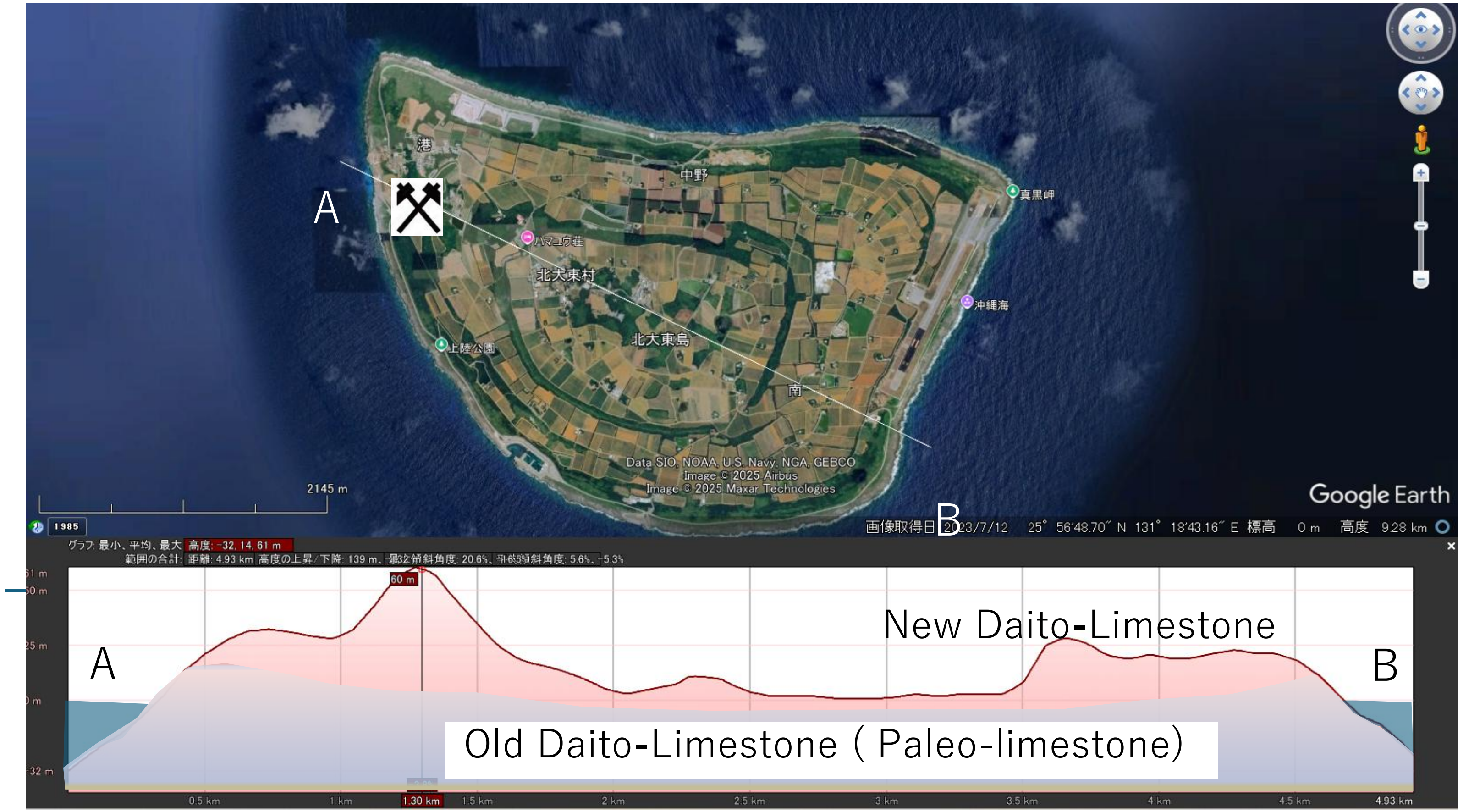


Image of the cross section of Kita-Daito Island: comprises two types of limestones(CRR). New Daito-Limestone is very common among tropical islands.

Ruins of phosphate loading

Enriching life through engineering

➢ Two types of limestone

Limestone is made up of hard skeletons such as corals, shellfish, sea urchins in coral reefs.

a. Paleo-limestone: hard grayish limestone formed more than 200 million years ago.
Usually used as an aggregate for cement concrete and asphalt concrete.
There are paleo-limestone mines in Motobu, northern part of Okinawa main island.

b. Ryukyu limestone : soft light-yellow limestone formed between 1.3 million and 100,000 years ago. Found in Okinawa and parts of Kagoshima Prefecture. often does not meet Japan's JIS standards for aggregate but **can be used for concrete.**

a. Paleo-limestone

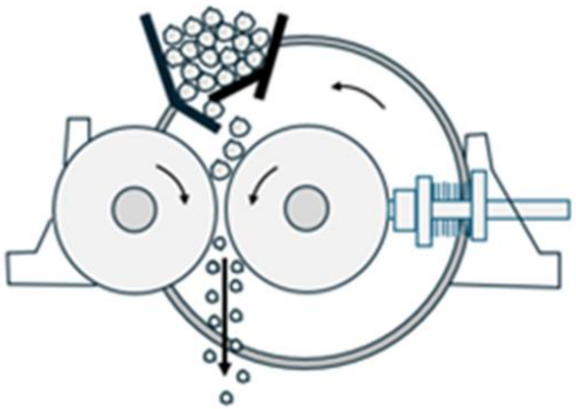
Quarry at Motobu

b. Ryukyu limestone

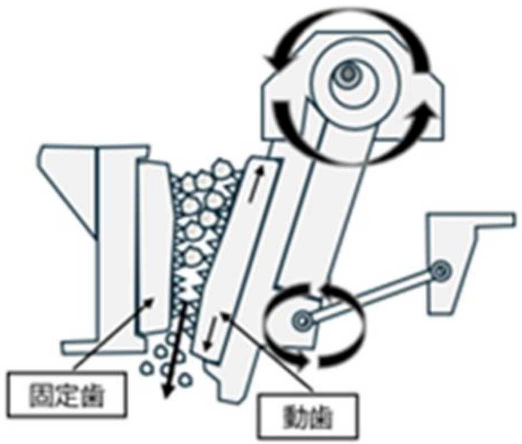
Quarry at Itoman

➢ Flow of the manufacturing process of crushed stone

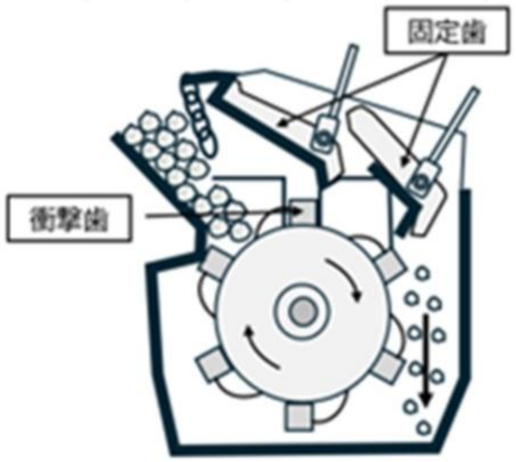
① Rough Feed → Feeder
② Primary crushing (jaw crusher)
③ Secondary crushing (e.g., cone crusher/impact crasher)
④ Particle size adjustment (screen)
⑤ Cleaning and removal of foreign objects (as needed)
⑥ Storage and Shipping



Jaw crusher



cone crusher



Impact crasher

（3） Conclusion：CRR Concrete

1） Possibility of CRR concrete

① Geologically, limestone has been continuously formed along the coast. The limestone that can be mined on land is from the Cenozoic Quaternary period or the Paleozoic limestone before 2.5 billion years ago.

② Okinawa Ryukyu limestone is a Cenozoic limestone, which is the same as that found in other tropical island countries.

③ Ryukyu limestone is generally less than 35% in the Los Angeles wearing test, and the water absorption rate is slightly over 3%, which does not meet the JIS standard. However, there are many examples of CRR used as an aggregate for concrete. It was also used in Okinawa until around 1970.

④ Concrete using CRR has low shrinkage and “linear expansion coefficient”, so it is advantageous for structures design because it is characterized by low temperature stress.

⑤ If CRR is used as a coarse aggregate based on the comprehensive information so far, there is no major problem if the moisture management of the aggregate is paid attention to.

2） Reference photos

➢ Ryukyu limestone products

- **Procedure**

  Quarrying → (grizzly may exclude large ones) to crushing plants (40-70mm or less with jaw crusher→ finer with impact crusher) → product storage → shipment

- **Products**

  ①Civil engineering products: Covering stone (200kg~2t), guri stone (50-70mm), crushed stone, bean ballast (5-12mm), graded crushed stone (M-40), crusher run (C-40),, etc.

  ② Architectural products: garden stone, cut stone, etc. Landscaping, architectural market

Quarry, quarrying is possible with a ripper without using blasting

Stone crushing plant

（Kaisei mine, Itoman, Okinawa）

➢ Ryukyu limestone utilization case (1)

Sidewalk and shoulder of Ryukyu limestone (Ryutan Street, Naha City)

Ryukyu limestone monument (right) and coral/resin paved sidewalk using bean ballast (Airport road)

A private house-style soba restaurant with a Ryukyu limestone entrance (in Itoman)

An inverted trapezoidal road gutter made before the restoration (near the Tokashiki Island Meteorological Observatory Station)

➢ Ryukyu limestone utilization case (2)

Shuri Castle Walkway

It is a resin pavement using aggregate called bean ballast (5~12mm). There is also a saying that it is safe because the hub (poisonous snake) stands out when the sidewalk is bright.

Cobblestone road (Ishidatami) in Shuri Kinjo Town (Prefectural designated historic site)

The cobblestone road in Shuri Kinjo Town is part of the "Pearl Road" built in the 16th century as a major road leading from Shuri Castle to Naha Port and the southern part of the main island of Okinawa. The paving stones are made of 20~30 cm of Ryukyu limestone, which is a method called "messy laying".

Source:
https://www.okinawastory.jp/spot/1360

Bean Ballast

2. Structural Damage and Countermeasures

■ Two Types of Pavement Damage

[→Text① P201 Appendix 4, ② JICA Pavement HB P. C-5]

Pavement damage could be divided into "structural damage" and "surface damage".

(1)Structural damage

This is the case where the pavement structure is not strong enough to bear the traffic load. Usually surface course and/or binder course becomes damaged due to causes in the base/subbase course and the below

(2) Road surface damage

This comprises various forms that occur in cases where the damage is limited to the surface course and binder course of asphalt mixture.

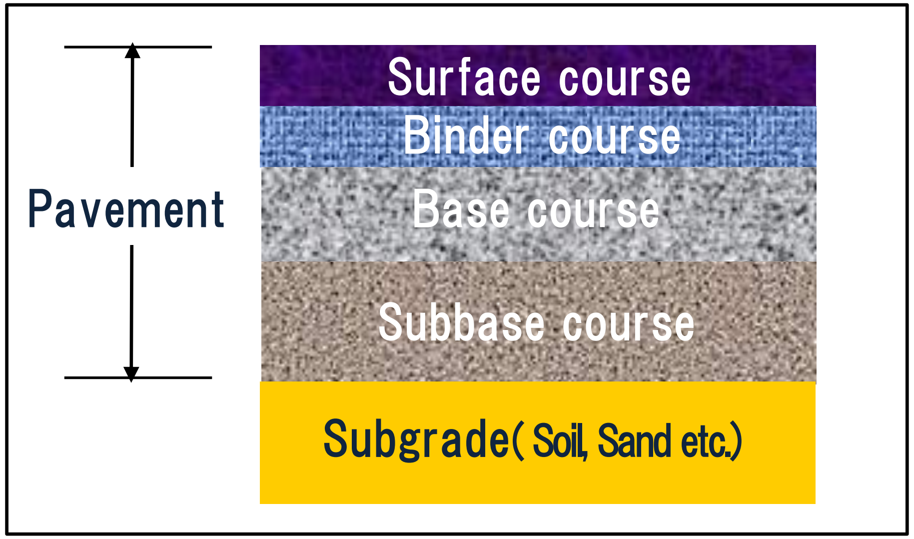


Fig. Composition of asphalt pavement

a. Structural damage

Alligator crack caused by overloading

Alligator crack caused by ground water, Yokohama

b. Road surface damage

Rutting at a gradient section, Ethiopia

Shrinkage crack in cold area, Nagano

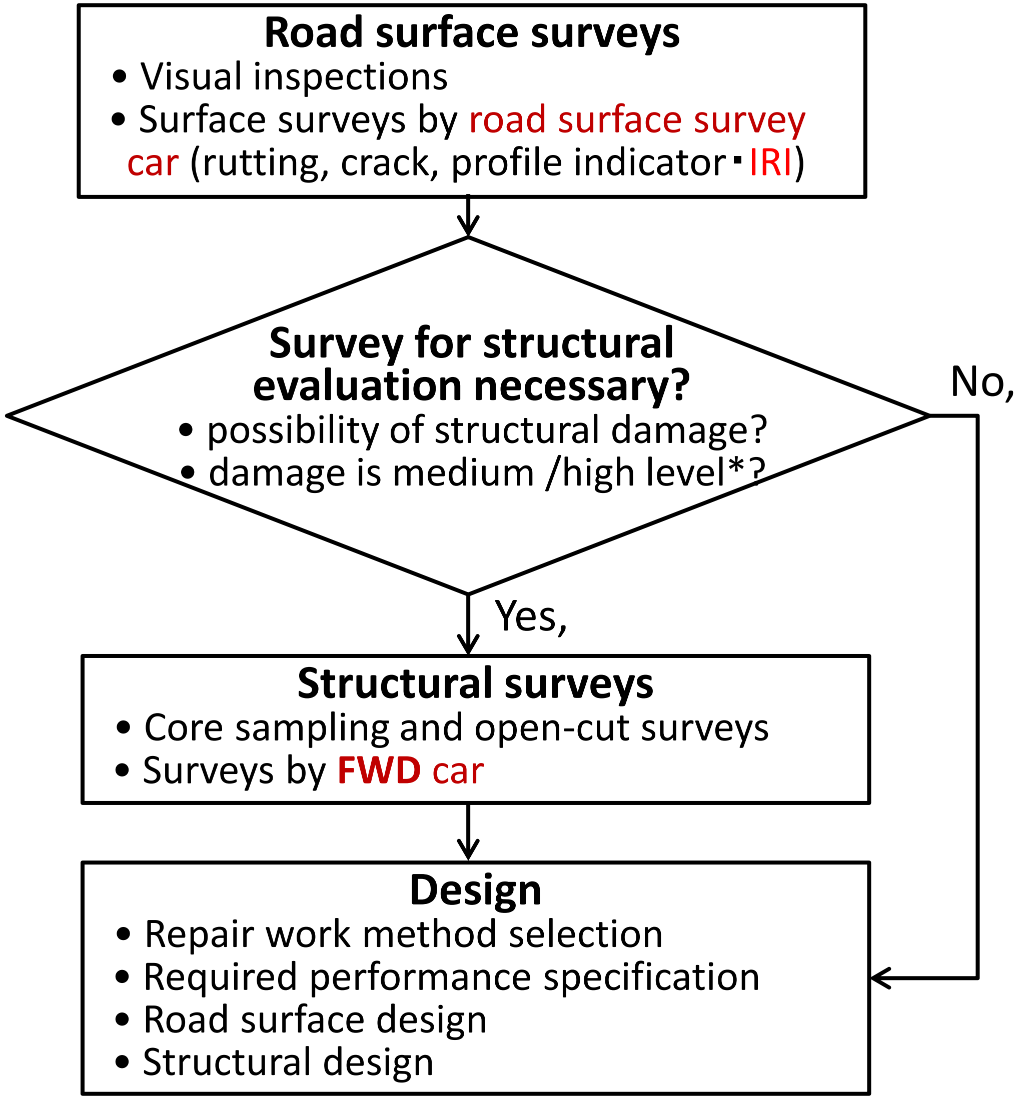
(1) Structural Damage

1) Factors Cause Structural Damage

- Basic mechanism of structural damage is lack of bearing capacity against traffic loading. The most common cause is weak bearing capacity. It may be brought by fatigue of pavement after the large number of wheel passes, weakened base/subbase course and/or subgrade usually brought about by water intrusion, and sometimes by inappropriate pavement design, poor construction procedures.
- The modern elastic multilayer system analysis concludes that the critical damage of the pavement starts from both fatigue cracking at the bottom of asphalt layer and the permanent deformation at the top of subgrade.
- Although low-thickness pavements are susceptible to fatigue cracks arising "bottom to top", thicker pavements are susceptible to "top to bottom" cracks.
- The first step to cope with the structural damage is to detect the pavement condition correctly. FWD survey is indispensable to diagnose the conditions of pavement in question inclusively.

2)Workflow for Pavement Rehabilitation (Periodical work)

[→Text P25, Fig. 3.2.2]



Road surface survey car (Nichireki)

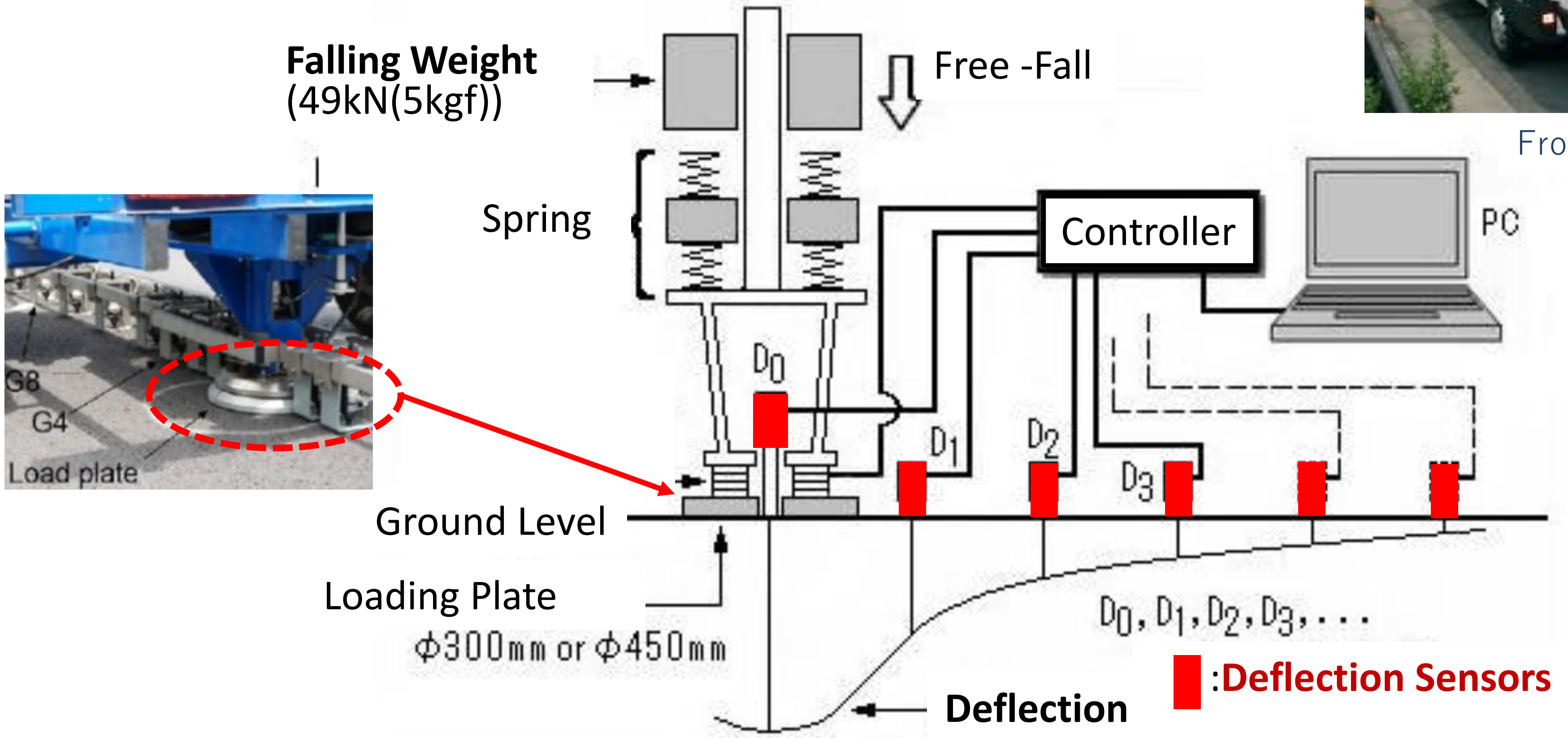
Car-mounted FWD (Obayashi Road)

* 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.” →Text Chapter 3.3 P37

■ Falling Weight Deflectometer (FWD) [→Text P83-94, Appendix7 255]

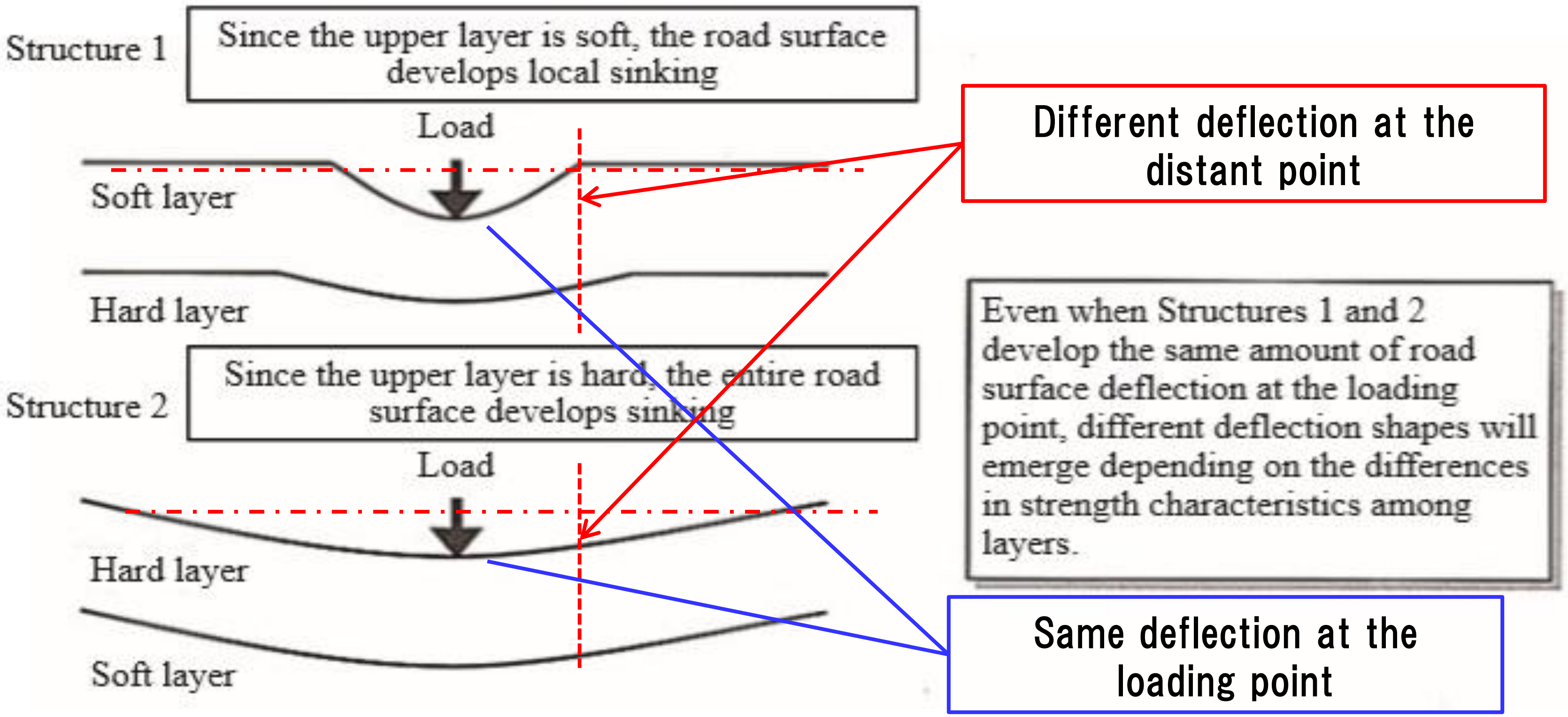
We can back calculate resilient modulus(M_R) of each layer of the pavement using Elastic Multilayer System Analysis. This is very useful to evaluate bearing capacity and soundness of pavement layer.

From NIPPO Home Page



➢ Advantages of FWD →Text P76,

We can back calculate resilient modulus(M_R) of each layer of the pavement using Elastic Multilayer System Analysis.



From text① :Figure-3.4.3: Structural evaluation of pavement based on the amount and shape of deflection

3）Diagnosis by FWD （Detailed diagnosis）

- For structural road survey, FWD survey will be carried out and road sections where the deflection exceeds the standard value are selected for further study. They estimate the strength of respective pavement layers, and it is used as a reference to determine the cause of damage and the repair method.

Table2-1 Allowable deflection of existing pavement 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

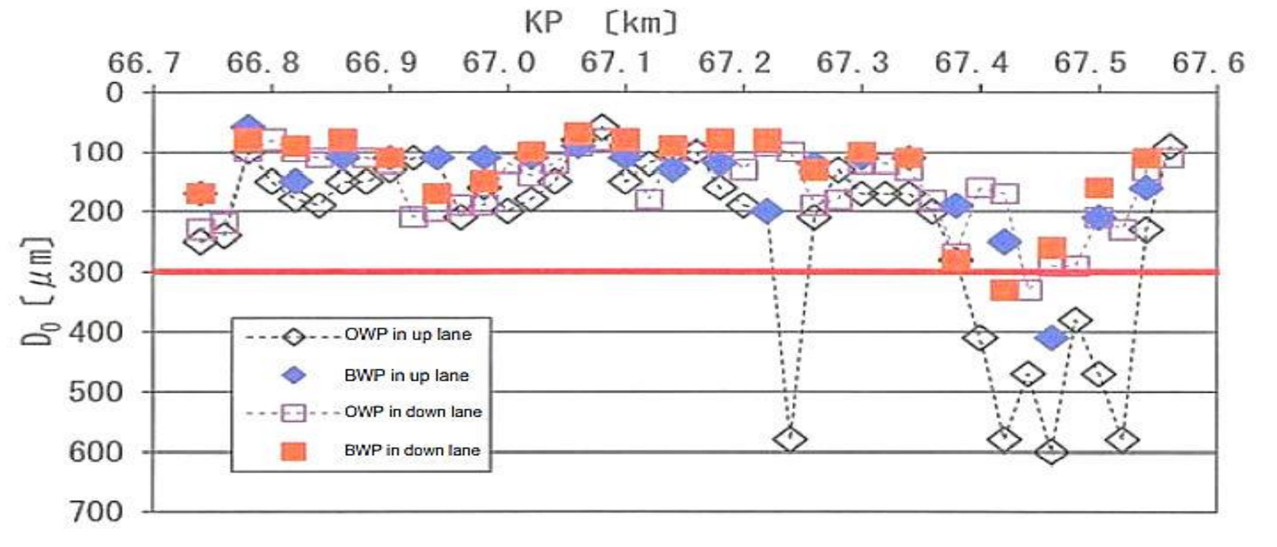


Figure-3.2.5: Example of survey results by FWD measurement (deflection)

→"Maintenance Guidebook of Pavement 2013", Appendix 6

Fig. Deflection measured by FWD
Red line shows the allowable deflection of traffic class N7.

→"Maintenance Guidebook of Pavement 2013",

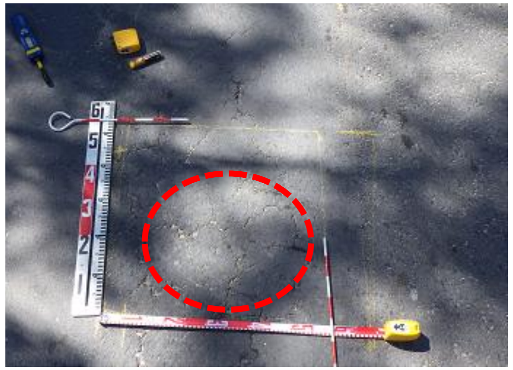
4）Portable FWD -- good for remote area

Total performance of the pavement

$$E_{P.FWD} = \frac{(1-\nu^2)P}{2rD}$$

$E_{P.FW}$: Deflection coefficient/Elastic modulus(MN/m^2) /(kN/mm^2)
P : Maximum loading(MN) /(kN)
D : Maximum deflection(m) /(mm)
r : Radius of loading plate(m) /(mm)
ν : Poisson's ratio

- Field survey（Measure the E value of each layer）



D_0 Measurement on the top

D_0 Measurement on basecourse

D_0 Measurement on subgrade

Completion of restoration

Product: [Small FWD System | Tokyo Measuring Instruments Laboratory Co., Ltd.]

All Photos: CTII

（2）Water Intrusion

■**Various types of water intrusion** [→Text ①P298 Appendix 10、②JICA P. Handbook P1-48]

Intruded water makes road weaker by degradation of pavement materials and by pumping which ejects fine materials when ejecting water from pavement and deteriorate pavement materials and reduces bearing capacity.

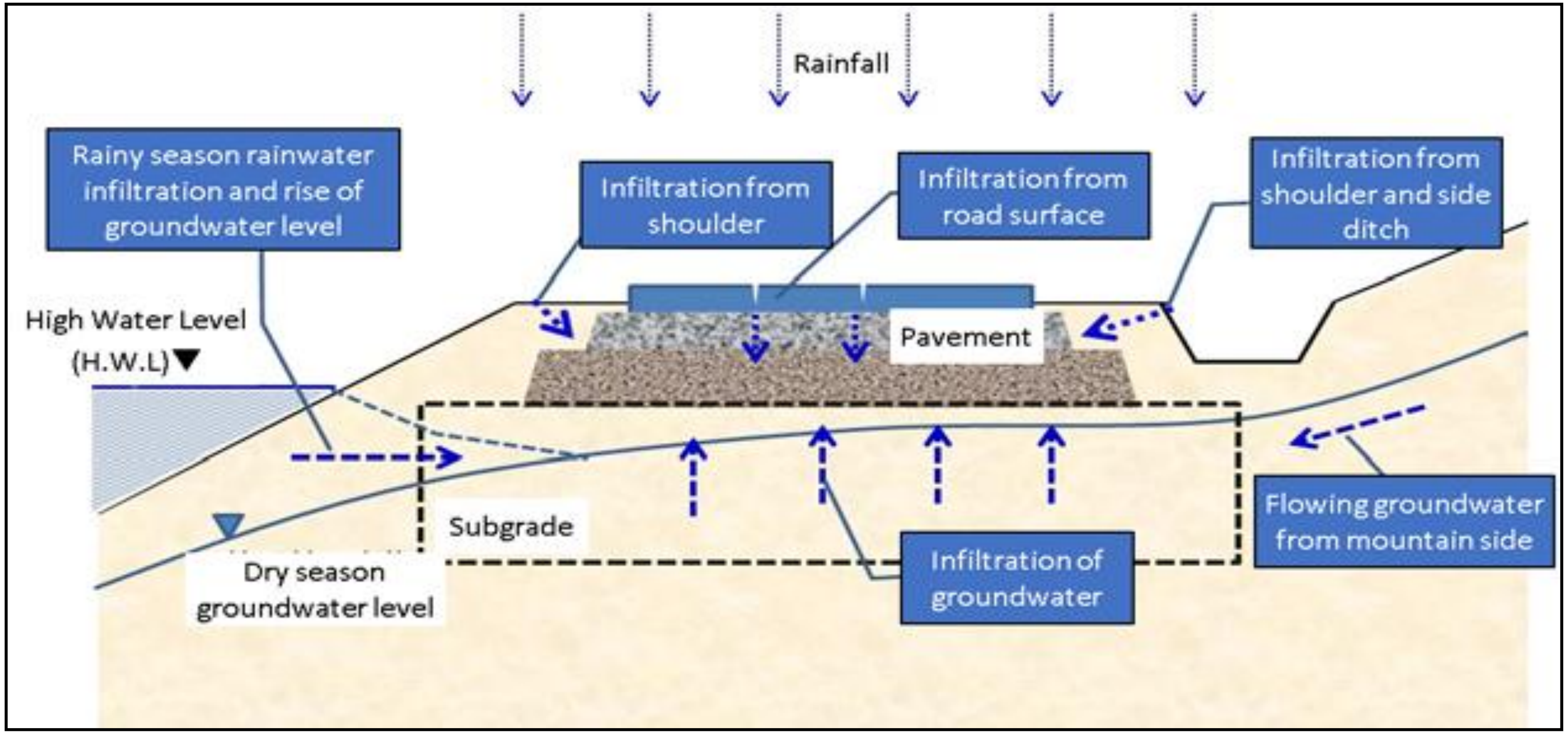
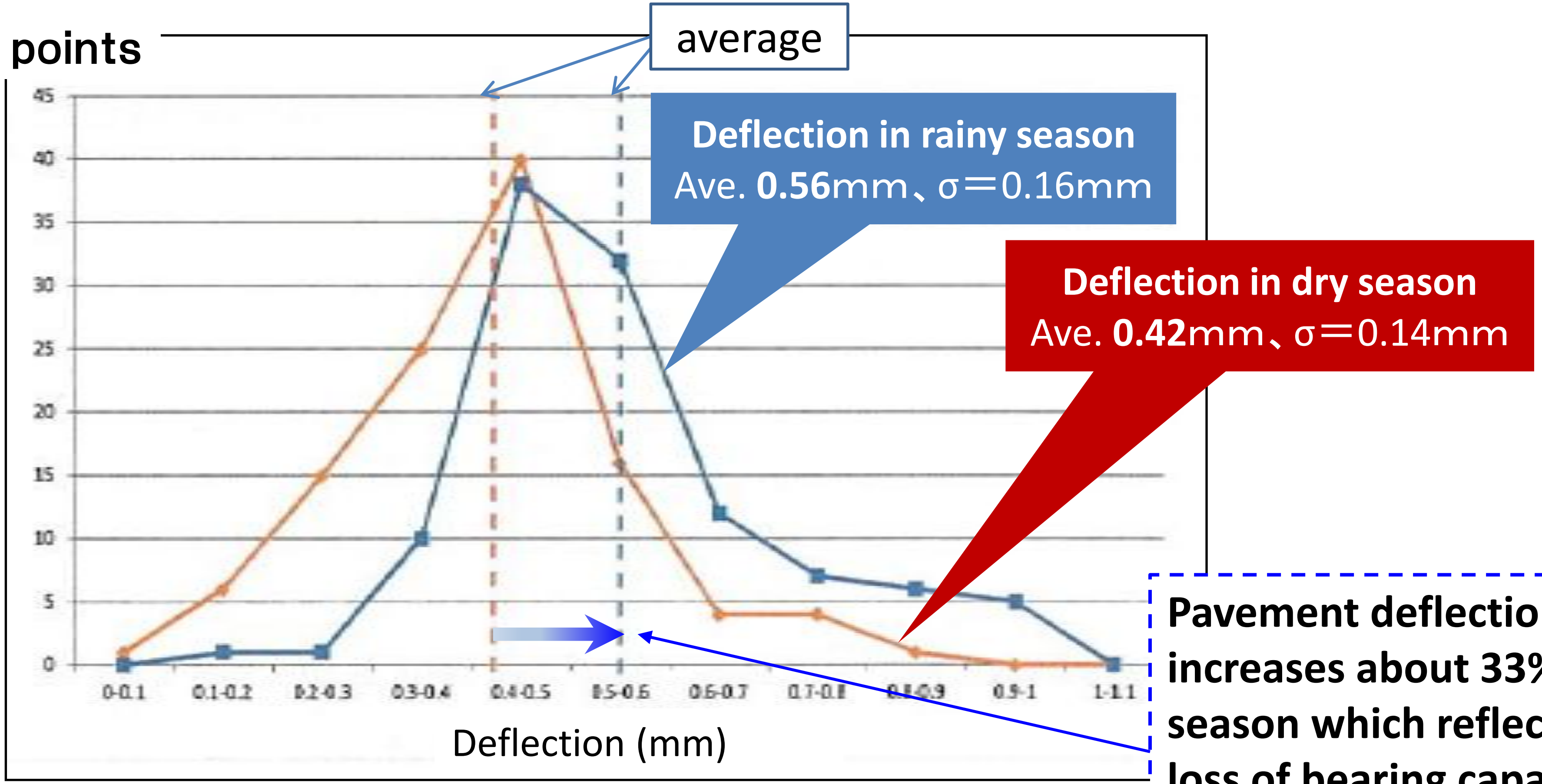


Fig. Various types of water intrudes into pavement

■ Pavement's strength differs by season—Impact of water



Pavement deflection increases about 33% in rainy season which reflects the loss of bearing capacity of the pavement cased by water content.

Fig. Differences in subgrade bearing capacity between rainy season and dry season

<by Benkelman beam test, in Cambodia by Konno>

■Principles of water control in the pavement

How to minimize adverse effects of water in the pavement?!

- Prevent water enter the pavement
- Provide drainage to remove it quickly
- Build the pavement strong enough to resist the combined effect of load and water

Yang. H. Huang, 2004. "Pavement Analysis and Design"

It is impossible to guarantee that road surfaces will remain waterproof throughout their lives, hence it is important to ensure that water is able to drain away quickly from within the pavement layers.

TRL. 1993. "Overseas road note 31"

Case 1 : Damage by Water Intrusion from Hill Side

- Pavement damaged by seepage from higher ground on trunk road in Ethiopia.
  (Rainy season, in August)

indicates damaged area

Solution : Drainage System at a Cut & Fill Section

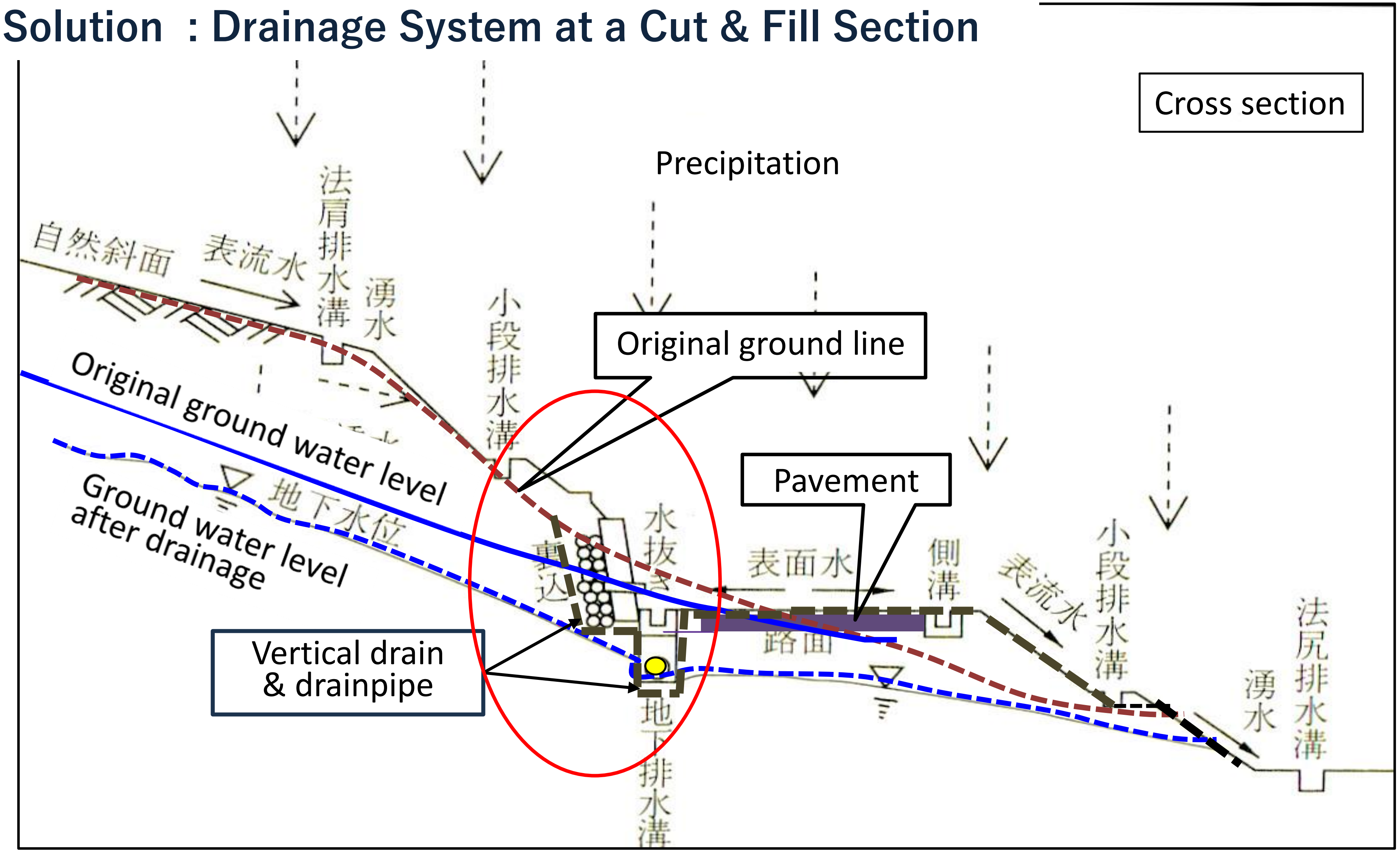


Fig. Ground water and drainage system at a cut section.

Case 2 : Damage by Water Intrusion at a Sag Point

Fig. Damages by water in base course at a sag point.
It is symmetrically damaged across the river.

Solution : Transversal Drainage

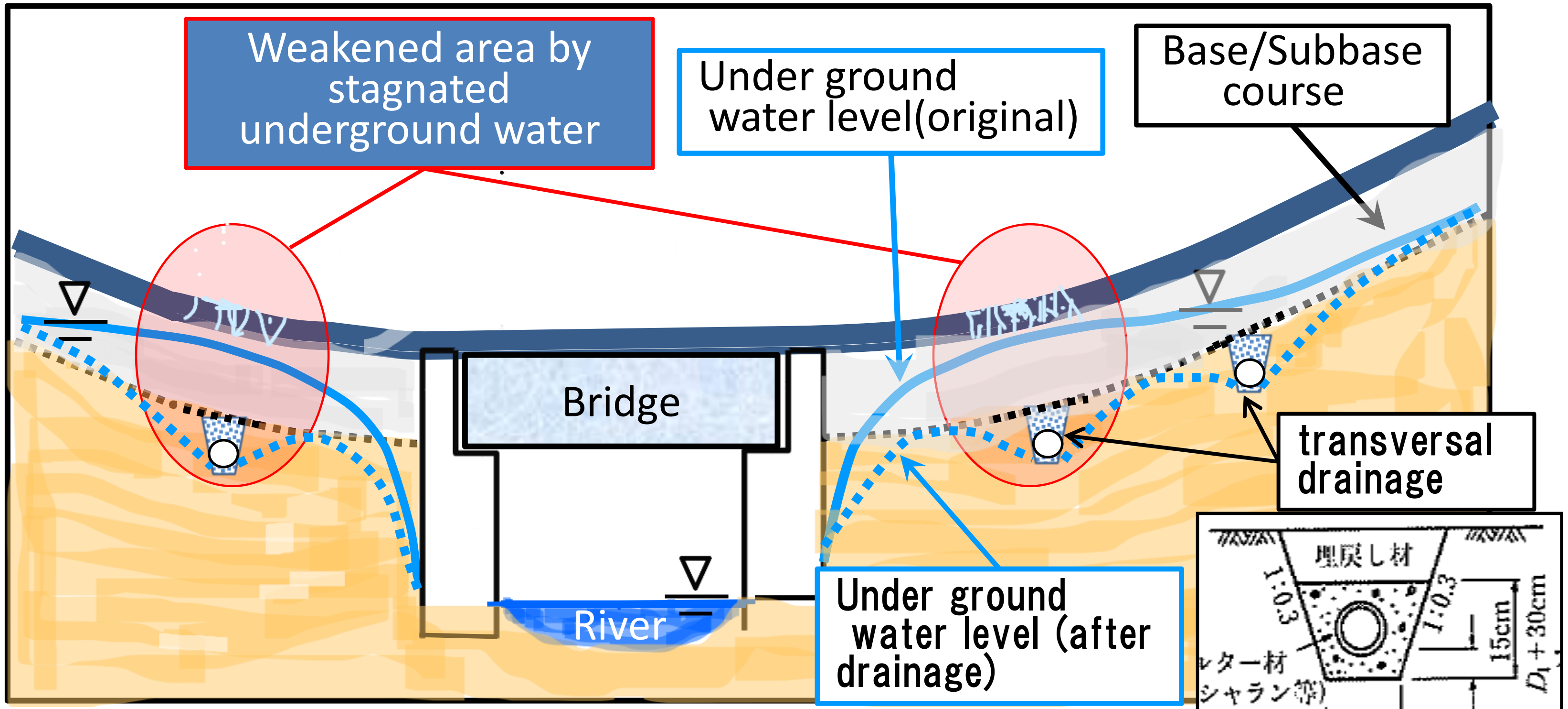
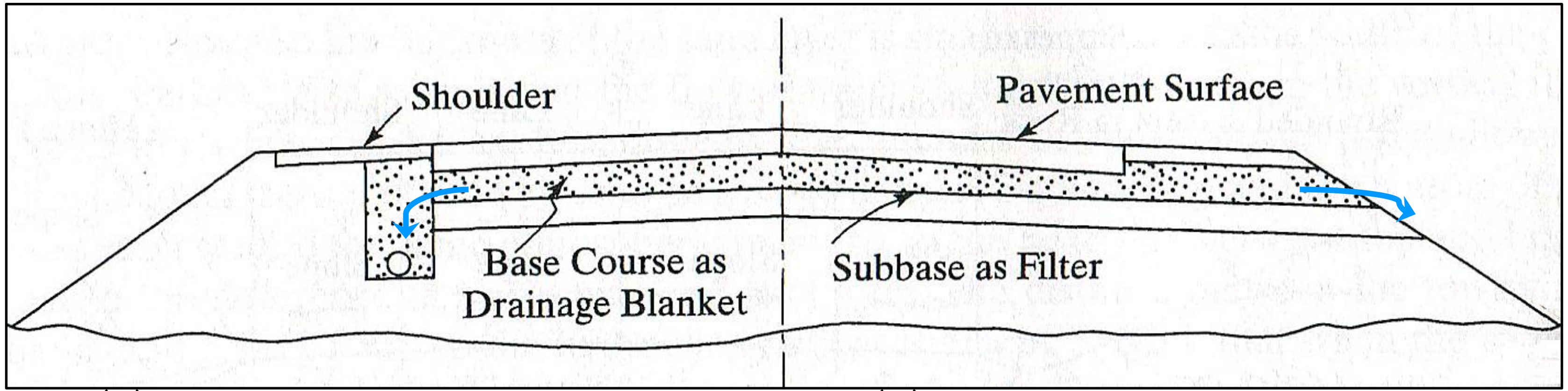


Fig. Profile of pavement and drainage

土工指針より

Fig. Plan of subgrade surface

Solution: Cross Section Configuration of Subsurface Drainage



(a) Longitudinal Drain with Collector Pipe

(b) Daylighted Construction for Drainage Blanket

* Y. H. Huang; Pavement Analysis and Design

Fig. Basic drainage system

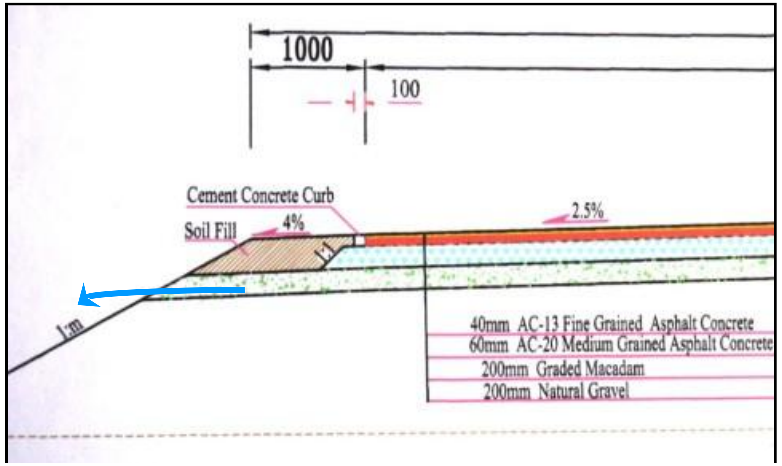


Fig. Example of expressway drainage

Fig. Shoulder cross drain (in Myanmar)

■Base course drainage with discontinuous shoulder through drain

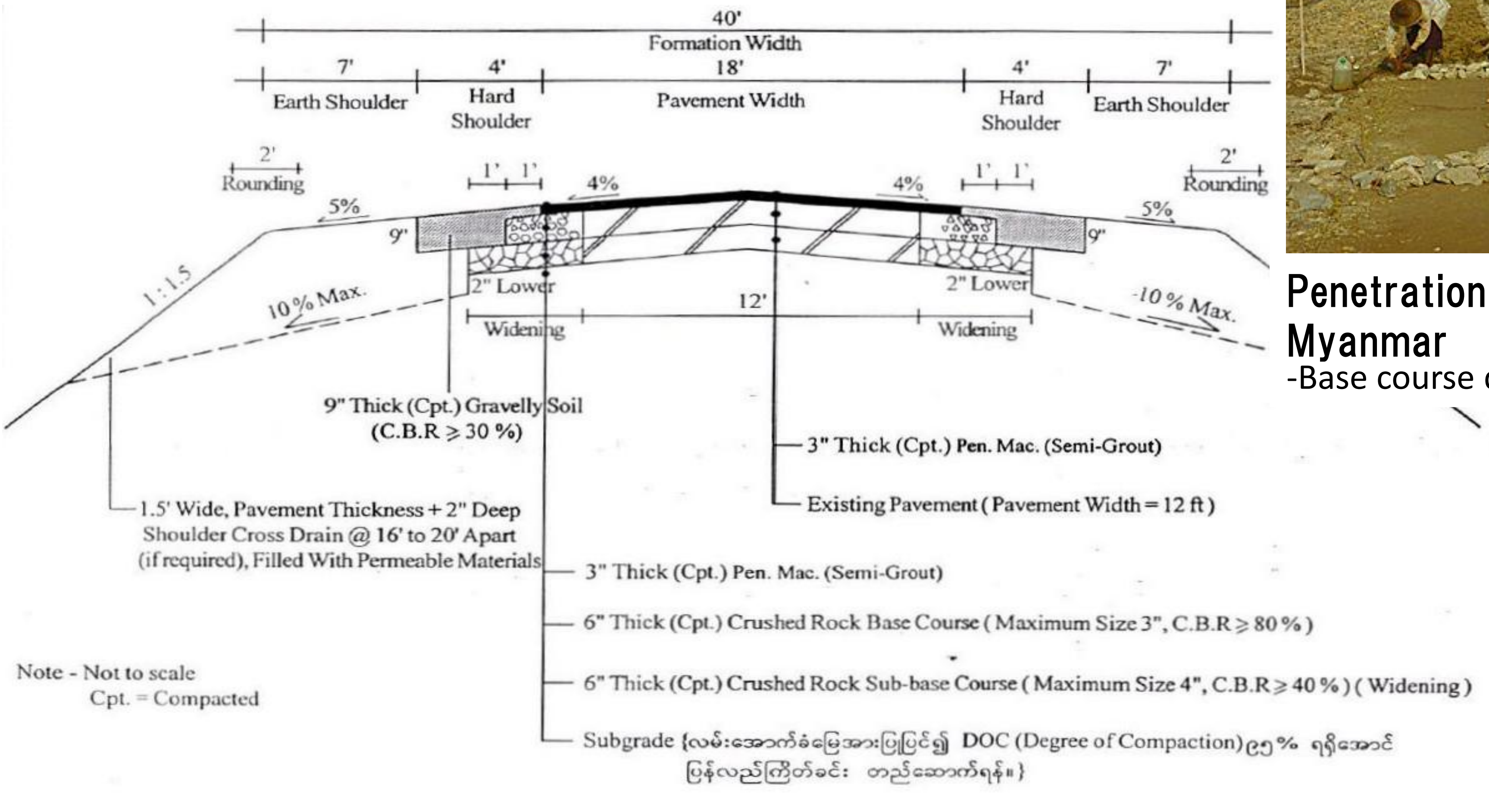


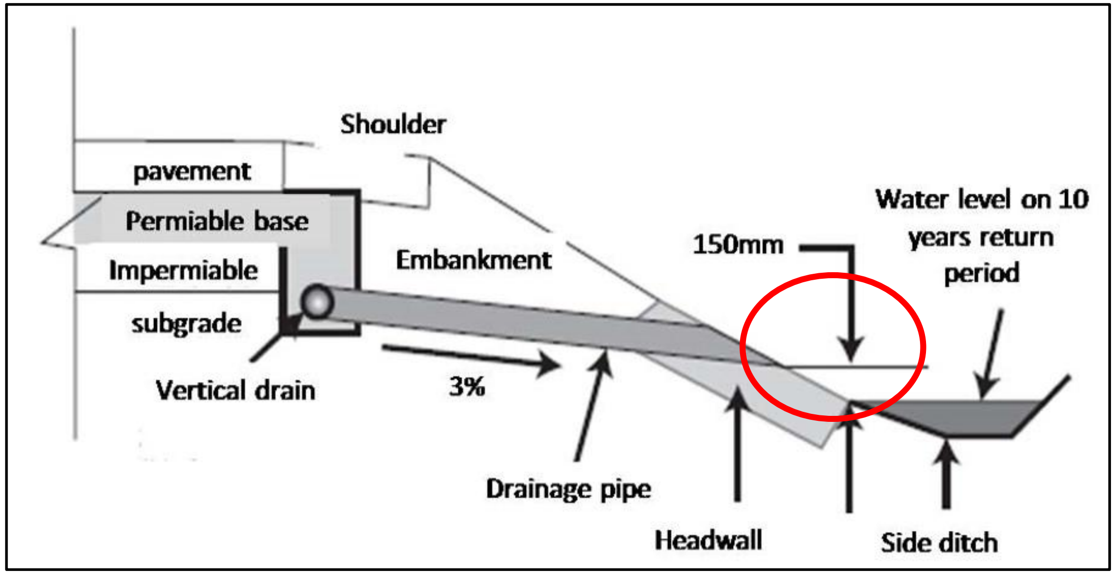
Fig. (17) Typical Design Cross Section of Shwe Bo - Myitkyina Road
(Mile 207/3 - Mile 209/6)

Penetration Macadam pavement in Myanmar

-Base course drainage is carefully carried out

■Longitudinal drain　with longitudinal collector pipe

This method reflects recent understanding on the importance of drainage to pavement in the US.



Cross section of vertical drain and drainage pipe.

CRPC in South Carolina. The dark line indicates that longitudinal vertical drain is newly installed. Drainage pipe outlet is seen in the red circle.(by Prof. Saburo Matsuno)

Case 3: Groundwater in a Cut Section

- Tokyo Metropolitan Express-way ‘Kariba-Sen’

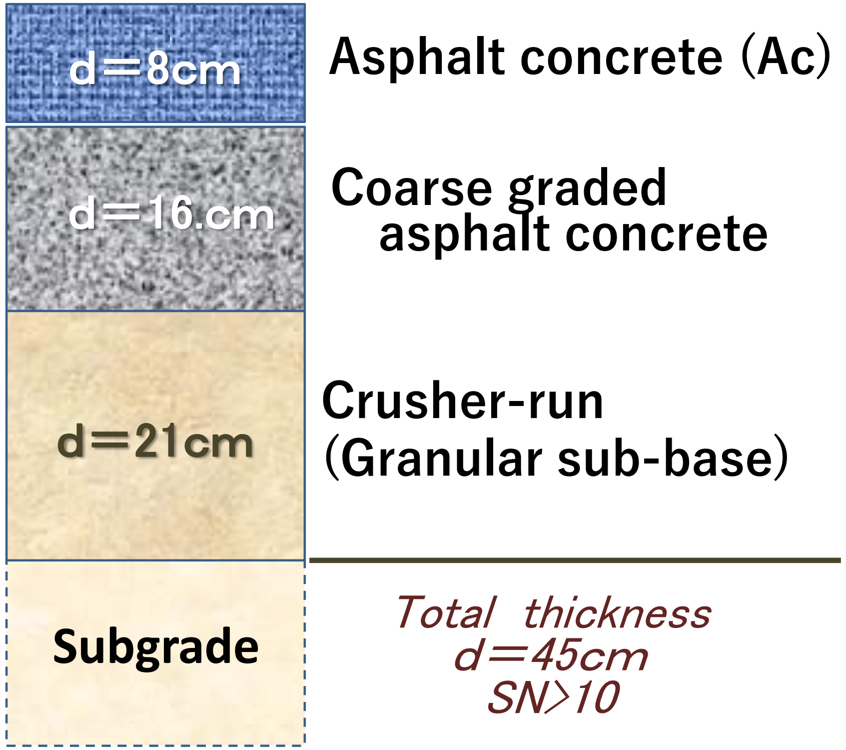
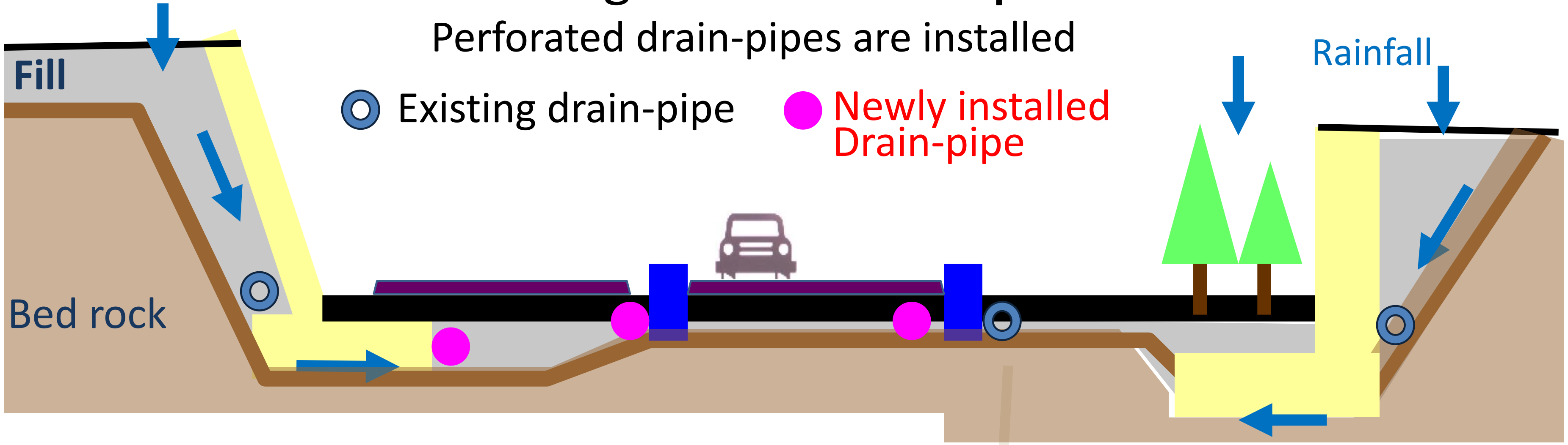
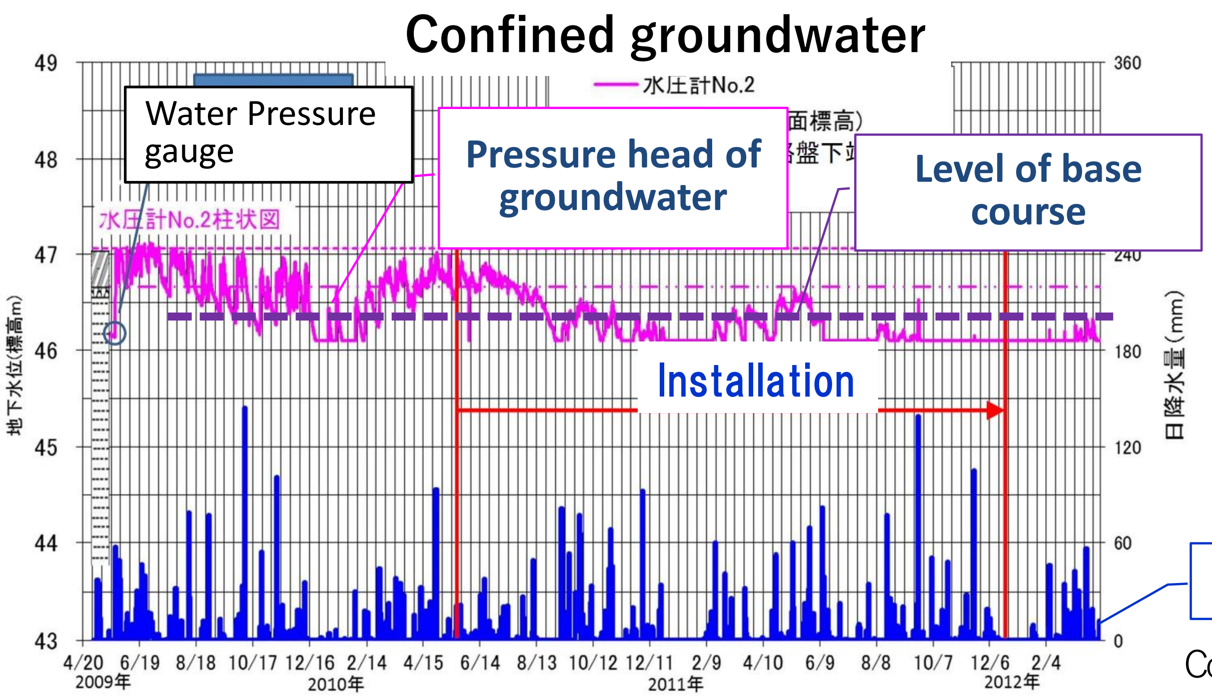


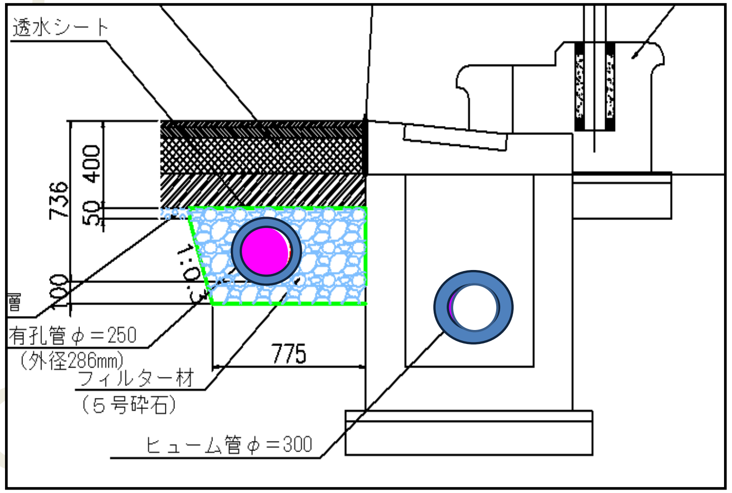
Fig. Pavement structure

Courtesy of Mr. Yamamoto, Metropolitan Exp. Way Tec. C.

Solution: Installation of Longitudinal Drain-Pipe





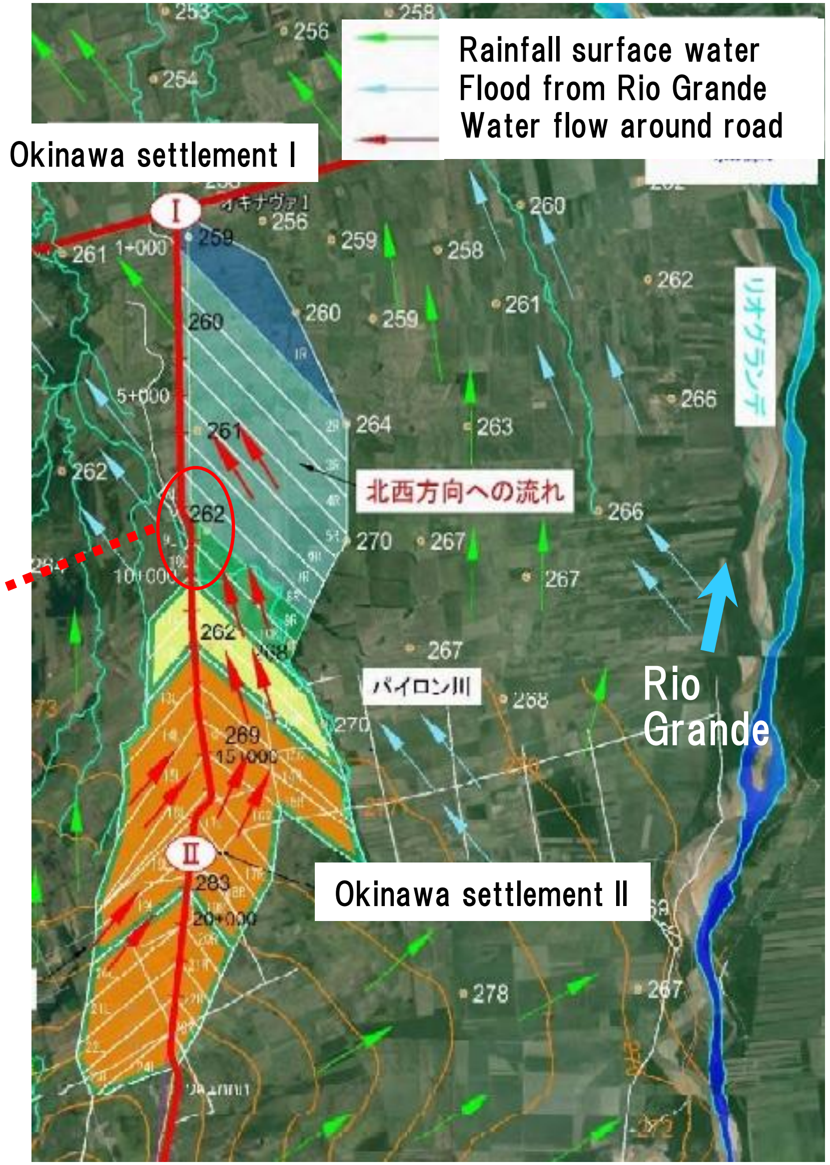


Detailed cross section

Courtesy of Mr. Yamamoto, Metropolitan Exp. Way Tec. C.

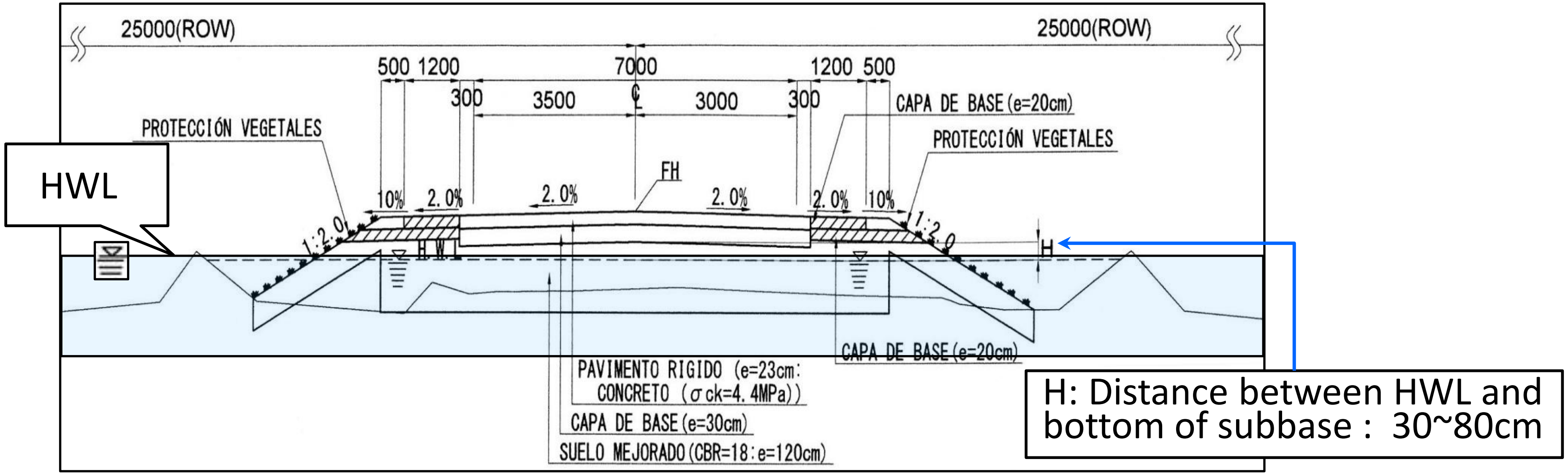
Case 4:Road Improvement on Flood Plain---Okinawa Road in Bolivia

Fig. Flood-prone section of Okinawa Road



Solution: Flood Mitigation

a)Keep pavement level higher than HWL



b)Provision of flood escape

Location of flood escape culverts around Sta. 8.00 km

3. Surface Damages and Countermeasures

(1)Plastic Rutting

1)Factors Cause Plastic Rutting

- External factors

① High Temperature of road surface ,
②Very slow and heavy traffic,
③Big bang of Bigger and heavier trucks in continental countries,
④Overloading

- Internal factors (Pavement mix)

①Excessive asphalt content,
②Aggregate strength and a particle shape,
③Aggregate grain size distribution,
④Asphalt penetration,
⑤Construction (quality) management

Fig. Deep rutting at a uphill section of road A1 in Ethiopia

[→Text① P268 Appendix 8: Measures Against Flow Rutting. ②JICA Pavement HB pp.1-19～30]

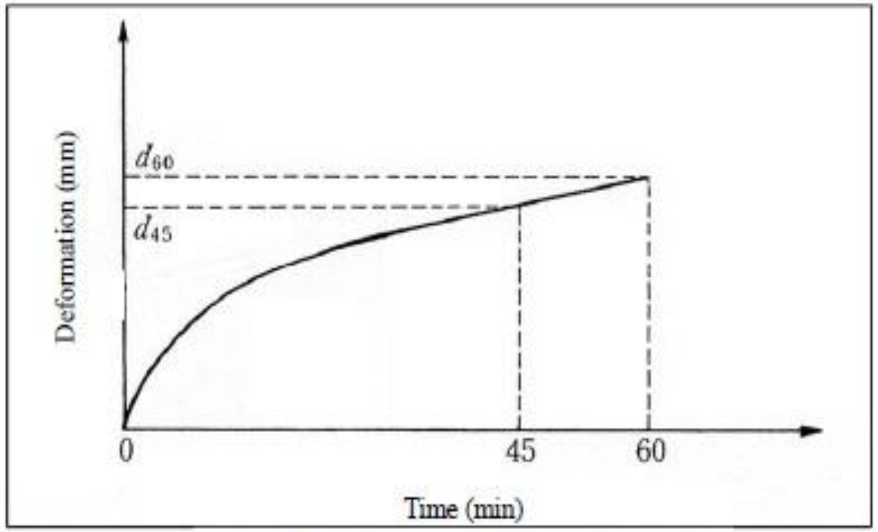
2) Wheel Tracking Test and DS number

[→Text① P269 Appendix 8 2-1 / ②JICA Pavement HB PP.I-24-27]

- Wheel tracking test is recommendable because it gives us of the overall evaluation of pavement performance against plastic rutting.
- The test result is expressed as dynamic stability (DS);

$$DS = 42 \times (60 - 45)/(d60 - d45) = 630/(d60 - d45)$$ (→ Appendix, Equation-8.2.1)

where DS: Dynamic stability (times/mm),
d60: Deformation in a test time of 60 minutes (mm), and
d45: Deformation in a test time of 45 minutes (mm).
Deformation must be measured down to the nearest 1/100 mm.



Appendix Figure-8.2.1: Test result (time-deformation curve)

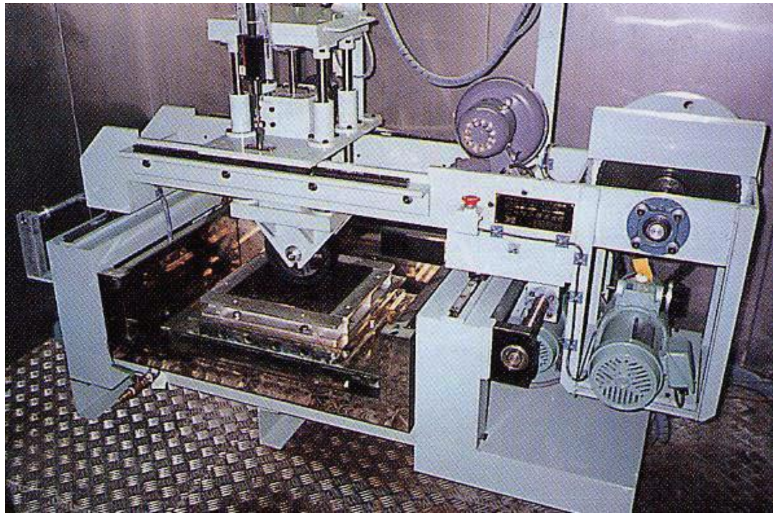


Fig. Wheel tracking test machine

■ DS Standards in Japan

➢ MLIT DS Standard (for ordinary roads)

Road Category	Pavement Design Traffic Volume (vehicles/day by direction)	Dynamic Stability Target Value (DS) (times/mm)
Type 1, Type 2, Type 3 Grade 1 and Grade 2, Type 4 Grade 1	3,000 or more	**3,000**
	Less than 3,000	**1,500**
Others		**500**

➢ NEXCO DS Standard (for express-ways)

Traffic Category		Dynamic Stability Target Value (times/mm)	Asphalt
Light-medium traffic	Less than 5,000 units/day per direction	**800**	**Straight asphalt**
Heavy traffic	5,000 units/day per direction or more	**3,000 or more**	**Modified asphalt**

Note) Traffic volume refers to large-vehicle traffic volume in the first year.

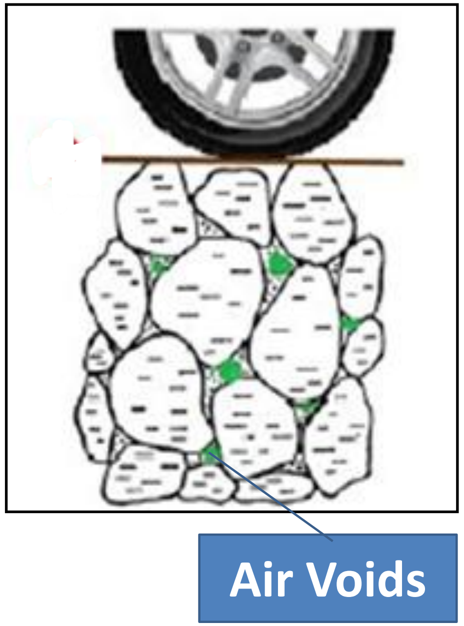
(2)Asphalt Mix Design and Construction Practice

1) Interlocking Coarse Aggregate

- Important principle is 'keep coarse aggregate interlocked'.
- This is difficult to judge in the field though, a number called `air voids` is used as an indicator to ascertain this condition.
- To ensure Air voids, do not use too much asphalt, and not use too much fine aggregates lower than the median.

Table: Residual air voids in the pavement on Natl. Hwy in Japan

	Wearing course	Binder course
At good condition sections	3.8%	2.9%
At poor condition sections	1.5%	1.3%



2) Asphalt penetration and asphalt content

- Another factor that increases flow resistance is the use of low penetration asphalt such as 40/60 asphalt.
- As can be seen in the figure below, excessive contamination is dangerous, and it is possible to reduce the amount of asphalt than OAC to the extent that there is no problem with workability or durability.

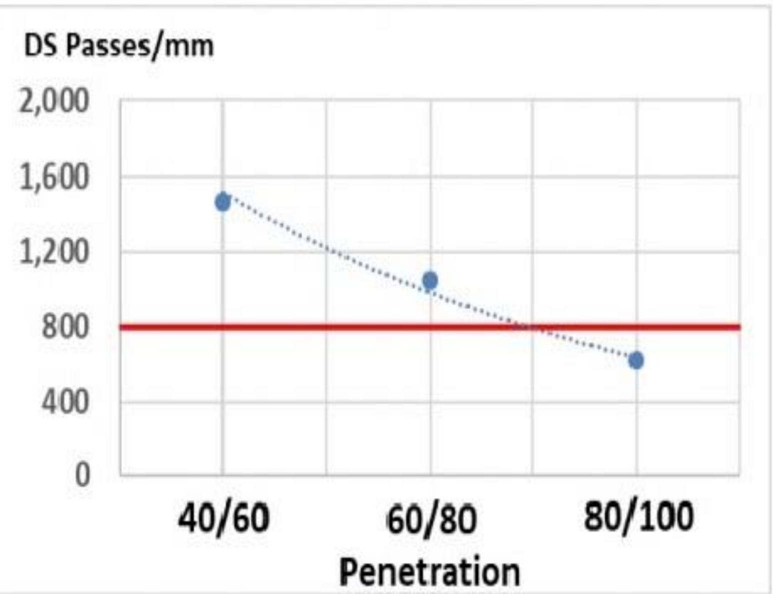


Figure 10.4 Relations between Penetration and DS

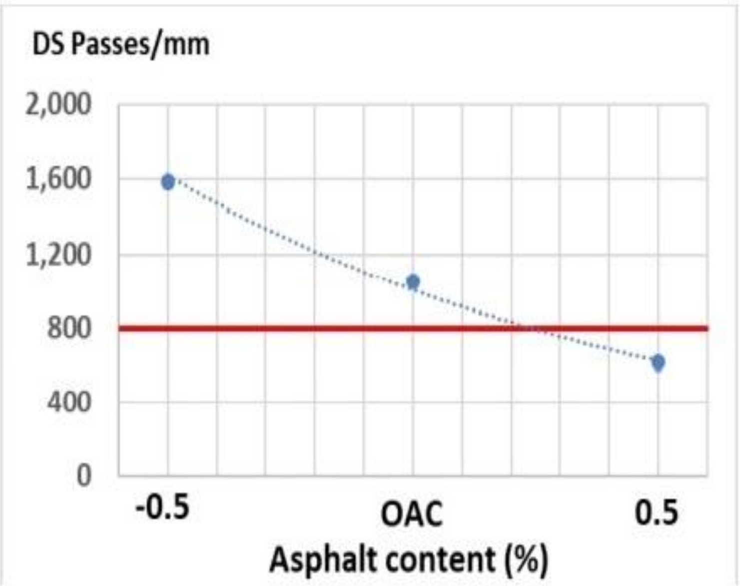


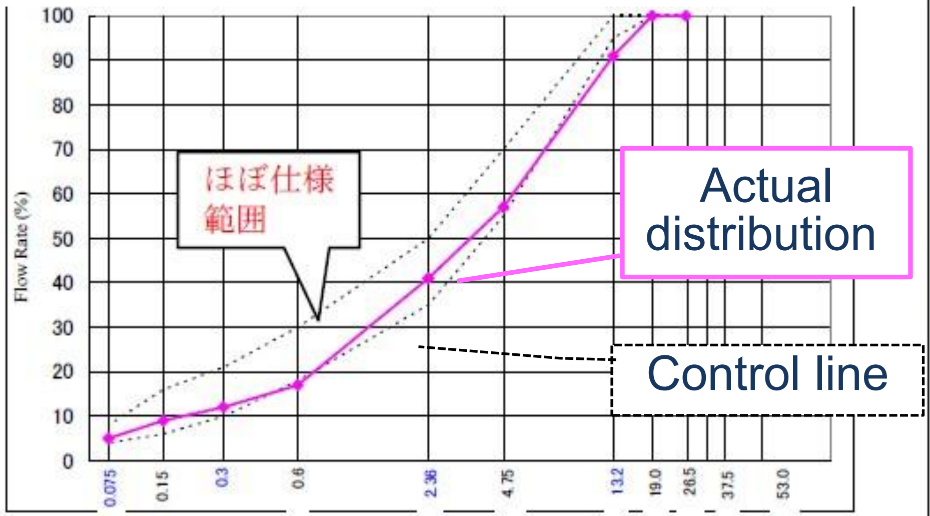
Figure 10.2 Relation between Asphalt Content and DS

→ "Road Pavement Handbook for JICA Grant Aid Projects" p. Appendix 10-11

3) Importance of Quality Control at a Mixing Plant

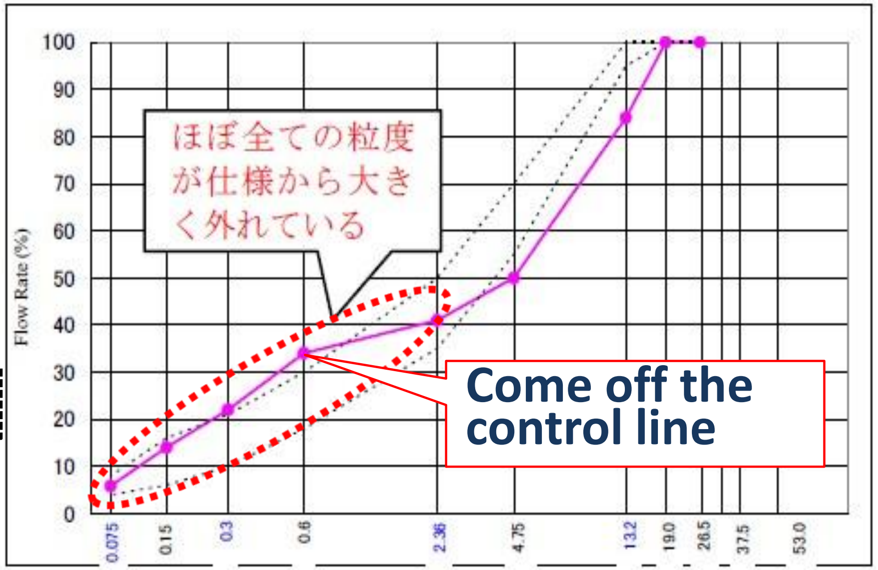
a. Good section

Balanced distribution of fine material & bitumen. Lower percent of fine and bitumen.

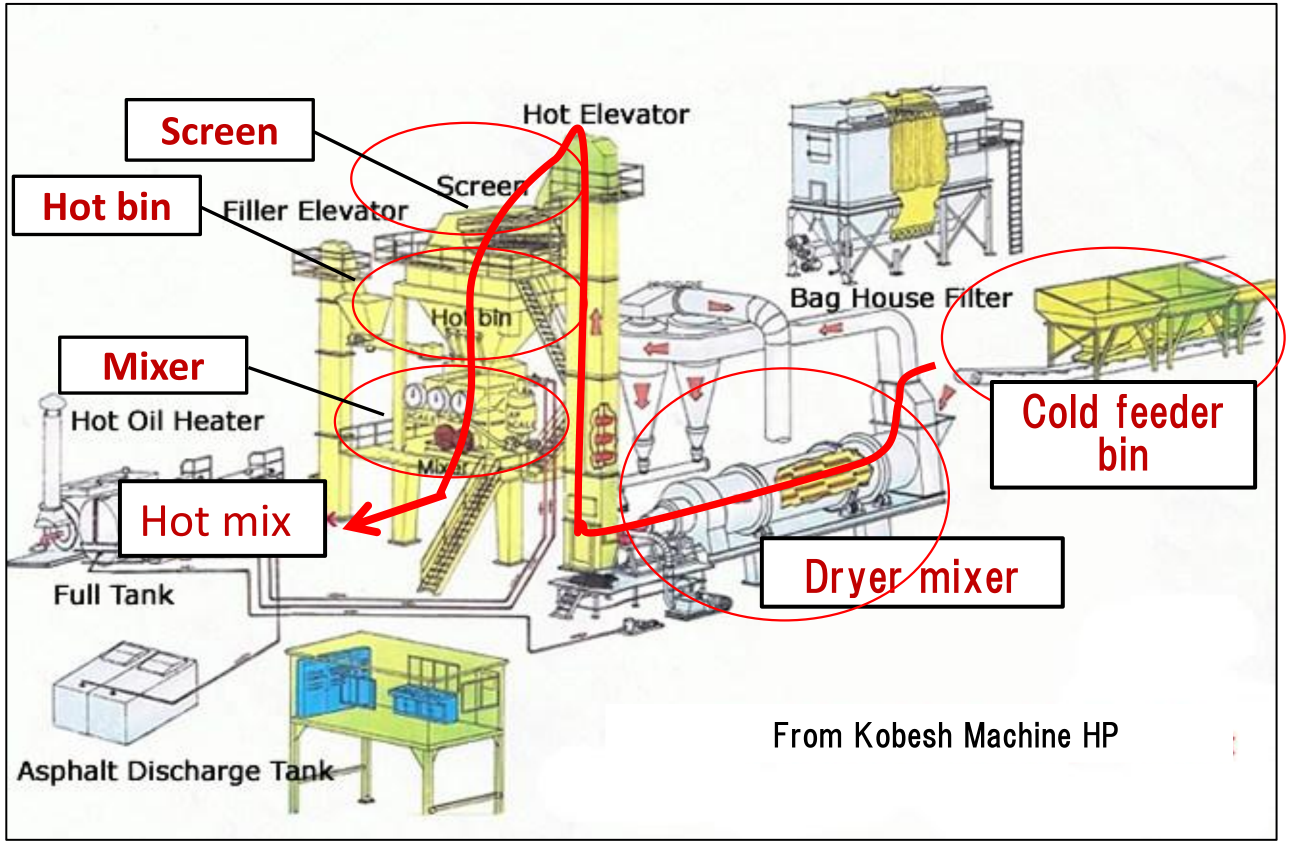


b. Poor section

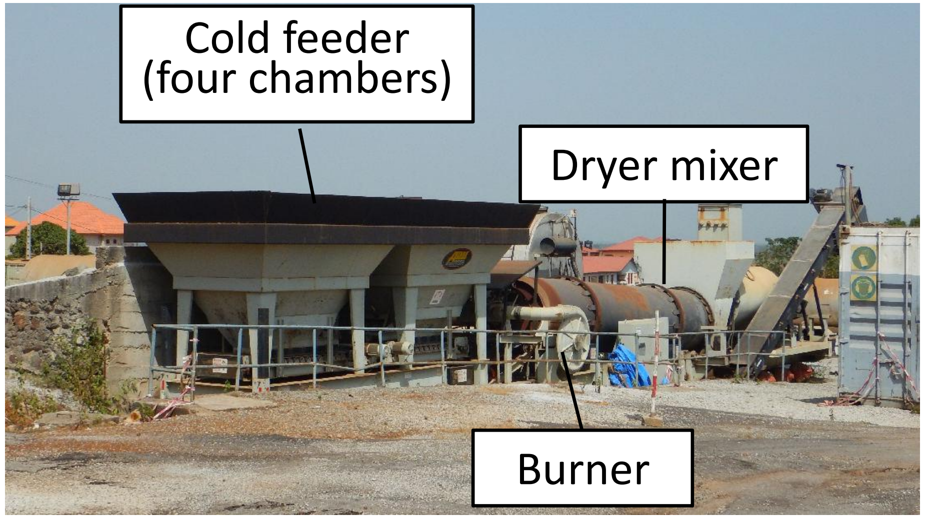
Excessive fine material & bitumen

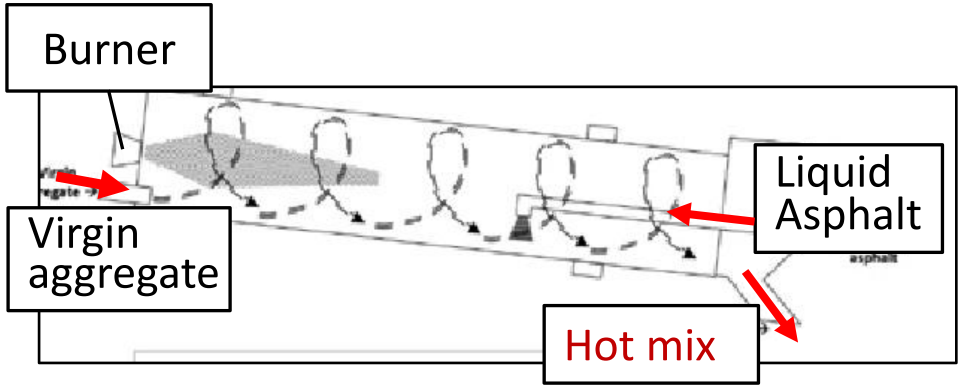


■Two types of asphalt mixing plant



a. Batch-type Asphalt plant





b. Continuous type Asphalt mixer

■Summary of rutting (Caused by plastic flow)

⇒No afraid of rutting if aggregate interlocking is secured!
The followings are the conditions to be thought.

① Aggregate grain shape (caution to flat shape and natural sand)
② Manage aggregate distribution (mix) design.
③ Choose lower penetration asphalt・・use harder bitumen without blocking workability (Penetration 40-60 is better).
④ Select asphalt contents max 0.5% less than the optimum asphalt content (OAC). Not to decrease too much to make the mix too stiff so that it does not crack easily.
⑤ Test of plastic resistance, DS (dynamic stability) by wheel tracking test.
⑥ Use plant mix modifier for severe condition such cases as long slope, intersection, roundabout etc.
⑦ Construction management → quality control at asphalt plant is indispensable.
⑧ Strict regulation against overloads

(3) Daily Control of Asphalt Plant

- Quality of asphalt mix is controlled by computer monitoring supplied volume from each hot bin. However, there was a case where quality of hot mix came off the requirement even printed data was perfect. →If granular size of each hot bin was off the requirement, what happens?
- Extraction and sieve out of hot asphalt mix every morning which will lead to find out defect of the plant in the first stage of trouble.

Table Example of daily control of asphalt plant (MLIT, Japan)

Control item	frequency	Necessary time
Hot bin sieve test (before mixing asphalt)	Every shipment Every morning	About one hour
Marshall test	Every shipment Every morning	Report next day
Extraction test	Every 100 ton	2-3hour(use centrifuge)

(4) Asphalt Pavement Cracking

Important items

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

Source: Maintenance Guidebook for Road Pavement 2013 edition, P202

➢ Linear Cracking

Longitudinal cracking

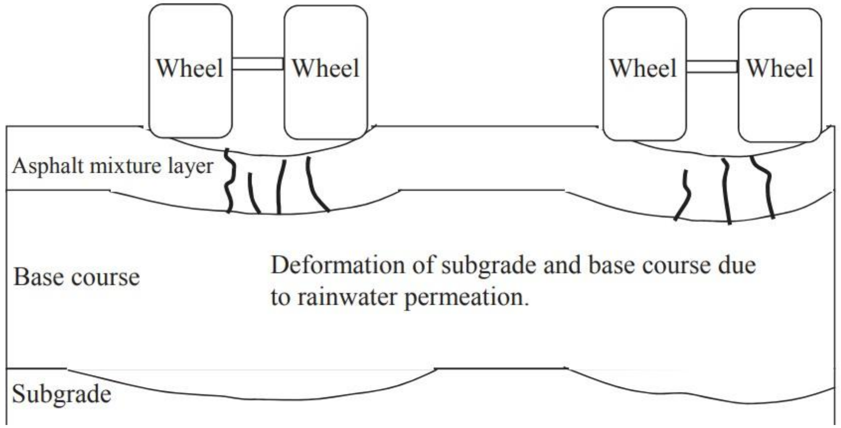
- **Fatigue cracking: Traffic loads cause tensile strain at the bottom of the asphalt mixture layer. Under the repeated action of such tensile strain, cracking occurs on the bottom. This cracking gradually extends upward before finally reaching the surface.**

Transversal cracking

- **Reflection cracking on a cement concrete slab**

→"Maintenance Guidebook of Pavement 2013", Appendix 4

➢ Alligator Cracking



Alligator cracking is a typical type of cracking which is caused due to decreased bearing capacity of subgrade or base course.
Alligator cracking will easily be developed into pot-holes.

→"Maintenance Guidebook of Pavement 2013", Appendix 4

Cracking due to **degradation or aging of asphalt**, it occurs even in road portions with low volume.

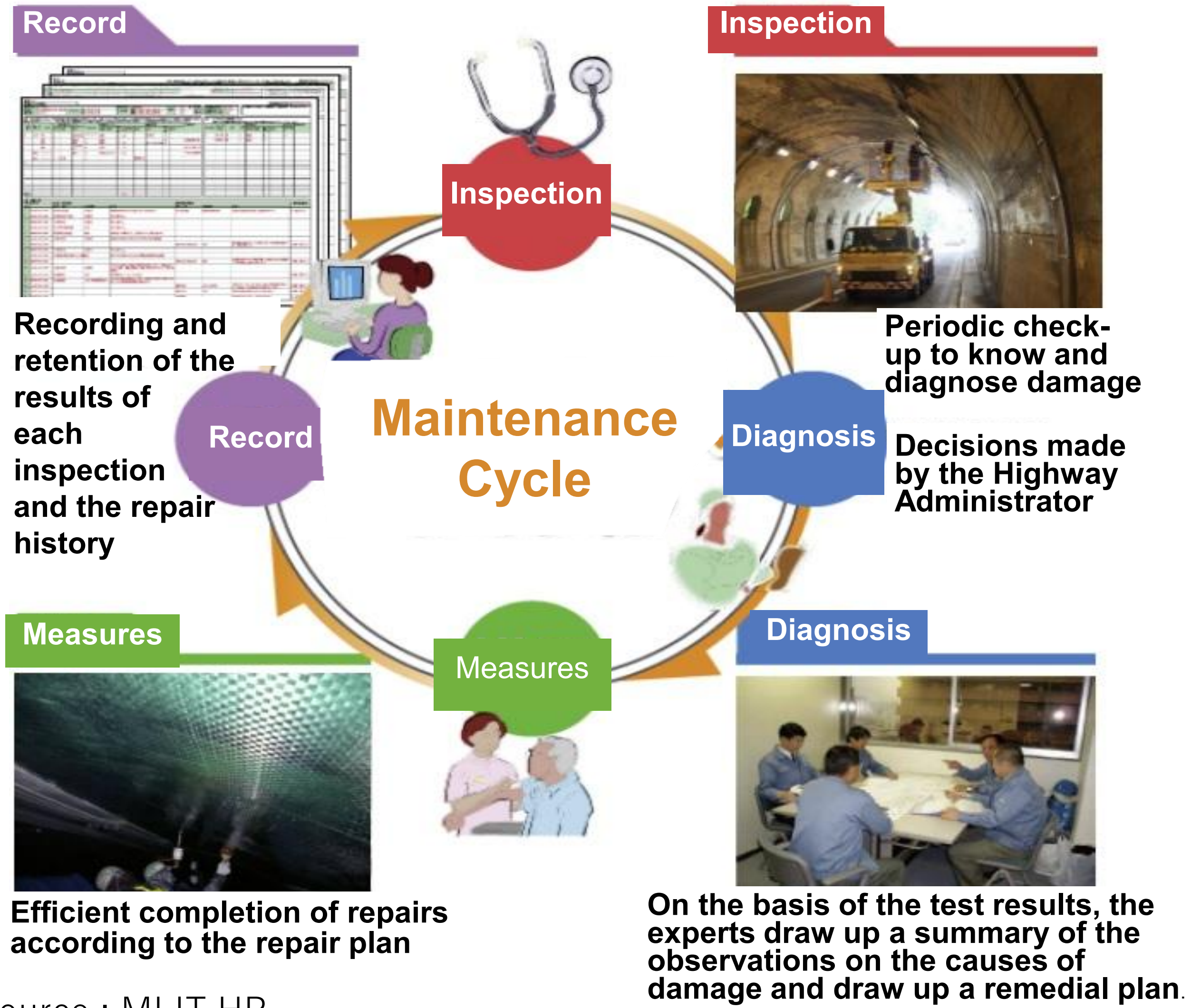
Cracking due to decreased bearing capacity of subgrade or base course **during thawing**.

→"Maintenance Guidebook of Pavement 2013", Appendix 4

4. How to select Maintenance/Repair Method

(1) MLIT Life Extension Plan -Inspection & countermeasures system

- Following the MLIT's "Infrastructure Life Extension Plan (Action Plan)", the regional offices are working by establishing their "Life Extension Plan" for bridges and roads.
- A system is established that includes the inspection and diagnosis of the roads (mandatory every 5 years), the implementation, the recording of the condition and the history of the measurements taken.
- Medium and long-term cost management→ Total cost reduction (LCC), budget leveling.
- Preventative maintenance, design integration during new construction and renewal, rationalization and consolidation of infrastructure.
- Develop maintenance industries.



Source : MLIT HP

➢ Classification of Soundness Diagnosis （MLIT ‘Pavement Inspection Guidance’）

Classification			Description
I	Sound		Low damage level: The degree of deterioration is minimal, and the pavement surface layer is sound according to the management criteria.
II	Surface function maintenance stage		Medium damage level: The degree of deterioration is moderate according to the management criteria.
III	Repair stage		Large damage level: The degree of deterioration exceeds the target values in relation to the operation criteria.
		III-1 Surface repair	Service year of the surface layer exceeds the target number of years (the layer(s) below the surface layer is assumed to be sound).
		III-2 Base-course replacement	Service year of the surface layer is under the target number of years (the layer(s) below the surface layer is assumed to be damaged).

出典：国交省舗装点検要領

➢ Damage Classification （MLIT ‘Pavement Inspection Guidance’）

	Class I	Class II	Class III
Cracking			
	Cracking ratio about 0-20%	Cracking ratio about 20-40%	Cracking ratio over about 40%
Rutting			
	Rutting about 0-20mm	Rutting about 20-40mm	Rutting over about 40mm

＊Generally, ruts, cracks, and irregularities (IRI) are often judged by the MCI index, which is a synthesis of the index.

出典：国交省「舗装点検要領」2016年

（2）Selection of Remedial Works （MLET: ‘Pavement Inspection Guidance’）

1） Soundness Diagnosis and Remedial works (general description)

Classification			Remedial works
I	Sound		-
II	Surface function maintenance stage		(Against cracking) Crack-sealing, fog-sealing, chip-sealing, patching, fulfill-rutting, thin-overlay (Against rutting) Cutting, patching, fulfill-rutting
III	Repair stage		
		III-1 Surface repair	Cut and overlay
		III-2 Base-course replacement	(Following detailed study & repair plan) Replacement of surface/base-course, reinforcement of base-course(cement stabilization etc.), renewal of pavement

■ Chipsealing

Chipseal: a pavement surface treatment that combines one or more layer(s) of asphalt with one or more layer(s) of fine aggregate.

Effective as a preventive maintenance scheme.

→ sprayed seal, surface dressing, bituminous surface treatment, seal

→application: DBST(Double Bituminous Surface Treatment)

Chipseal construction : YouTube "Chipseal Indiana"

Chipseal on local road: Indiana State Hwy #47

■ Patching

Removal of damage affected portion and put on tack-coat.

Compaction by a blade

■ Crack sealing

Field Manual for Crack Sealing in Asphalt Pavements (0-4061-P3) (utexas.edu)

→"Maintenance Guidebook of Pavement 2013"

2）Selection of Remedial Works Using FWD survey

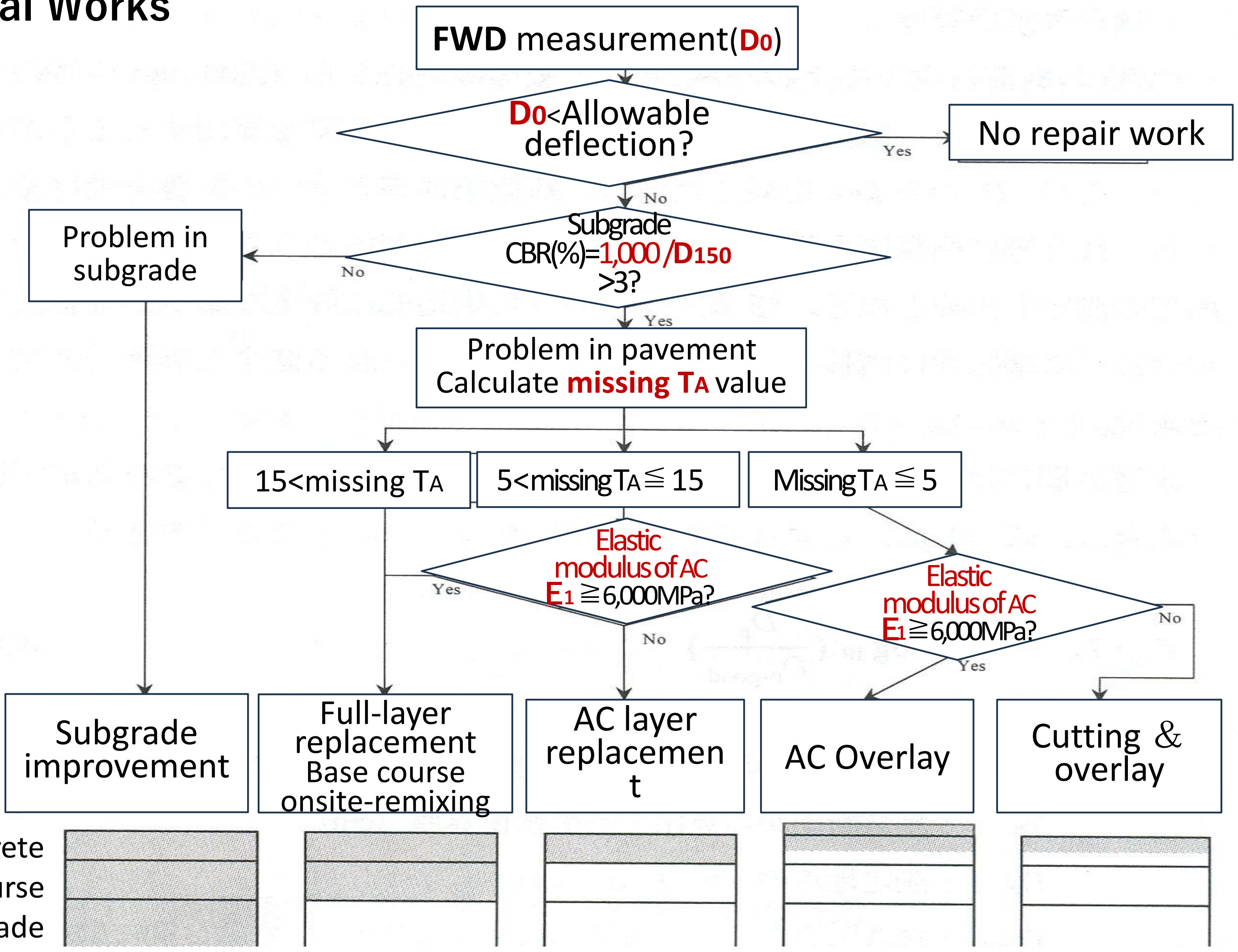
Critical Numbers are colored:

D_0: Deflection at the center of loading plate→Slide # 21

D_{150}: Deflection at a distance 150cm from the loading plate

Missing T_A: Difference between design T_A and existing T_A value

E_1: Elastic modulus of asphalt concrete .



出典：アスファルト舗装の詳細照査・修繕設計便覧, 図-4.3.2

■ Critical Numbers

① T_{A0} （=T_Aー Missing T_A）

a. $$T_{A0}=T_A - 34.5 \log_{10}\left(\frac{D_p}{D_{p\text{-}good}}\right)$$

ここに，T_{A0} :Residual equivalent thickness (cm)

T_A : Equivalent thickness of design pavement

D_p : D0-D150 (mm)

$D_{p\text{-}good}$: Dp at sound portion of the corresponding section/ adjacent section where the conditions are the same as repair section.

b. $$T_{A0}= -25.8 \log_{10}(D_0 - D_{150}) + 11.1$$

If $D_{p\text{-}good}$ is not available formula b. will be applicable.

② CBR_{sg}

$$CBR_{sg} = \frac{1}{D_{150}}$$

ここに，CBR_{sg} : Subgrade CBR (%)

D_{150} : Deflection at the point 150cm from the center of loading

出典：アスファルト舗装の詳細照査・修繕設計便覧, PP.56-57

③ E1

$$E_1 = \frac{23{,}520(D_0 - D_{20})^{-1.25}}{h_1}$$

In which E_1 : Elastic modulus of asphalt mix layer(s) including asphalt stabilization layer

D_0 : Deflection at the center of loading plate (mm)

D_{20} : Deflection at 20cm from the center of loading (mm)

h_1 : Thickness of asphalt mix layer(s) including asphalt-stabilized layer

④ T_{A0} ：Calculate residual equivalent thickness using E.C.F for existing pavement

Without FWD survey, residual equivalent thickness is derived using **Equivalent Conversion Factor (E.C.F)** for Existing Pavement.

$$T_{A0} = a1 \times h1 + \ldots + an \times hn = \sum_{1}^{n} ai \times hi$$

T_{A0}: Residual Equivalent Thickness (cm)

ai : Equivalent Conversion Factor(E.C.F) for Existing Pavement

hi : Thickness of each layer(cm)

→Table: Equivalent Conversion Factor for Existing Pavement (next slide)

出典：アスファルト舗装の詳細照査・修繕設計便覧, PP.56-57

Table : Equivalent Conversion Factor for Existing Pavement [→Text P 251]

Pavement layer	Material/ Treatment	Conditions	E.C.F* (a)	Notes
Surface & Binder	Hot Mixture	Slightly damaged but may progress to a moderately damaged condition	0.9	Maximum value for mild damage, minimum value for severe damage. The middle is determined according to the situation.
		Moderately damaged but may progress to a heavily damaged condition	0.85-0.6	
		Heavily damaged	0.5	
Base course	Bituminous Stabilization		0.8-0.4	The maximum value is applied to the same state as at the time of new construction, and others are determined according to the situation.
	Cement/Bituminous Stabilization		0.65-0.35	
	Cement Stabilization		0.55-0.3	
	Lime Stabilization		0.45-0.25	
	Hydraulic Slag		0.55-0.3	
	Mechanically Stabilized Crashed Stone		0.35-0.2	
Subbase course	Crusher-run, slag, sand & etc.		0.25-0.15	
	Cement /Lime Stabilization		0.25-0.15	

*E.C.F.: Equivalent Conversion Factor (a)

出典：舗装設計施工指針表-３．６．３

Thank you for your participation

Laos Natl. Road #9