# JICA Road Maintenance about Soil Quality

**12th November 2025**

Okinawa Construction Technology Center
Seminar lecturer: Takashi Horita

# Contents


Chapter 1 Why do we need to study soil?
1) What kind of civil engineering structures do we build?
2) What are soil and soil mechanics?
3) Various problems related to soil
Chapter 2 What is soil?
1) How the ground is formed
2) Ground in mountainous areas (rocks)
3) Ground in urban areas (soil: sand and clay)
4) Engineering aspects of soil
5) Soil surveys
Chapter 3 Why is it necessary to understand soil quality in civil engineering?
1) Why is it necessary to understand soil quality and ground?
2) For bridges, the bridge foundation type is determined by ground surveys.
3) For tunnels, the tunnel lining specifications are determined by rock surveys.
4) Standard tunnel construction sequence
Chapter 4 Road maintenance and repair work
1) Repair work related to road pavement work
2) Repair work for road pavement and road facilities
3) Bridge reinforcement and repair work
4) Road cleaning work and tunnel facility repair work
5) Road buried pipe installation work and grouping work
Chapter 5 Soil characteristics of embankment
1. Stability of embankment
2. What is soil compaction?
1) The concept of soil compaction
2) Soil compaction test methods
3) Soil compaction test results
4) Characteristics of soil compaction
5) Embankment compaction management methods
6) Actual on-site embankment compaction management
3. Stability of foundation ground
Chapter 6 Groundwater
1) Groundwater flow caused by rainfall
2) Deformation of embankments caused by groundwater
3) Why are slopes prone to collapse when it rains?
Chapter 7 Landslides and landslides
1) Landslides on roads
2) Characteristics and signs of landslide topography
3) Disaster hazard maps along road routes
4) Characteristics and signs of landslide topography
5) Landslide prevention measures
6) Characteristics and measures for collapse of rock slopes
Chapter 8 Earthwork planning
1) Creating embankment plans
2) How to calculate the volume of earthwork
3) Changes in the volume of earthwork during construction

# 1) What kind of civil engineering structures do we build?

## ① Permanent structure

・ Permanent structures are social infrastructure structures such as permanent earth structures (embankments), concrete, and steel structures.

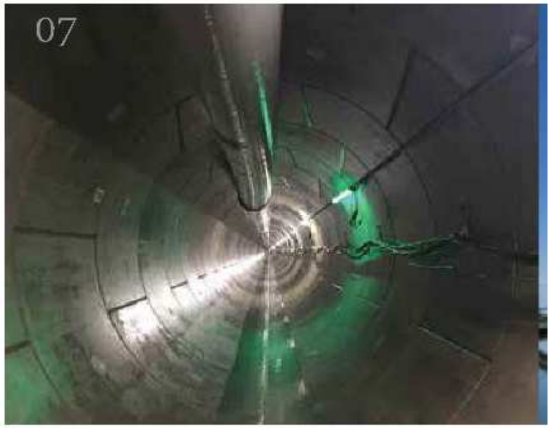
・ For example, roads, rivers, levees, bridges, dams, tunnels, drainage channels, subways, monorails, etc.

・They are built on the surface of the ground or underground.

・ Permanent structures have a lifespan of 30 to 50 years and are subject to a wide range of loads, including earthquake forces and snow loads, so they generally require a high safety factor.

・ Safety factor of the structure: Fs=3.0




## ② What are temporary structures?

・Structures that are necessary during the construction period to create permanent structures and are essential to the construction. Structures, construction, and plans that are removed at the end of the construction period.

・For example, structures such as temporary fences, construction offices, parking lots, scaffolding, formwork, shoring, retaining walls, jib or gate-type cranes, piers, construction roads, temporary bridges, temporary rockfall prevention fences, temporary drainage channels, and settling ponds.

・Temporary construction such as ground excavation, ground improvement, and drainage.

・Temporary structures are temporary structures that are installed for a short period of time (1 to 2 years), and are designed for the loads that will act during that period, and generally have a low safety factor. (Limited locations, limited periods, limited load conditions, etc.)

・Safety factor of structures: Fs=1.5

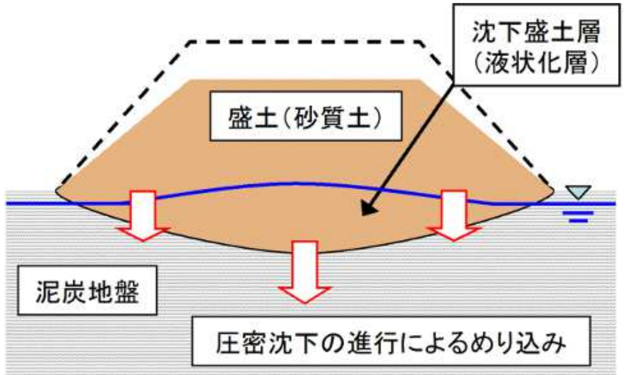
・Loads are not assumed to occur during earthquakes. For example, 20t dump trucks, 50t crawler cranes, or snow loads are not taken into account.

Temporary structures are structures whose structural members are designed under limited conditions according to each construction site.

## 2) What are soil and soil mechanics?

・Civil engineering structures include a variety of structures, including permanent and temporary structures, such as roads, dams, and river structures, and these structures are constructed on the ground's surface or underground.

・Over the years of use, these structures will subside, break, or deteriorate due to natural disasters and other reasons.




・We need to understand why these subsidence and collapse phenomena occur, and make newly constructed structures durable for long-term use. To do this, we need to understand the local soil conditions and use soil mechanics to create designs that can withstand use. These structures don't have to be made of soil, concrete, or steel.

・The field that understands, researches, and theorizes the mechanical properties of soil, such as soil strength, subsidence, and deformation, is called "soil mechanics."

## 【Soil】

A mixture of minerals, organic matter, gas, and liquid that covers the surface of land throughout the Earth.

## 【Soil mechanics (geomechanics)】

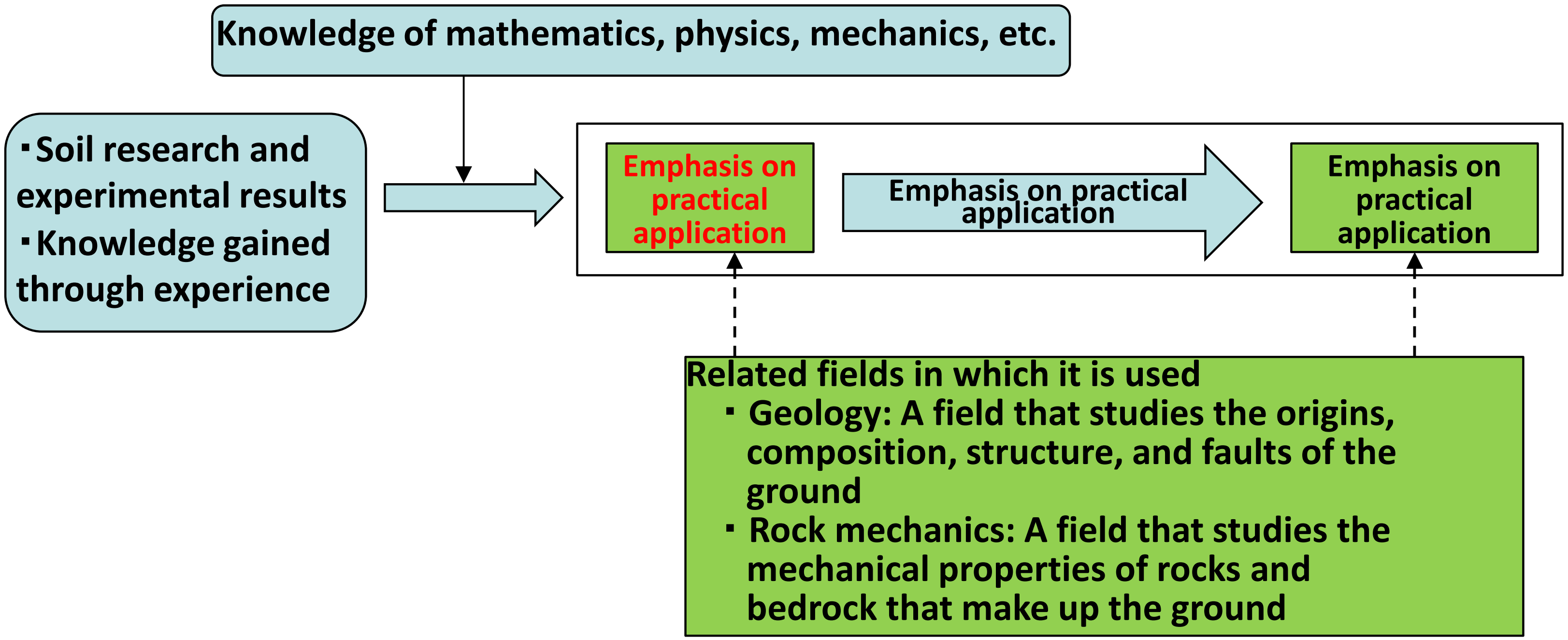
・A type of mechanics that deals with theories and applications of soil properties such as mechanical properties and permeability, stress and displacement within the ground, earth pressure, bearing capacity, and slope stability. Recently, it has been called geomechanics.

・Mechanics for explaining phenomena that occur in the field according to theory.

・Mechanics for explaining phenomena that occur in the field according to theory.

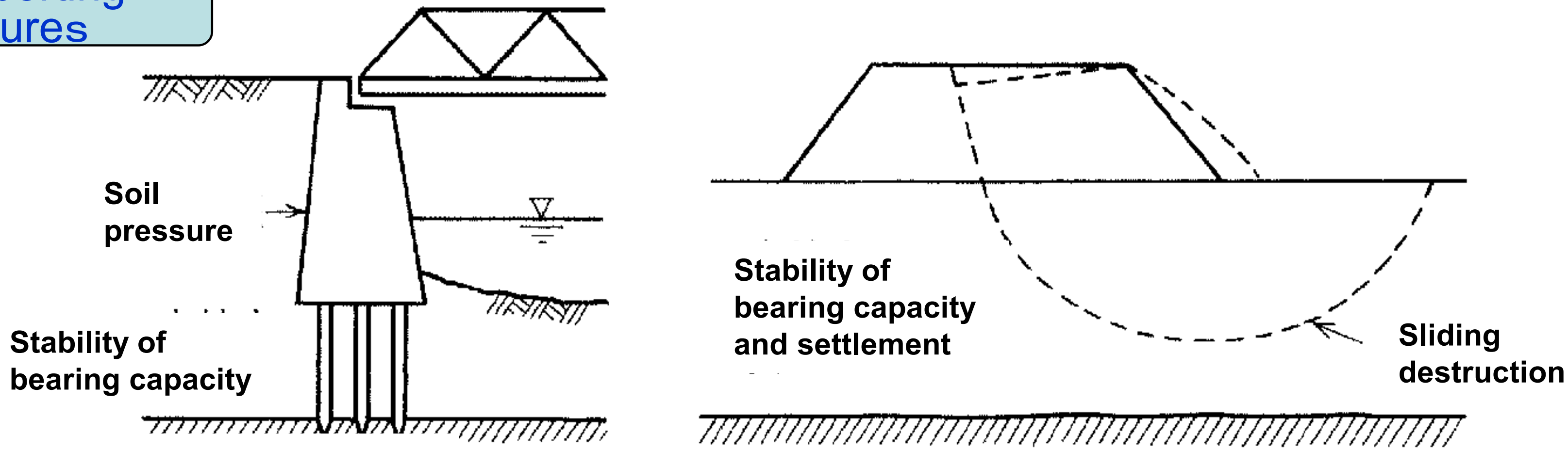
・Numerous phenomena that occur in the field occur in various grounds, and are a collection of miscellaneous and complex events.

【It is one of the three mechanics in civil engineering (structural mechanics, hydraulic mechanics, and soil mechanics)】

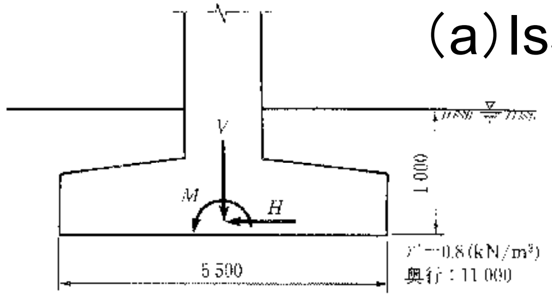


# 3) Various problems related to soil: We need to solve the "soil-related problems" that we worry about on a daily basis.

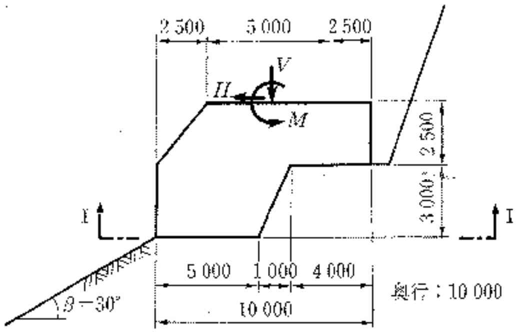
① Supporting structures



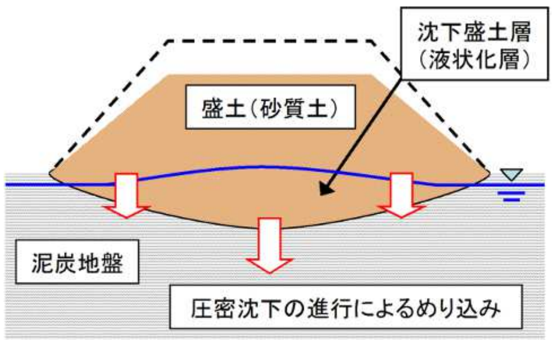

（a）Issues as a supporting ground




Ground support for spread foundation piers (1)

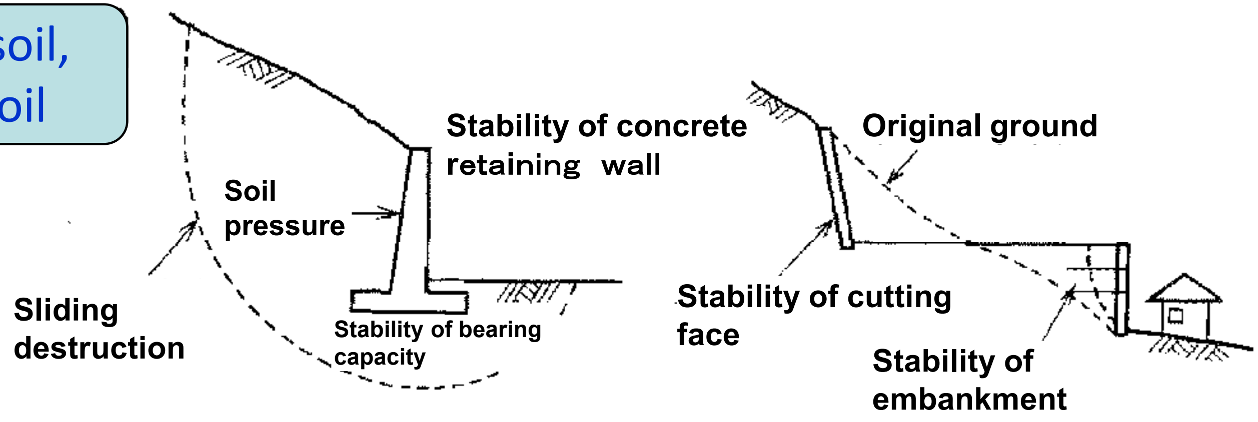



Ground support for spread foundation piers (2)

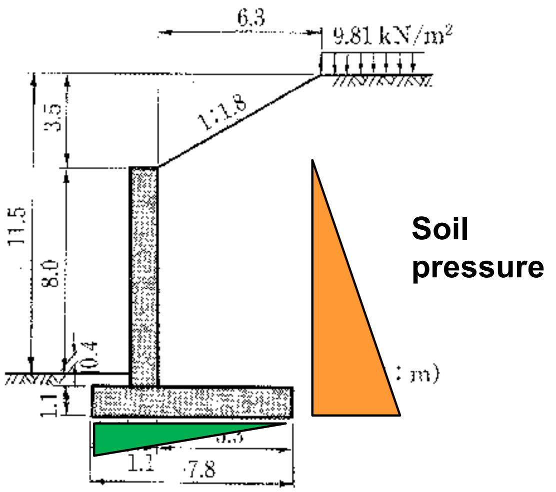



Subsidence of the ground supporting the embankment

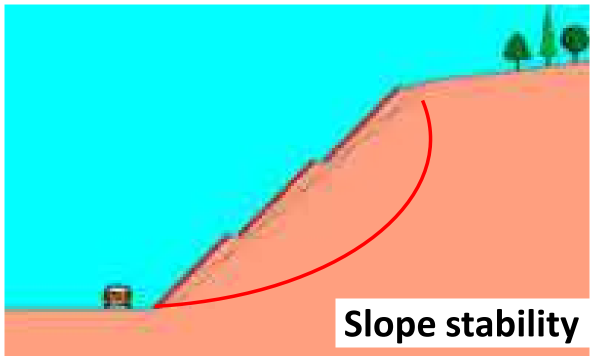
# ② Digging the soil, retaining the soil

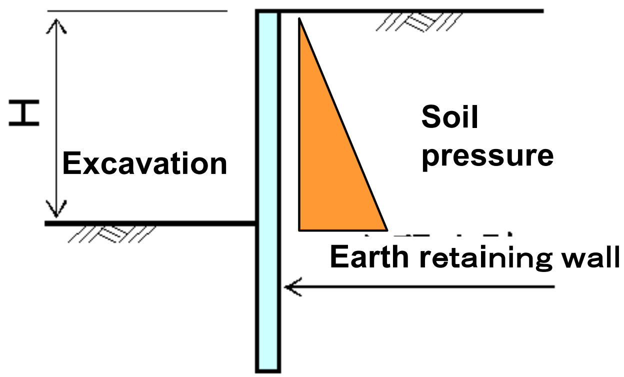


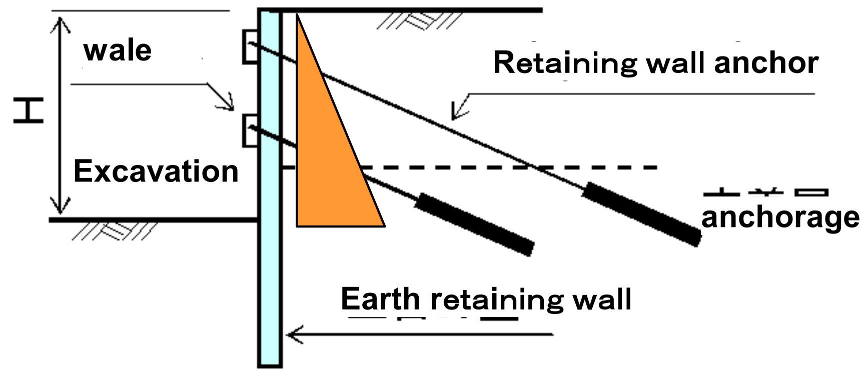

(b) Issues as a **stability** of ground itself



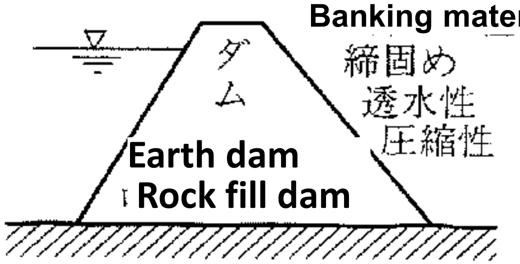

Retaining wall stability



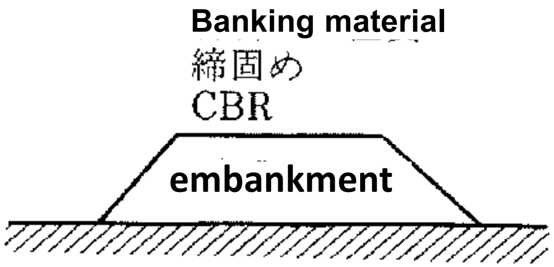



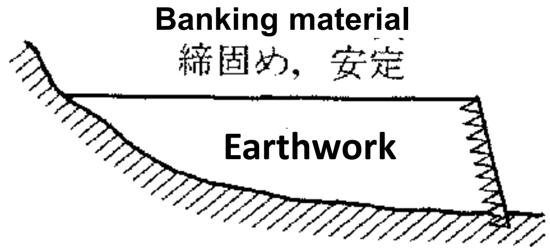
## ③ Building structures with earth



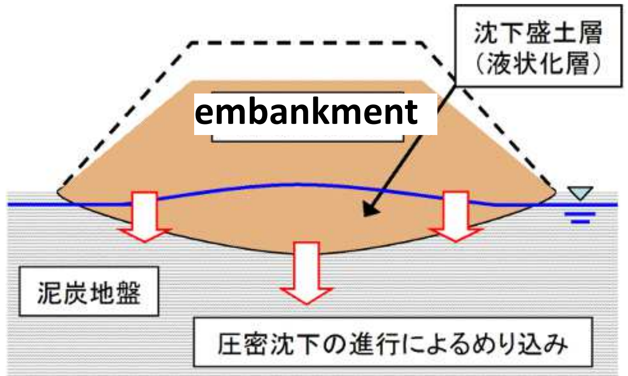

Stability of bearing capacity




Stability of bearing capacity and Settlement




## (c)Issues as a **marerial** of ground itself



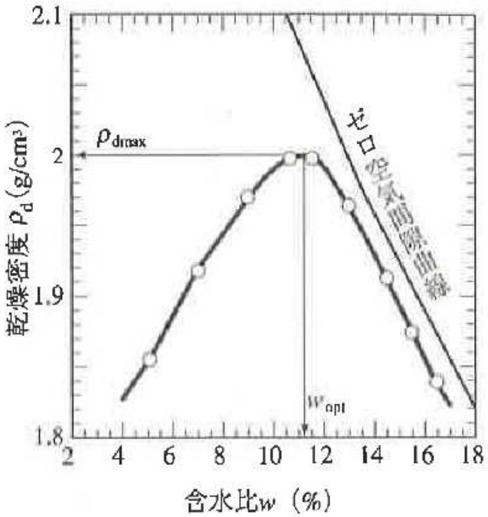
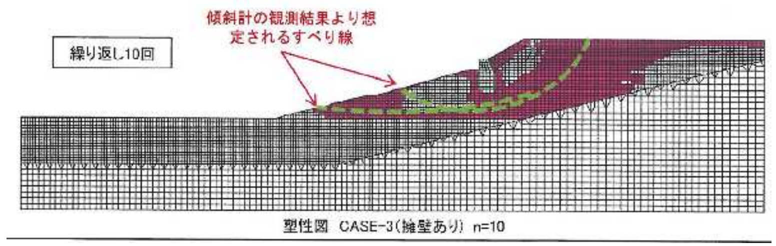
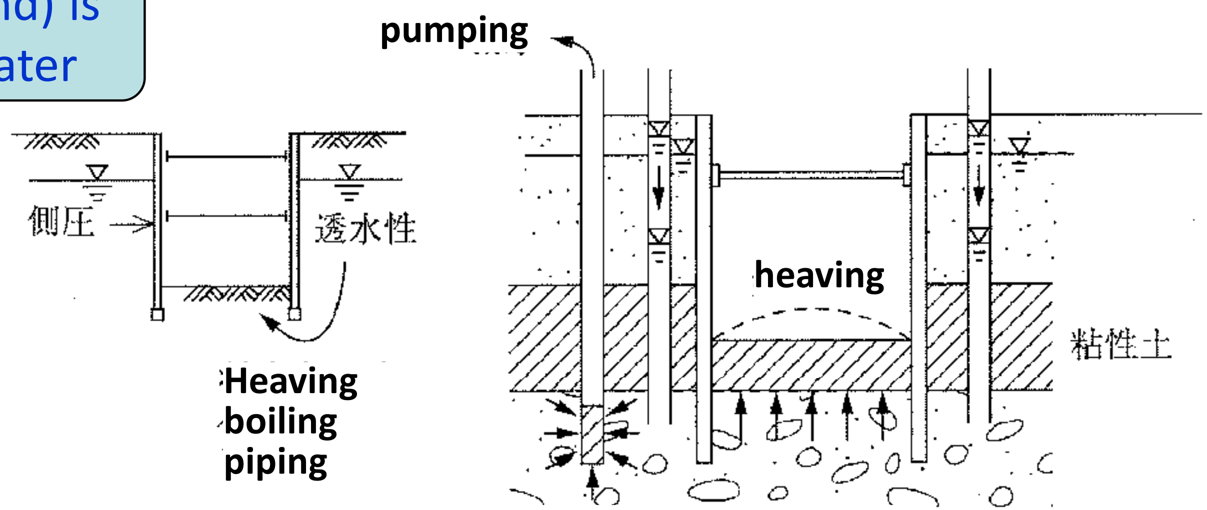




Fig. 3 Soil compaction curve

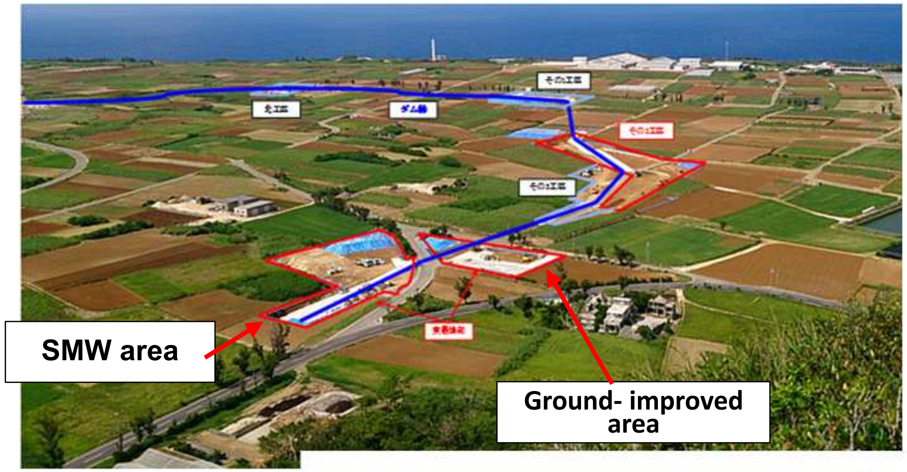

Fig. 5 Heavy machinery and equipment for compacting soil and sand



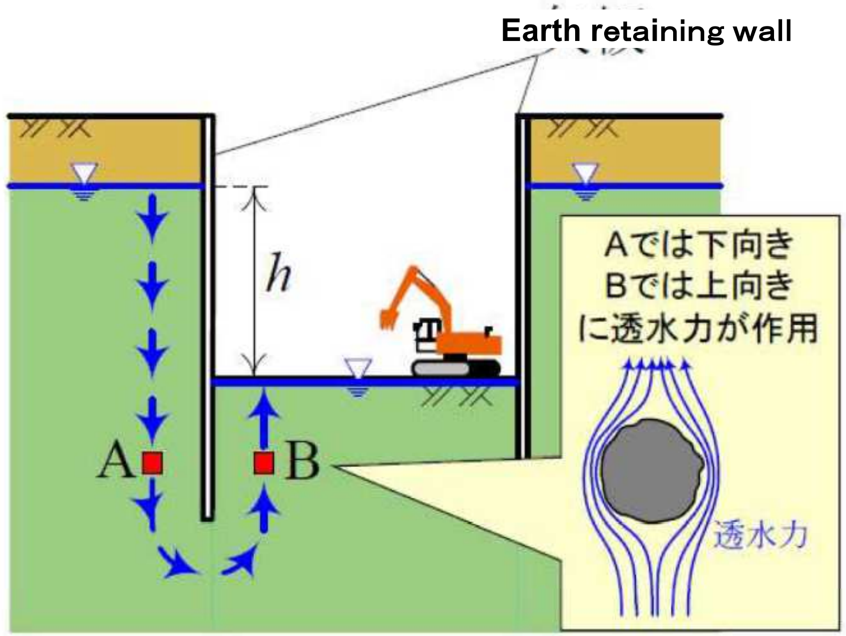
④ The soil (ground) is permeable to water



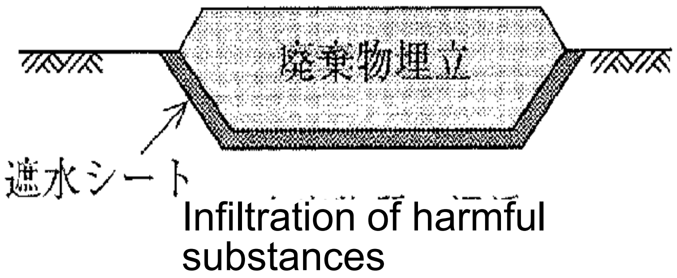

(d) Issues as groundwater

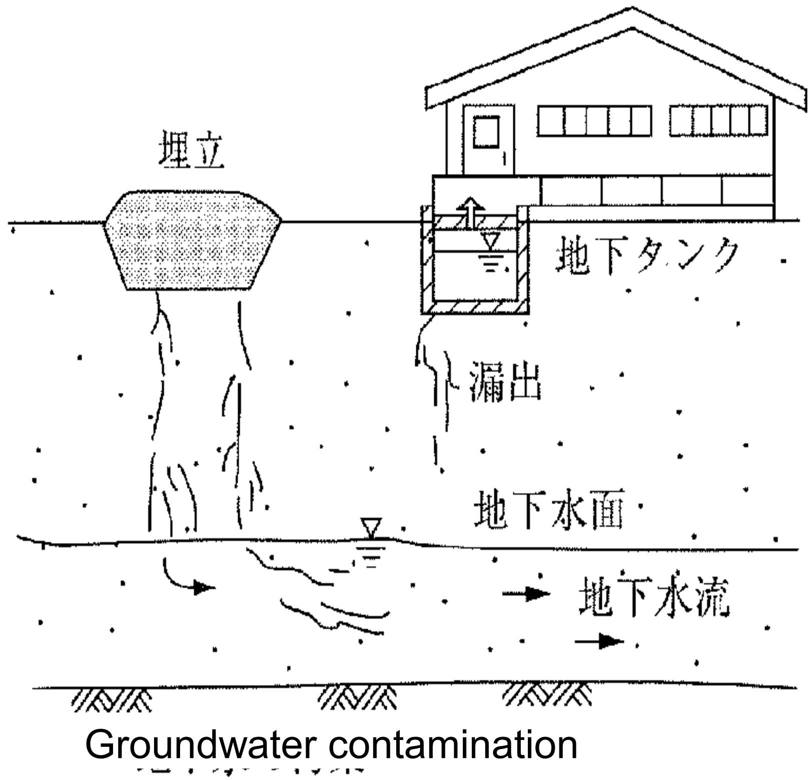






## ⑤ Disposing of waste materials underground (ground)

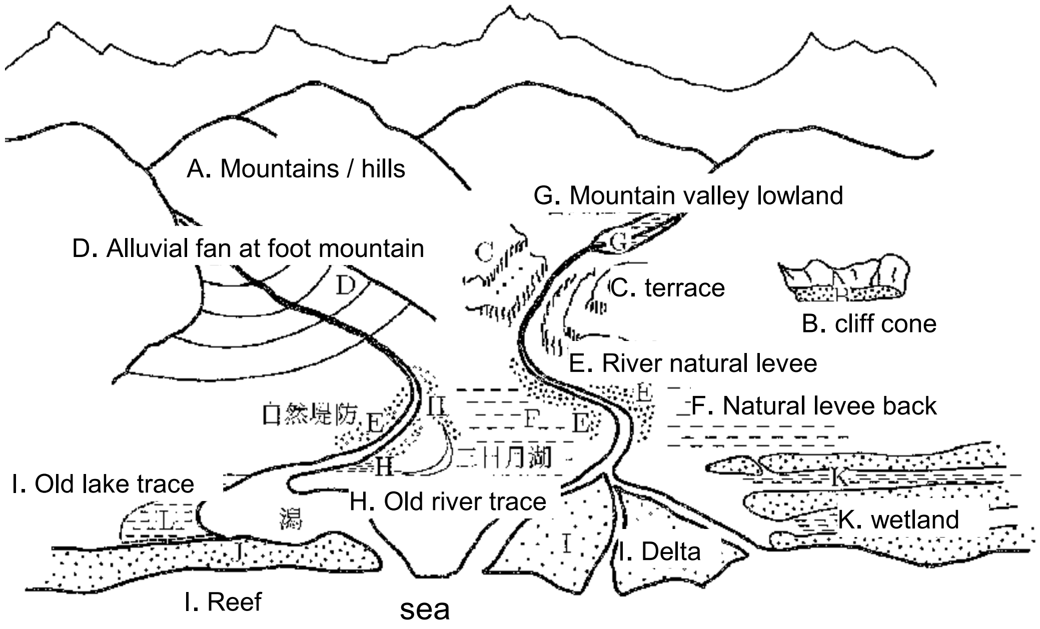


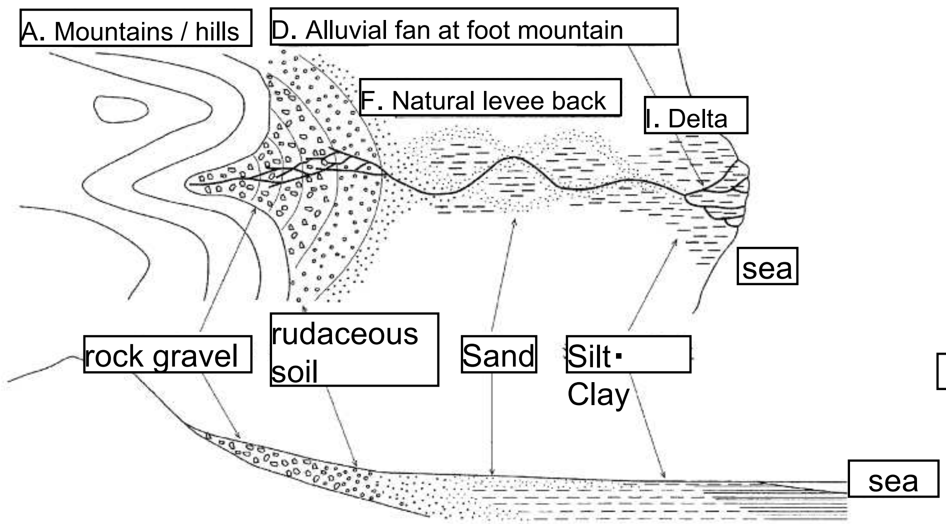

(e) Issues as environment of ground itself

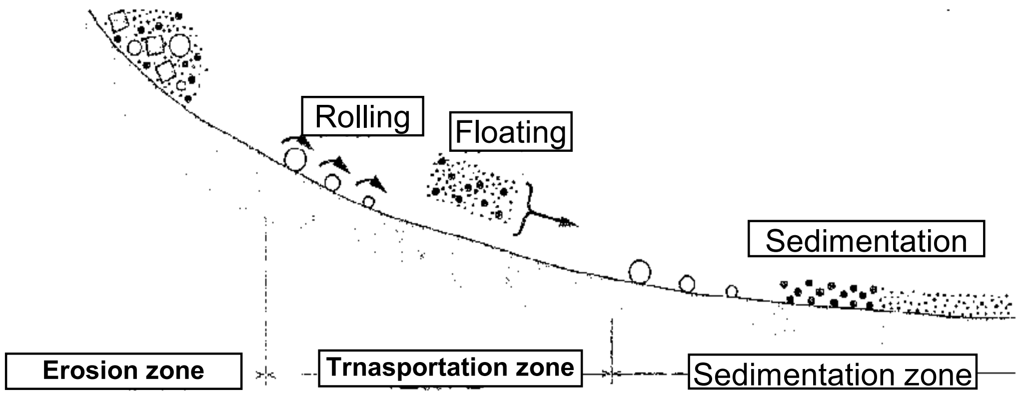
## 1) How the ground is formed

Now, how is the ground made?
From the mountains to the sea, the ground varies depending on the location. And is different in your countories（island or continental）. Here, I will talk about standard ground generation in Japan.




| | | |
|---|---|---|
| A | Mountains / hills→ | Rocky terrain |
| BC | cliff cone, terrace → | rock gravel, rudaceous soil |
| D | Alluvial fan at foot mountain → | Rudaceous land |
| E | River natural levee → | sand ground |
| F | Natural levee back → | Viscous land |
| G | Mountain valley lowland → | Corroded land |
| HK | Old river trace, wetland → | cohesive soil, wetland |
| I | Delta → | Sandy ground |



【How geological layers are formed】

## 2) Ground in mountainous areas (rock)

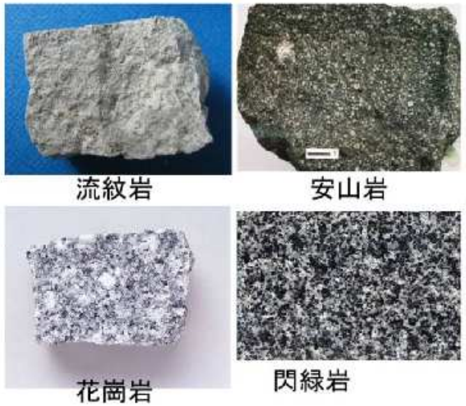
Most of the ground in mountain areas is made up of rocks.
Rocks are broadly classified into three types according to their formation: "sedimentary rocks, igneous rocks, and metamorphic rocks.

In civil engineering, structural properties such as rock hardness, strength, weathering, and cracks are important, not classification based on the origin of the rock.
An example of this is shown in Fig. 1 Schematic rock classification.

砂 岩

**Sedimentary rock**

**Igneous rock**




**Meta-morphic rock**


**Fig. 1 Schematic rock classification (Kojima 1979)**

| 分類記号 | 坑壁・露頭 | 岩片の硬さ | 風化の程度 | 節理面状態 | 節理間隔 | コア | 評価 | $V_p$ (km/s) |
|---|---|---|---|---|---|---|---|---|
| D | | 指でつぶれる | 土壌化 所々に岩片 | 密着粘土化 われ目不明瞭 | 5cm 以下 ～破砕 コア砂～礫状 | | | 0.5 |
| $C_L$ | | ハンマー打撃で濁音、容易に崩れる | 内部まで風化 造岩鉱物粘土化 | われ目明瞭だが粘土化密着 | 5～15cm 多 礫～岩片状 | | 粘土化 | |
| $C_M$ | | 濁音 われやすい | 全体褐色化 造岩鉱物の変質目立つ | 開口われ目多く、粘土を挟む | 5～30cm 多 岩片 ～短柱状 | | 透水性 | 2.0～3.0 |
| $C_H$ | | やや濁音 われにくい | 全体やや褐色 造岩鉱物やや変質 | 密着～ やや開口 粘土を薄く挟む | 15～30cm 多 短柱状 | | | |
| B | | 金属音 われにくい | われ目沿い褐色化 鉱物変質なし | 密着～ やや開口 粘土挟まず | 30～50cm 多 短柱～棒状 | | 強 度 | |
| A | | 金属音 われにくい | 新 鮮 | 密着，粘土挟まず | 50cm 以上 コア棒状 | | | 4.0～5.0 |

不良 ←→ 良

**Fig. 2 Rock grade and main geophysical constants**

| 岩盤等級 | 岩盤の変形係数 (kg/cm²) | 岩盤の静弾性係数 (kg/cm²) | 岩盤の粘着力 (kg/cm²) | 岩盤の内部摩擦角 (°) | 岩盤の弾性波速度 (km/sec) | ロックテストハンマー反発度 | 孔内載荷試験による 変形係数 (kg/cm²) | 孔内載荷試験による 接線弾性係数 (kg/cm²) | 引き抜き試験によるせん断強度 (kg/cm²) |
|---|---|---|---|---|---|---|---|---|---|
| A～B | 50,000以上 | 80,000以上 | 40以上 | 55～65 | 3.7以上 | 36以上 | 50,000以上 | 100,000以上 | 20以上 |
| $C_H$ | 50,000～20,000 | 80,000～40,000 | 40～20 | 40～55 | 3.7～3 | 36～27 | 60,000～15,000 | 150,000～60,000 | |
| $C_M$ | 20,000～5,000 | 40,000～15,000 | 20～10 | 30～45 | 3～1.5 | 27～15 | 20,000～3,000 | 60,000～10,000 | 20～10 |
| $C_L$ | 5,000以下 | 15,000以下 | 10以下 | 15～38 | 1.5以下 | 15以下 | 6,000以下 | 15,000以下 | 10～5 |
| D | | | | | | | | | 5以下 |

# 3) Ground in urban areas (sediment: sand and clay)

**In urban areas, much of the ground is composed of earth and clay.**
**Earth and clay are roughly classified into three types: sand, silt, and clay.**

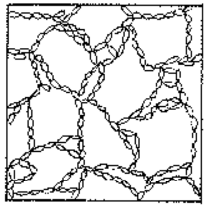
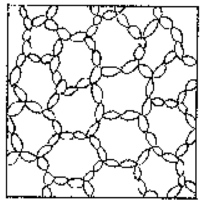
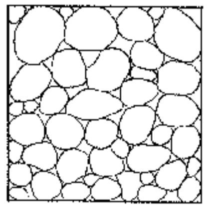
**Sand**

**Silt**

**Clay**

**Comparison of engineering properties of sand and clay**

| Name | Colloid | Clay | Silt | Sand: Fine sand | Sand: Coarse sand | Gravel |
|---|---|---|---|---|---|---|
| Size (mm) | 0.001 | 0.005 | 0.075 | 0.042 | 2.0 | |
| Permeability | Low ← | | | | → High | |
| Compressibility | Big ← | | | | → Small | |
| C. density | Slow ← | | | | → Fast | |
| Structure | Cotton wool structure → Honeycomb structure | | | Unit structure | | |

| | Cotton wool structure | Honeycomb structure | Unit structure |
|---|---|---|---|
| Features | ・Strength is determined by adhesive strength between particles.<br>・The void is large. | ・Strength is determined by adhesive strength between particles and the contact of particles.<br>・Kanto loam layer | ・Strength is determined by the frictional force between particles.<br>・The gap is large. |
| Schematic diagram |  |  |  |

The quality of the ground depends on the number of years since the strata were formed. The shorter the number of years since the strata were formed, the softer they are. Most of Japan's plains are sedimentary strata formed during the alluvial age, such as river deltas, and are often soft.

20 million years ago | 20,000 years ago

| Tertiary period | Diluvium epoch | | | Alluvial epoch | |
|---|---|---|---|---|---|
| Hardpan<br>Soft rock | Sandy gravel layer | Tokyo loam<br>Tenma layer | Kanto loam<br>Hard diluvial clay | Sedimentary layer | Fan-shaped sedimentary layer, natural levee, back swamp delta, landfill, etc. |

Hard ← → Soft

## 4) Engineering aspects of soil

When looking at soil (ground) from an engineering perspective, there are five points to look at (points of view) as shown on the right.

① Weight of soil
② Strength of soil
③ Deformation of soil
④ Earth pressure
⑤ Groundwater

① Weight of soil (self-weight, buoyancy): The soil and ground act as the primary load on the temporary structure.

- Self-weight of soil, water pressure, buoyancy, soil sagging rate (volume change rate)

② Soil strength (ground stability):

If the ground passively bears a load, will it not fail in shear or sink?

- Vertical bearing capacity, horizontal resistance
- Slip resistance value of arc sliding on a slope (adhesion)
- Tip bearing capacity of piles, surface friction

③ Soil deformation (subsidence and lateral flow):

- If the ground passively receives a load, will it not undergo shear failure or subside?
- Consolidation settlement of clayey soil and immediate settlement of sandy soil
- Impact of ground deformation on the surrounding area (impact of embankments, ground improvement, etc.)
- Liquefaction of the ground

④ Earth pressure (load acting on structures): Acts as a load.

- Active and passive earth pressure acting on retaining walls and retaining walls
- Static earth pressure acting on underground structures

⑤ Groundwater

- Seepage, landslide, debris flow
- Swelling, boiling, piping

## 1. Weight of soil (omitted)

## 2. Strength of soil

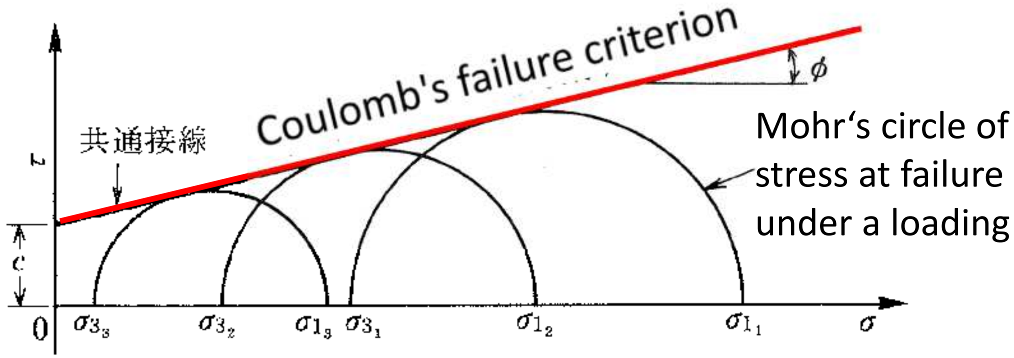
Generally, the shear strength of soil is expressed by the following formula.

$\tau f = c + \sigma \tan \Phi$ (Coulomb's failure criterion)

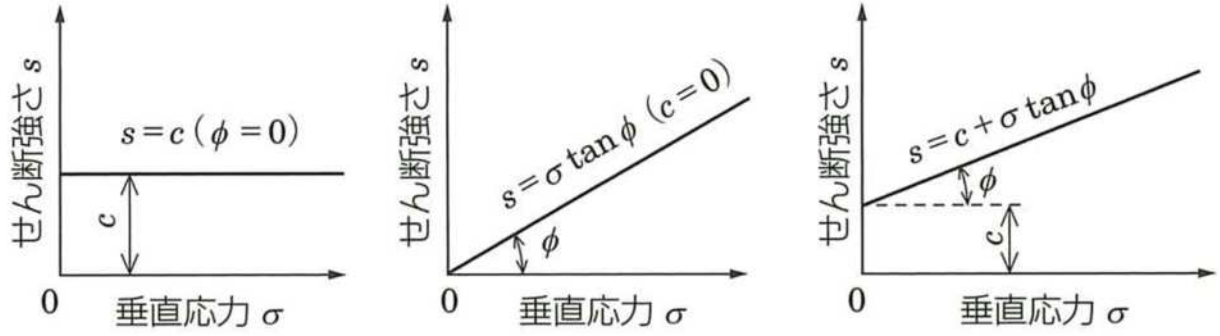
Where $\tau f$: Shear strength (kN/m$^2$)

$\sigma$: Normal stress on the shear plane (kN/m$^2$)

$c$: Adhesion of soil (kN/m$^2$)

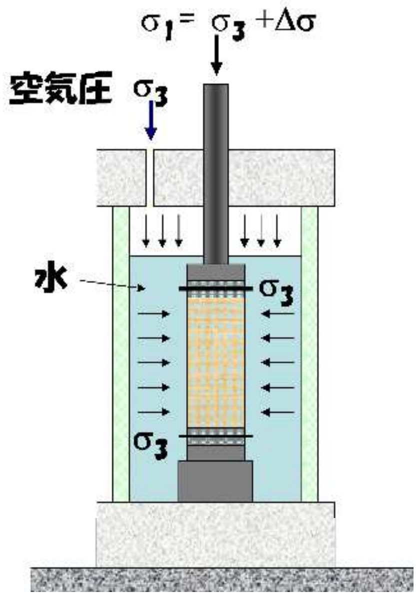



Determination of c and Φ using Mohr's stress circle




（a）Statureted clayey soil （b）Dry sand （c） General soil＆sand

図 5・6 Coulomb's equation for different types of soil



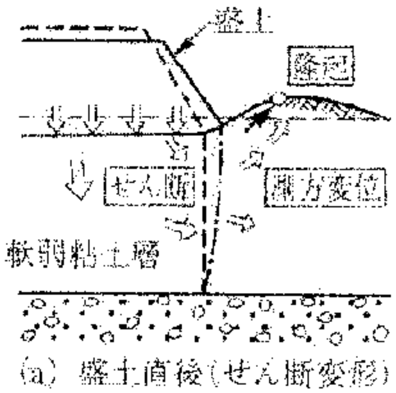

**Schematic diagram of triaxial compression test**

・砂質土：$c$=0 とみなせる土→ F.5.6 (b)

・粘性土：$\phi$=0 とみなせる土→ F.5.6 (a)

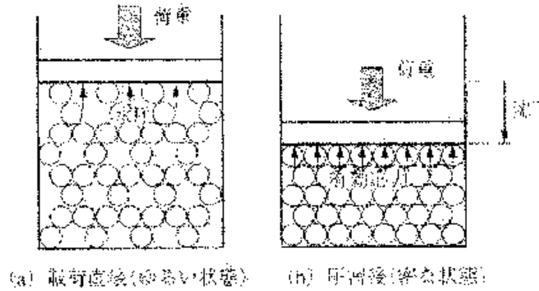
## ③ Soil deformation (subsidence and lateral flow)

Ground deformation can occur in two directions: vertical (subsidence and uplift) and horizontal (slope collapse and lateral flow).





When soil supports structures, embankments, etc. and receives these loads, it undergoes compressive deformation. Because soil particles are incompressible, when soil is compressed, the voids (air and water) in the soil are actually changing. There are two types of deformation in the ground: vertical (subsidence and uplift) and horizontal (slope collapse and lateral flow) (as shown in the figure below).




Soil particles → non-compressible
Pores (water, air) → pores change

- When sand (sandy soil) is subjected to a load, the pores change and it settles immediately → immediate settlement
- When clay (clay soil) is subjected to a load, it settles over time → consolidation settlement

沈下特性の違い（砂質土，粘性土）

| | 沈下量 | 沈下時間 | |
|---|---|---|---|
| 砂質土 | 少ない | 短い | 即時沈下 |
| 粘性土 | 多い | 長い | 圧密沈下 |

# ④ Earth pressure (load acting on structures)

When constructing structures such as retaining walls and boxes, or when excavating, loads are applied from the ground. This load is earth pressure (water pressure). Examples of structures that resist earth pressure include retaining walls, boxes, etc.
What is this earth pressure?
(However, the basic concept of earth pressure has not changed in the last 150 to 250 years. It is the theory of Coulomb earth pressure and Rankine earth pressure.)

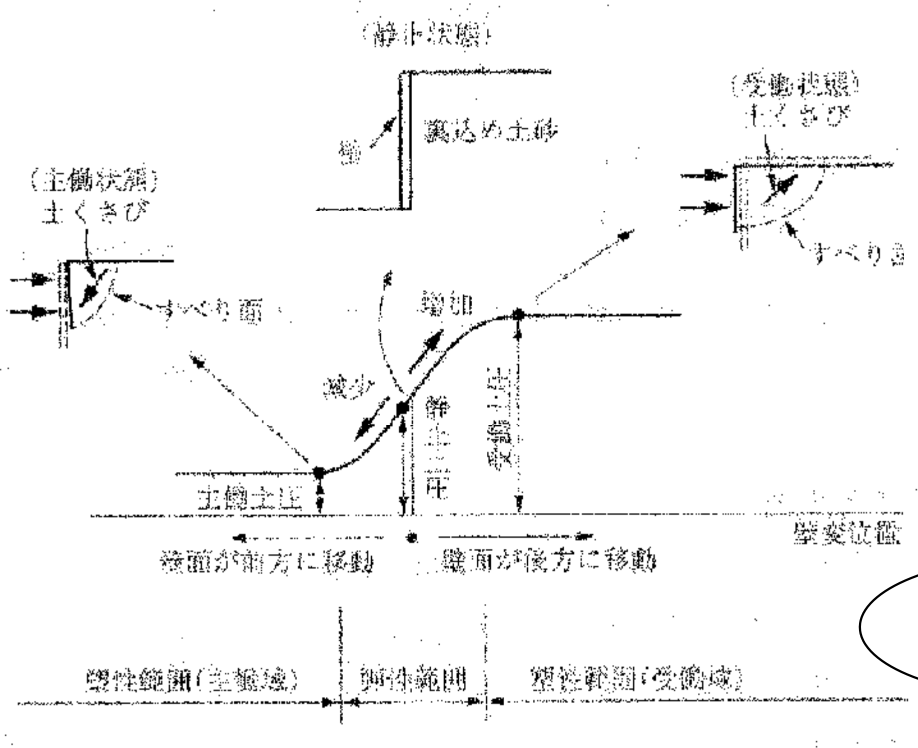


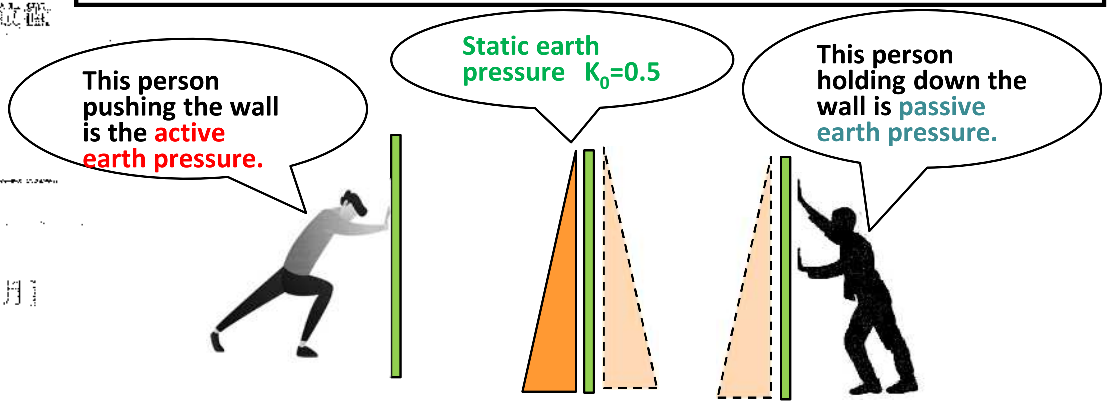

図1-18 壁面の変形と土圧の関係
[出典:地盤工学会「土と基礎の設計計算演習」p. 240, 平成12年11月]

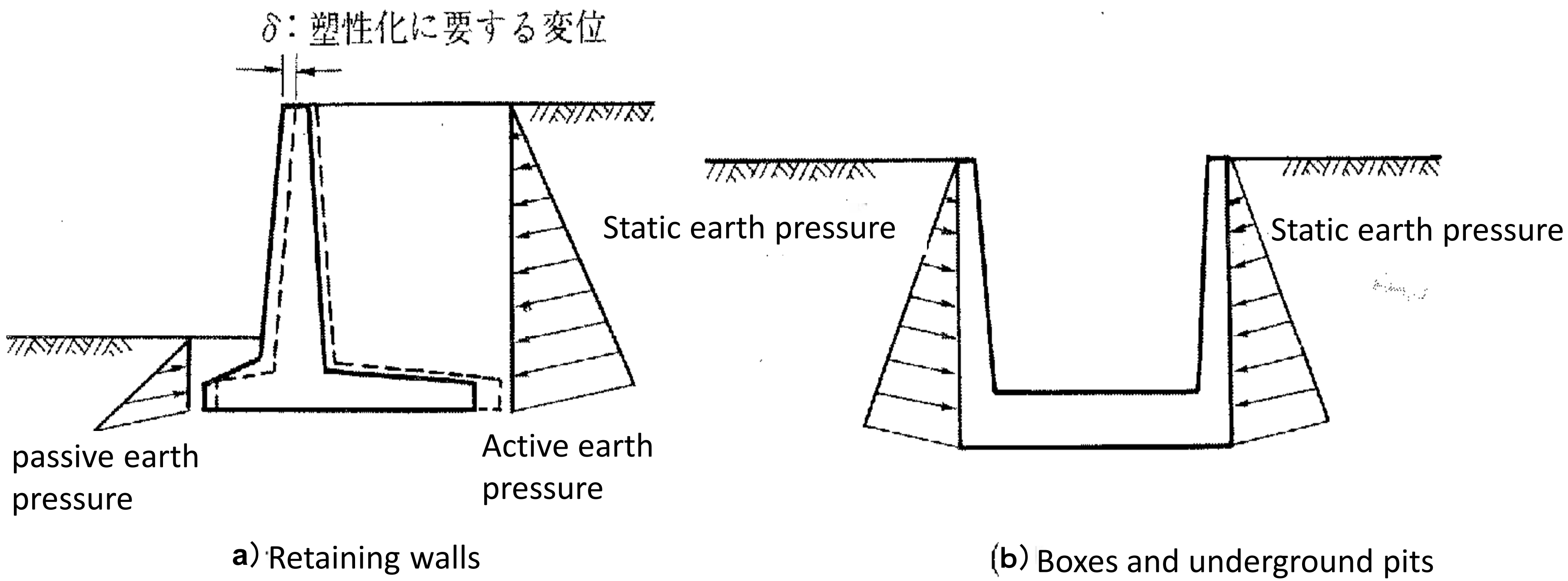
表1-4 土圧係数の一例(標準的な砂質土の場合)

| 土圧の種別 | 記号 | 一般値 |
|---|---|---|
| Active earth pressure | $K_a$ | 0.3~0.4 |
| Static earth pressure | $K_0$ | 0.4~0.6 |
| Passive earth pressure | $K_p$ | 2.5~3.7 |

※c=0 kN/m², φ=25~35° として計算
$K_0 = 1 - \sin\phi$, $K_a = \tan^2(45° - \phi/2)$, $K_p = \tan^2(45° + \phi/2)$

Active earth pressure < static earth pressure < passive earth pressure





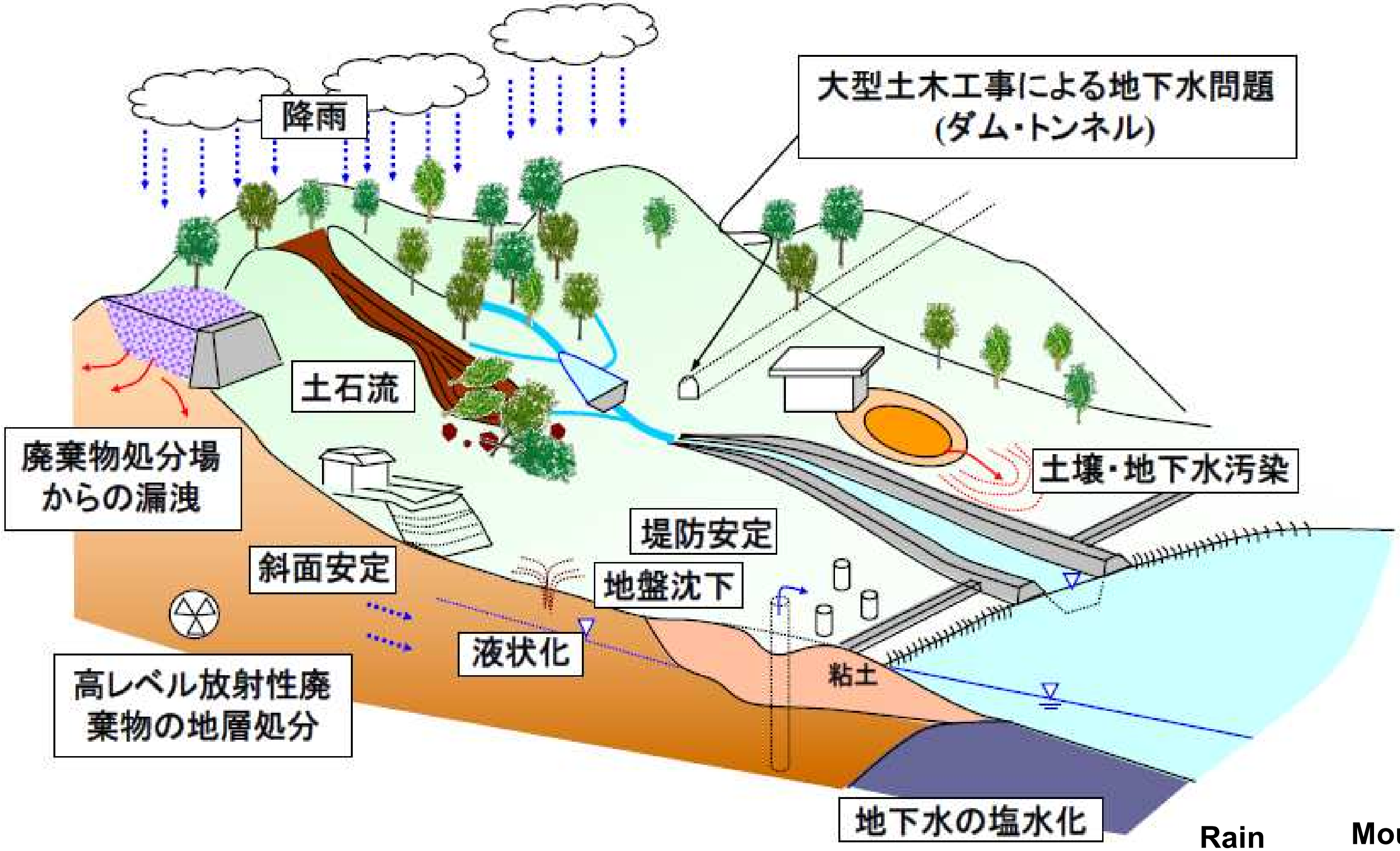

**Concept of design earth pressure**

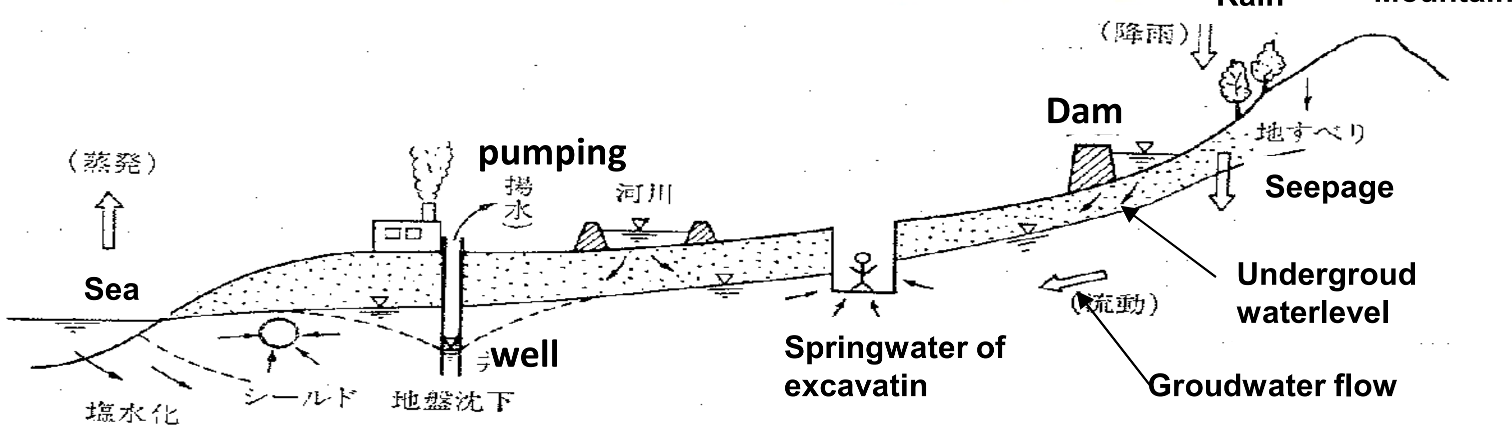
【How earth pressure is used】

Retaining walls and retaining walls design → Active earth pressure at the back,
passive earth pressure at the front⇒Used in temporary structure design.
Boxes and underground pits → Static earth pressure

## ⑤ Groundwater

＜Is groundwater a nuisance? → Where does groundwater come from?＞



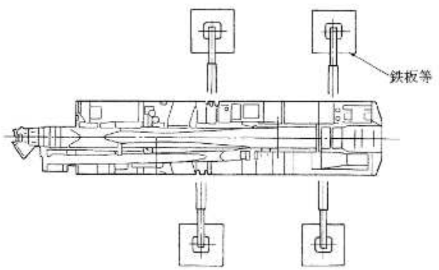



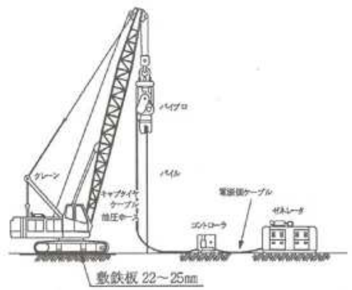
# 5） Ground investigation

To design temporary structures, we need to understand the engineering properties of the soil we have explained so far, but we can't know the soil at the site just by looking at it.

Is the soil at the site strong or weak? How much earth pressure will be applied when excavating? If we don't understand what kind of soil the soil at the site is, we won't know what kind of temporary structure we should build. (Is the ground hard or soft? Will it stand on its own? Is the ground heavy or light?)

For example, when performing crane work at the site, for example, when bringing in a 100T crawler crane, if the ground at the site is soft with clay soil, it will sink into the ground and cannot be brought in. In that case, we don't know whether we need to improve the ground or lay steel plates.

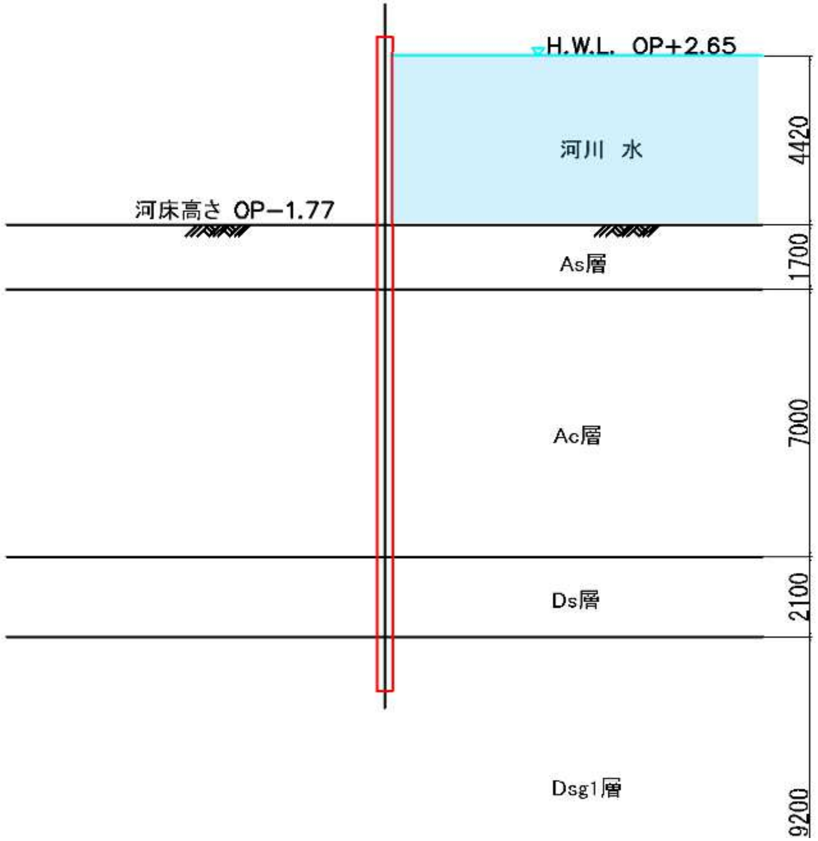



I also don't know whether the slope gradient should be 5%, 10%, or 15% when carrying out open excavation. Should the retaining wall be steel sheet pile type III or IV when excavating? Should the shoring be H-300 or 400?


Therefore, a "soil survey" must be carried out to understand the soil conditions at the site, otherwise a judgment cannot be made.

## ＜Soil engineering criteria＞




**【Soil Index】**

① Soil thickness
② Groundwater level
③ Soil unit weight (wet, submerged k/Nm$^3$ )
④ Soil N-value
⑤ Internal friction angle（ϕ°）
⑥ Adhesion（C kN／m$^2$）
⑦ Deformation coefficient （E kN／m$^2$）
⑧ Permeability coefficient（s cm／sec）

| 地層 | 深度 | 層厚 | N値 | 単位体積重量 | | 内部摩擦角 | 粘着力 | 変形係数 |
|---|---|---|---|---|---|---|---|---|
| | | | | 湿潤 | 水中 | ϕ | C | α・E0 |
| | (m) | (m) | | (kN/m3) | | (°) | (kN/m2) | (kN/m2) |
| 河床高さ | OP-1.77 | ― | ― | ― | ― | ― | ― | ― |
| A s 層 | OP-3.47 | 1.70 | 8 | 17 | 7 | 31 | ― | 20,000 |
| A c 層 | OP-10.47 | 7.00 | 3 | 16 | 6 | ― | 51 | 7,500 |
| D s 層 | OP-12.57 | 2.10 | 15 | 18 | 8 | 32 | ― | 37,500 |
| D s g 1 層 | OP-21.77 | 9.20 | 30 | 19 | 9 | 36 | ― | 97,500 |

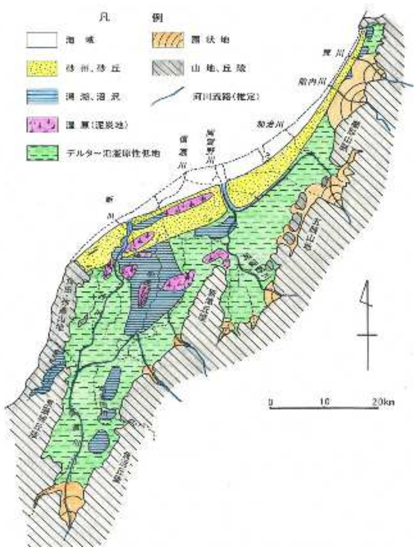
## 5-1) What is ground investigation

**Ground investigation is a general survey conducted to clarify the topography, geological structure, distribution of soil quality, groundwater conditions, and engineering properties of the soil and rock that make up the ground.**

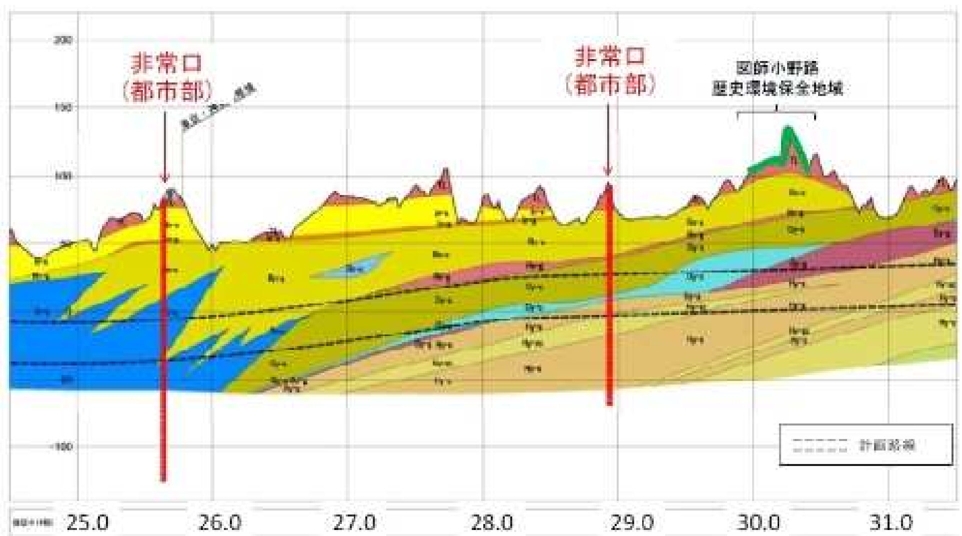
**Ground investigation can be classified as shown in the table below.**

| Item | Ground investigation | Investigation contents |
|---|---|---|
| 5-3） | In-situ test (test in field) | Directly examine the performance of the lot number at the site being surveyed. |
| 5-4） | Laboratory soil test | Soil data will be collected at the survey points and examined using indoor soil tests. |

**The “geological survey report” or “borehole column map” that you are familiar with is a geological survey report. The figures below show the geological distribution map and longitudinal section map often found in geological survey reports.**




**Geological distribution map**




**Geological longitudinal map**

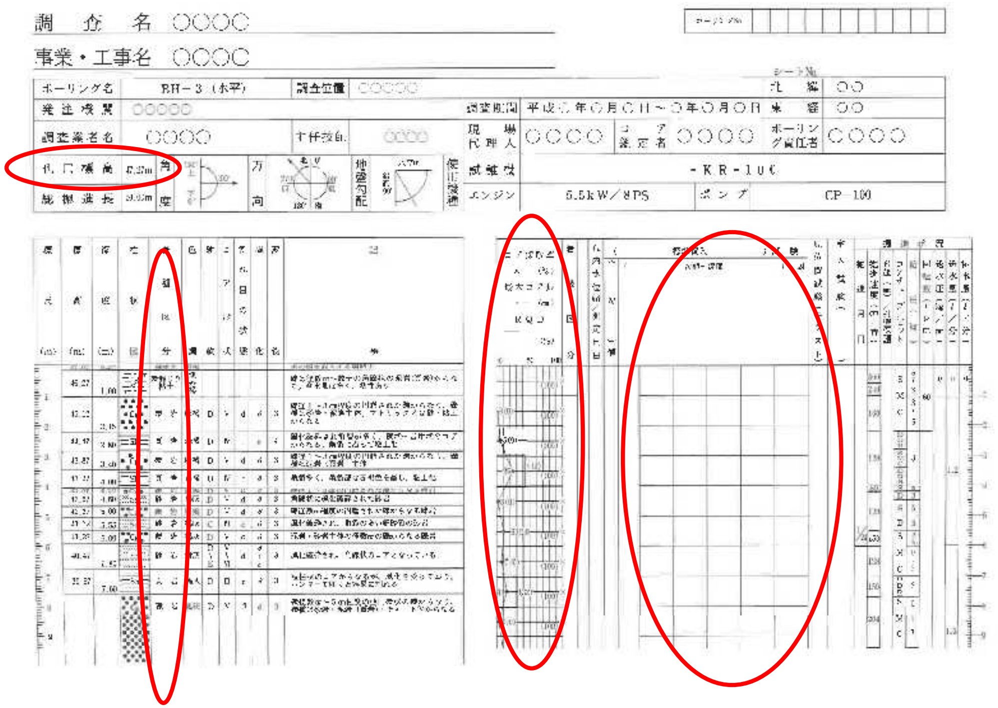
# 5-2）What can you tell from the boring log?

・The boring log shows the soil at the site.
・It is a clue of design and construction.

① Predict the ground composition of the entire site.
② Grasp the groundwater level. Is there a pressurized water layer?
③ Design a structure suitable for the ground.
④ Is the construction method suitable for the ground? Change the construction method.

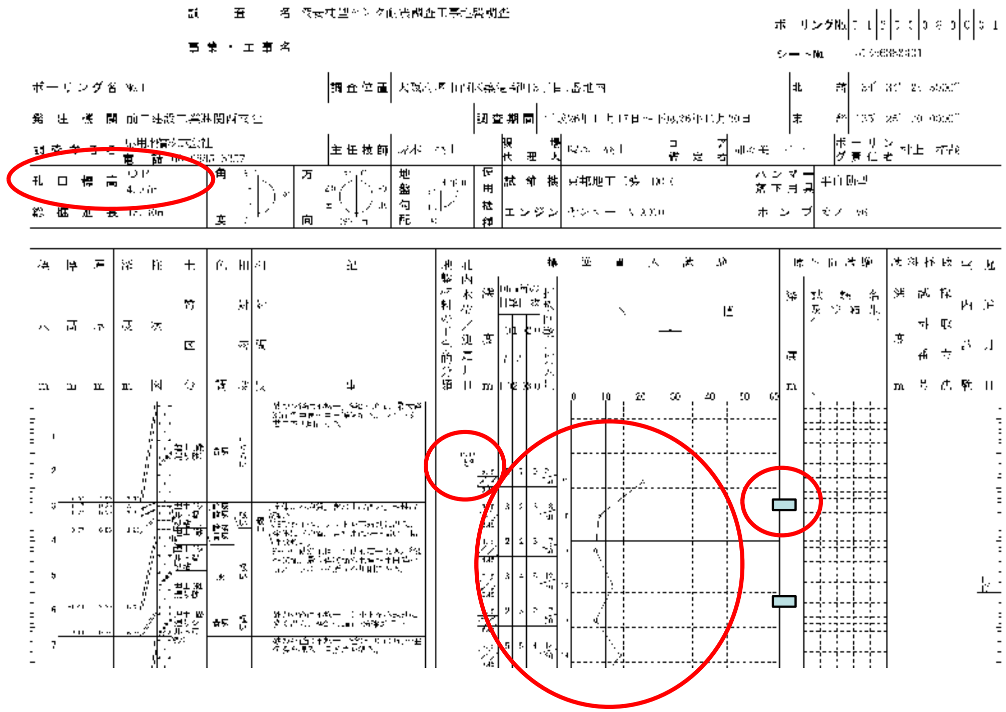
## Fig. 1 Boring log of rock

・Height of borehole
・Rock species
・Depth and thickness of strata
・RQD (rock crack height per1m)
・Bedrock is too solid to measure N value.




## Fig. 2 Boring log of earth and sand

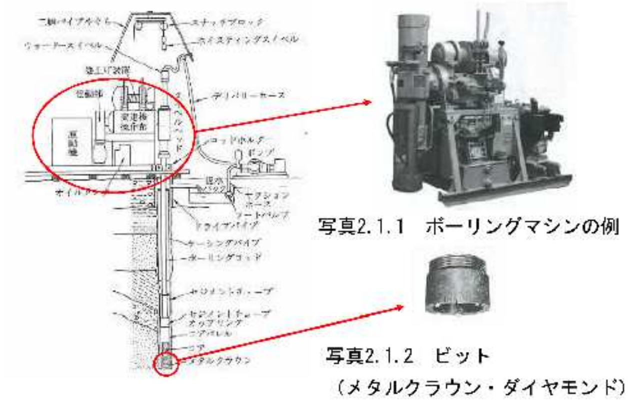
・Height of borehole
・water level in borehole
・Depth and thickness of strata
・N-value (Self-sustaining and supportive ground)
・Depth of mechanical and physical tests.



# 5-3） In-site test

## ① Boring survey→ Core sampling, stratum thickness and soil properties

(1) Rotate the bit to perform drilling and core sampling.
(2) Drilled holes are also used for various in-situ test holes.




Boring core

## ②Standard penetration test→ N value

(1) A hammer with a mass of 63.5 kg is automatically dropped onto the anvil from a height of 760 mm to drive the SPT sampler.
(2) N value is the number of blows required to drive the SPT sampler 300 mm.

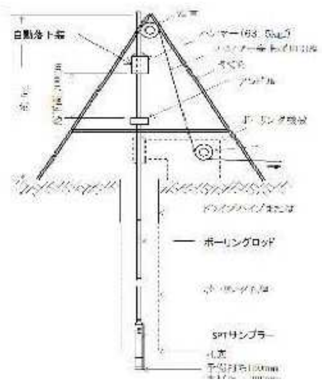


Fig. 2.2 Example of standard penetration test equipment

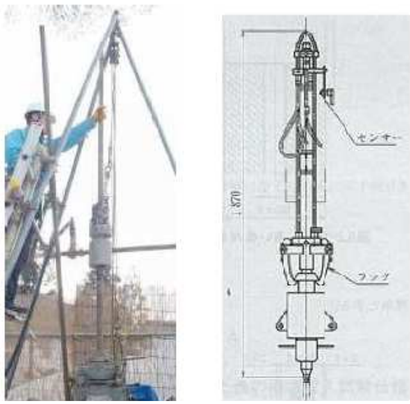
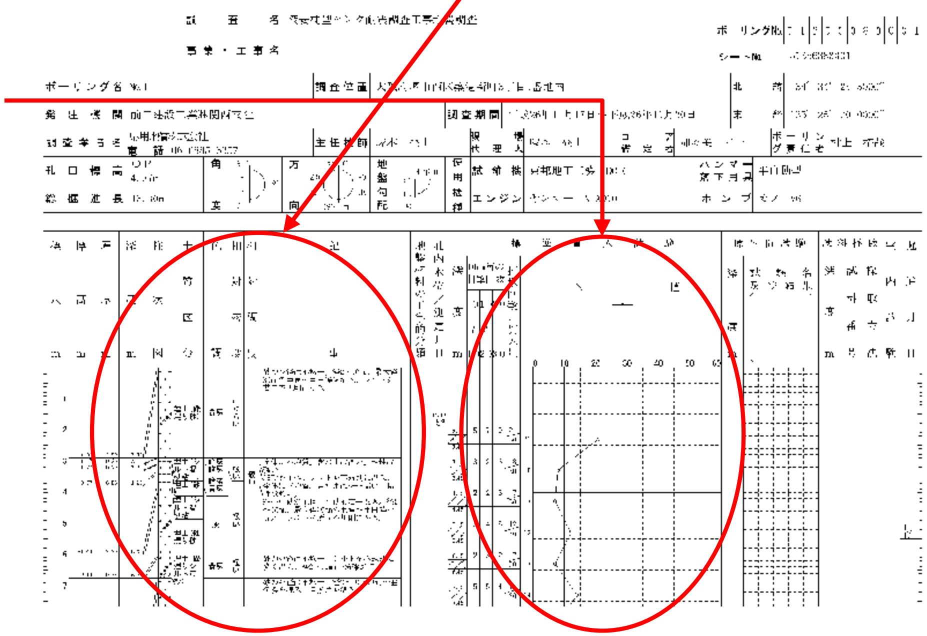


Photo 2.3 Example of automatic drop device



Boring column diagram

## 5-4）Soil quality test (laboratory test of soil)

① **Soil particle size test - Soil layer properties : uniform sand, balanced mixed grain size distribution, easy to fluidize, etc.?**

写真-2　ふるい分析

写真-3　沈降分析

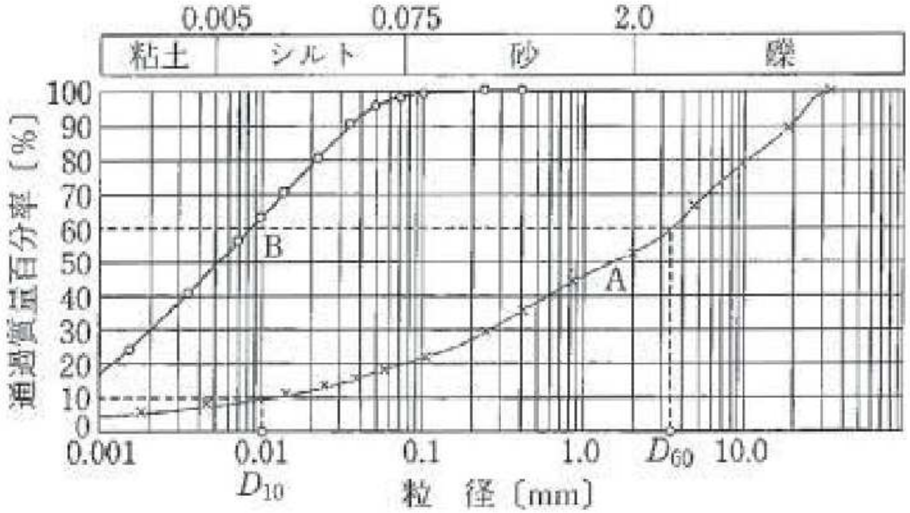
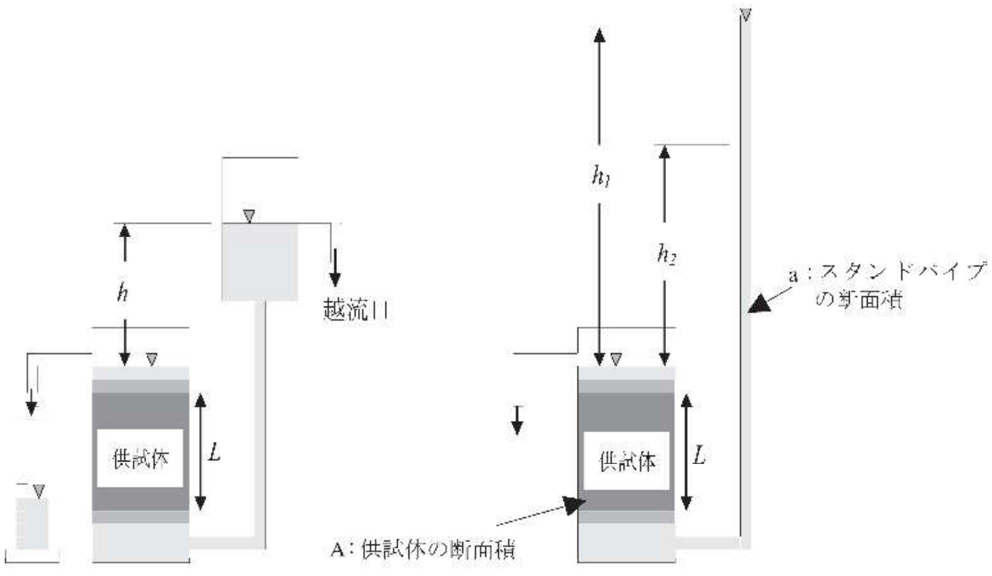



図-2　**Particle size accumlation curve**

② **Soil permeability test to determines the permeability of soil.**




(a) 定水位透水試験　(b) 変水位透水試験

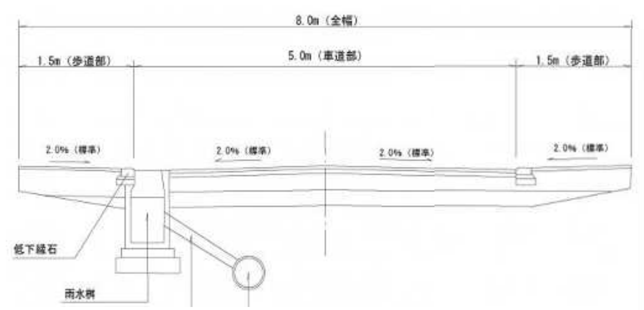
【Soil hydraulic conductivity】

Sand　　　　: $1 \times 10^{-0}$ ～ $1 \times 10^{-2}$ cm/sec
Silt and clay: $1 \times 10^{-3}$ ～ $1 \times 10^{-5}$ cm/sec
impermeable layer: $1 \times 10^{-5\sim6}$ cm/sec

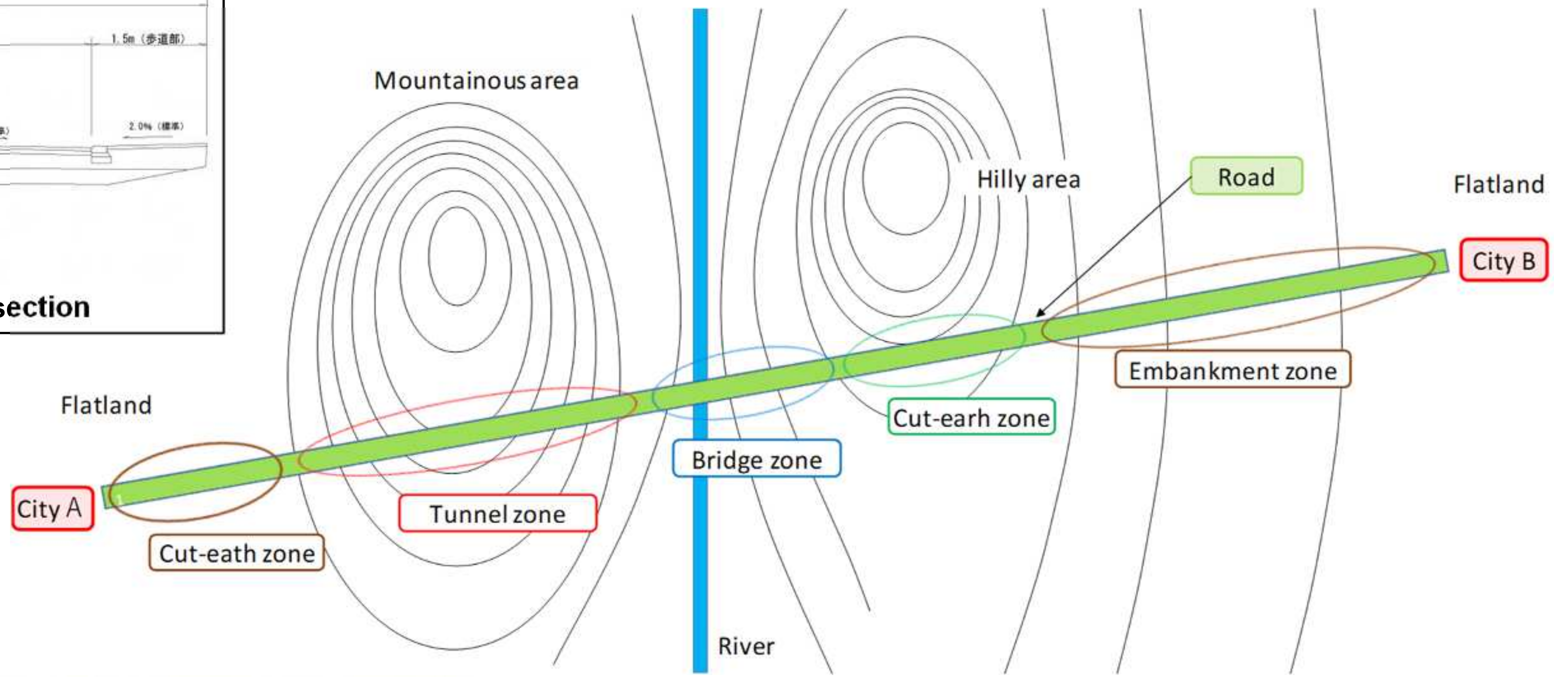
## 1） Why is it necessary to understand soil quality and ground?

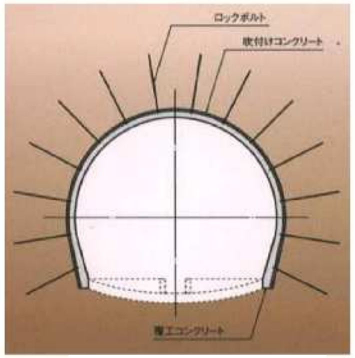
We have planned to build a road between city A and city B with a width of 8 meters. There are mountains and rivers between the two cities, and a road cannot be built without various civil engineering structures.

The road can be built with earth and concrete structures such as tunnels, bridges, cut-earth and embankments as shown in the figure below. To build these structures on the ground (design and plan), it is necessary to understand the properties of the original ground (bedrock, earth and sand).




8m wide road cross-section

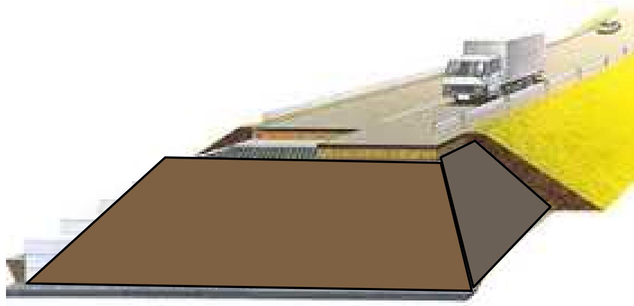


Tunnel zone

Bridge zone

Cut-earth zone

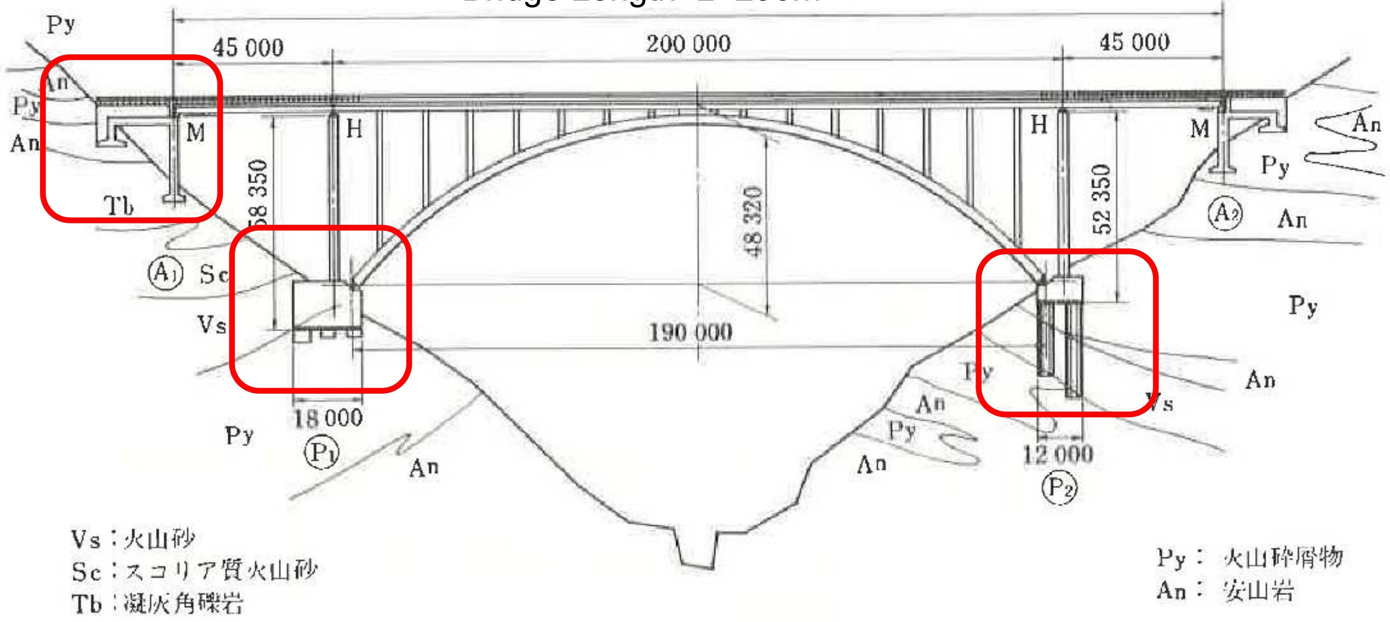


Embankment zone

## 2) For bridges, the bridge foundation type is determined by ground surveys.

Investigate the ground properties of the bridge foundation and select a bridge foundation type suitable for the ground.

Bridge Length L=290m



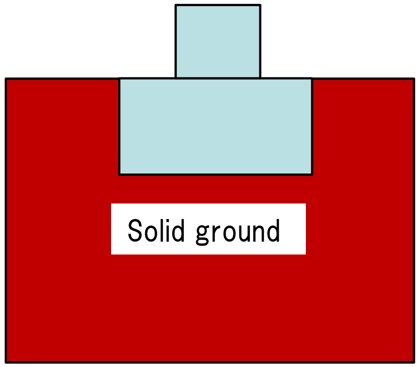




Fig. 2 Direct foundation

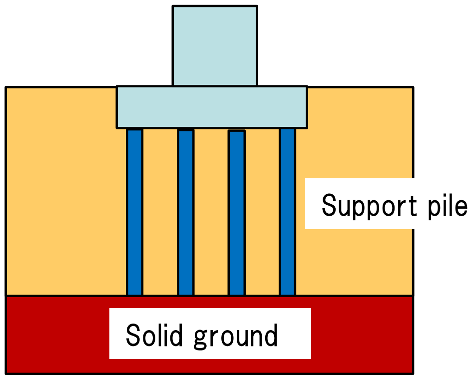



Fig. 3 Pile foundation (support pile)

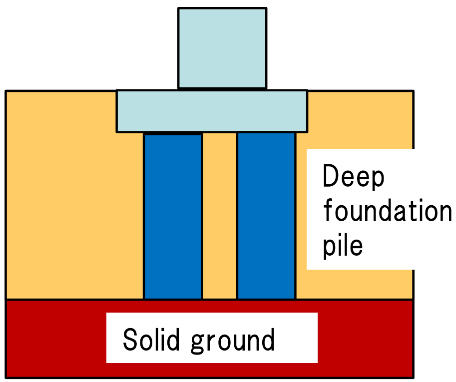



Fig. 4 Deep foundation pile foundation

# 3) For tunnels, the tunnel lining specifications are determined by rock surveys.

The design and construction method of the tunnel is determined by the rock properties of the tunnel section (cracks between rock classes A to D).

**Fig. 1 Rock grade and main physical constants**

| 岩盤等級 | 岩盤の変形係数 (kg/cm$^2$) | 岩盤の静弾性係数 (kg/cm$^2$) | 岩盤の粘着力 (kg/cm$^2$) | 岩盤の内部摩擦角 (°) | 岩盤の弾性波速度 (km/sec) | ロックテストハンマー反発度 | 孔内載荷試験による 変形係数 (kg/cm$^2$) | 孔内載荷試験による 接線弾性係数 (kg/cm$^2$) | 引き抜き試験によるせん断強度 (kg/cm$^2$) |
|---|---|---|---|---|---|---|---|---|---|
| A～B | 50,000以上 | 80,000以上 | 40以上 | 55～65 | 3.7以上 | 36以上 | 50,000以上 | 100,000以上 | 20以上 |
| $C_H$ | 50,000～20,000 | 80,000～40,000 | 40～20 | 40～55 | 3.7～3 | 36～27 | 60,000～15,000 | 150,000～60,000 | |
| $C_M$ | 20,000～5,000 | 40,000～15,000 | 20～10 | 30～45 | 3～1.5 | 27～15 | 20,000～3,000 | 60,000～10,000 | 20～10 |
| $C_L$ | 5,000以下 | 15,000以下 | 10以下 | 15～38 | 1.5以下 | 15以下 | 6,000以下 | 15,000以下 | 10～5 |
| D | | | | | | | | | 5以下 |

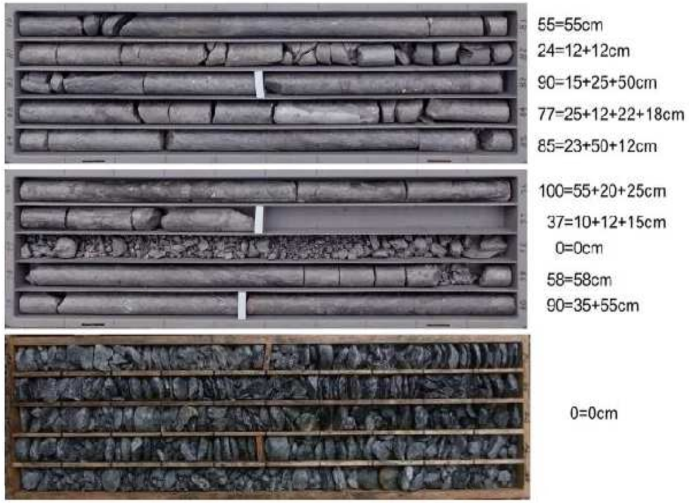



Fig. 2 boring core and RQD

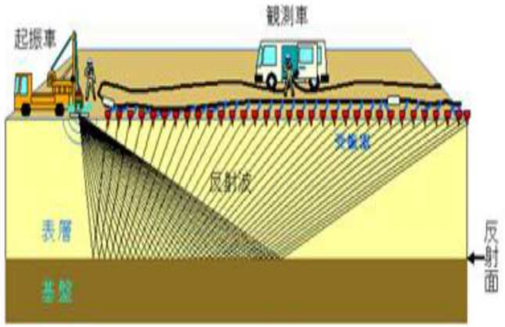



Fig. 3 Schematic diagram of land reflection method elastic wave exploration

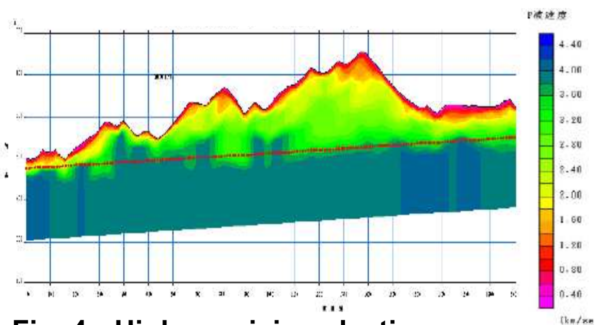


Fig. 4 High-precision elastic wave exploration record

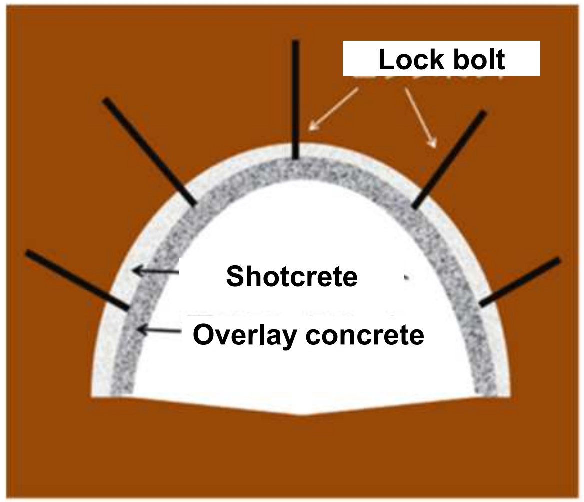



Fig. 5 Standard cross section of NATM tunnel

# 4) Standard tunnel construction sequence

① Excavation

② Charge / blasting of Gunpowder

③ Mucking

④ Built-in steel support

⑤ Sprayed concrete

⑥ Lock bolt

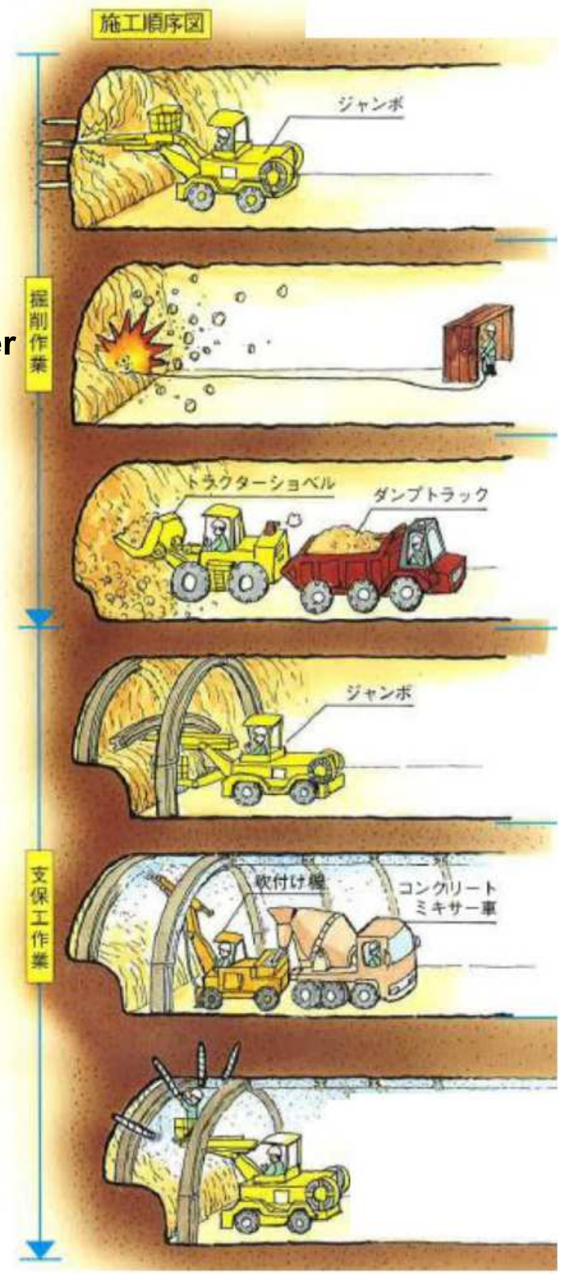



Fig. 5 Tunnel construction method and flow diagram

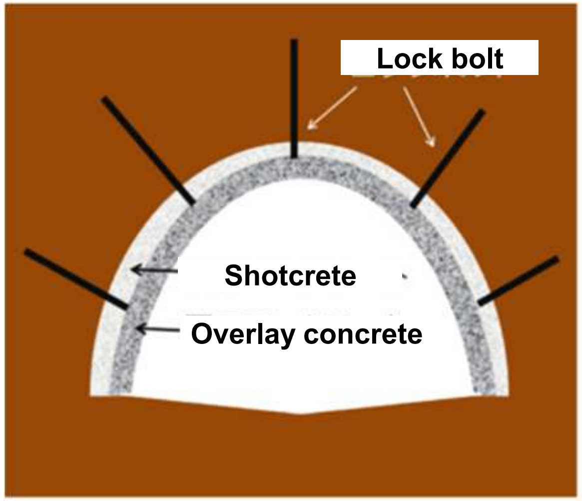



Fig. 6 Standard cross section of NATM tunnel

Fig. 7 Steel shoring construction status ④

Fig. 8 Shotcrete situation ⑤

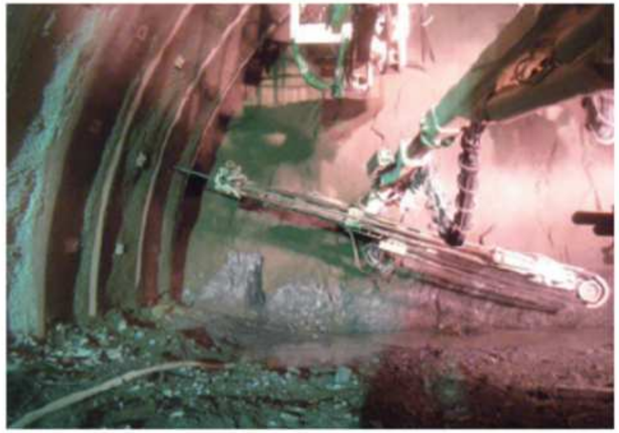


図9　ロックボルト削孔状況⑥

## 1） Types of road maintenance and repair work

**In Japan, the following works are subject to standard cost estimation for road maintenance and repair work. I'll talk about that briefly.**

① Repair work related to road paving work

**Paved road surface cutting work**

**Pavement road cutting work using a concrete cutter**

**Pavement breaking work using large breakers**

**Road base compaction work using tire rollers**

**Road base compaction work using road rollers**

**Road compaction work using road rollers**

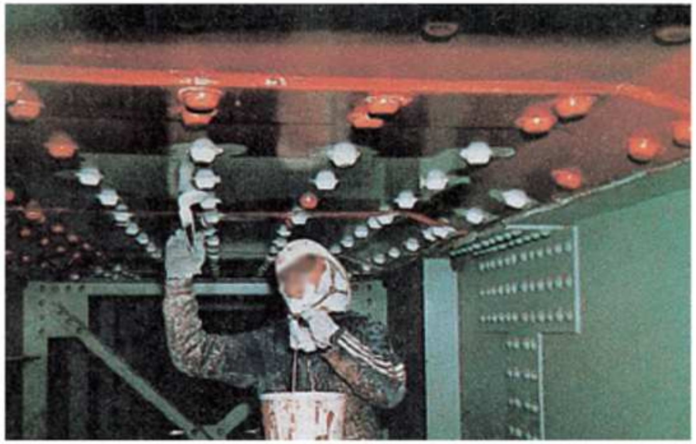
## ② Repair work for road pavement and road facilities

Paved road cleaning work

Asphalt melt injection work for pavement cracks

Painting work for rockfall prevention fence posts

Guardrail painting work



Painting work on steel floor slabs

Carbon fiber sheet reinforcement work for concrete floor slabs

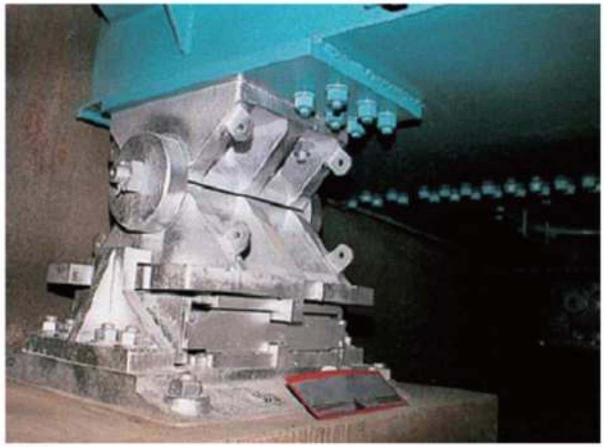
## ③ Bridge reinforcement and repair work

**Concrete reinforcement and steel anchor work for bridge piers**

**Concrete reinforcement and steel anchor work for bridge piers**

**Bridge collapse prevention using PC steel bars on bridge piers**

**Bridge bearing replacement (old bearing)**



**Bridge bearing replacement (new bearing)**

**Bridge collapse prevention using bridge pier chains**

## ④ Road cleaning work and tunnel equipment repair work

Road weeding with shoulder-mounted mower


Road cleaning work using a brush-type road cleaning vehicle

Cleaning roadside ditches with a vacuum truck

Tunnel lighting cleaning work using elevating vehicles

Tunnel lining crack prevention injection work

Installation of waterproof board by elevating truck

## ⑤ Road buried pipe installation work and grouping work

Installation of sheath pipes for electric wires, optical cables, etc.

Installation of sheath pipes for electric wires, optical cables, etc.

Pedestrian bridge stairs repair work

Grouping method trench cutting work

Grouping method

Note: The grouping method is a method of increasing the braking performance of road surfaces by cutting a 6mm **B** x 4mm **H** groove in the road surface and allowing road surface drainage to flow into the groove. In addition, by grouping in the lateral direction, this method can warn drivers of drowsy driving and speeding violations.

# 1. Stability of embankment

**There are two types of materials used for road embankments.**

① Rock: The bedrock is crushed into pieces with a maximum particle size of 600 mm or less, and fine-grained soil and sand are mixed in to create the embankment.

② Soil and Sand: The fine-grained content and water content of the soil are controlled before the embankment is created.

When embankment is carried out, the ground bearing capacity of the foundation ground and the degree of compaction of the embankment itself are important factors for the stability of the embankment.

① Ground bearing capacity of foundation ground, subsidence

② Stable embankment: arc wandering, embankment subsidence

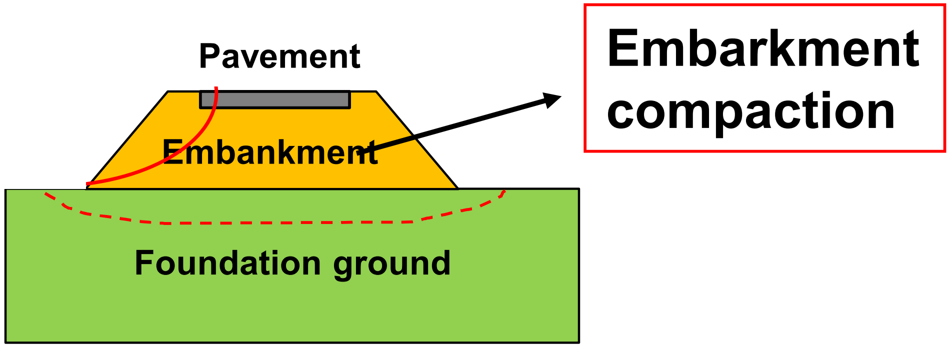



Fig. 1 Embankment section

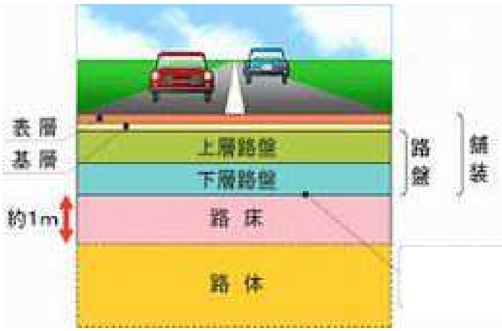



Fig. 2 Cross-section of embankment

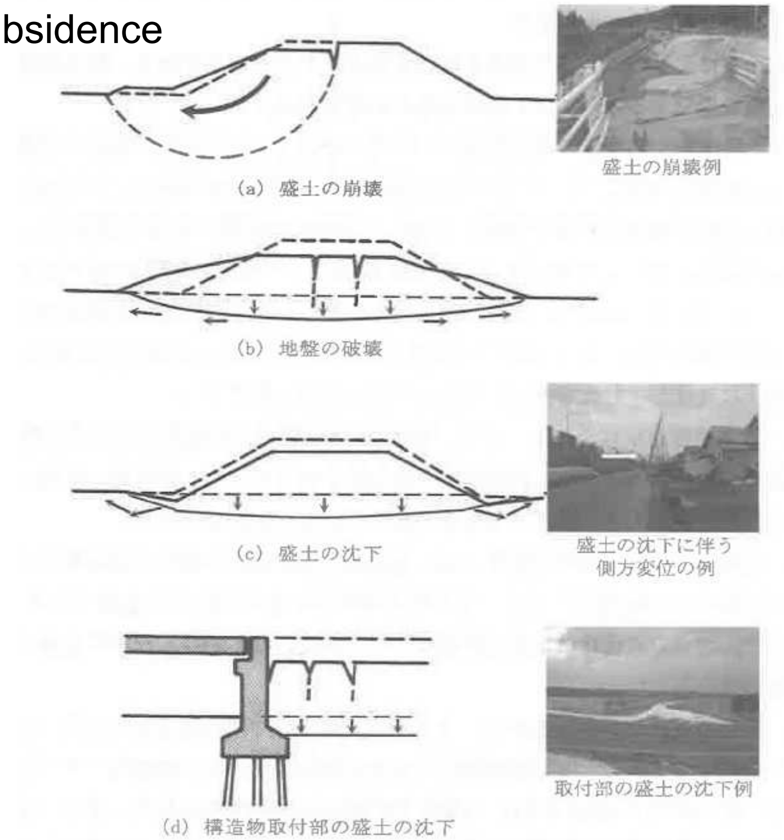
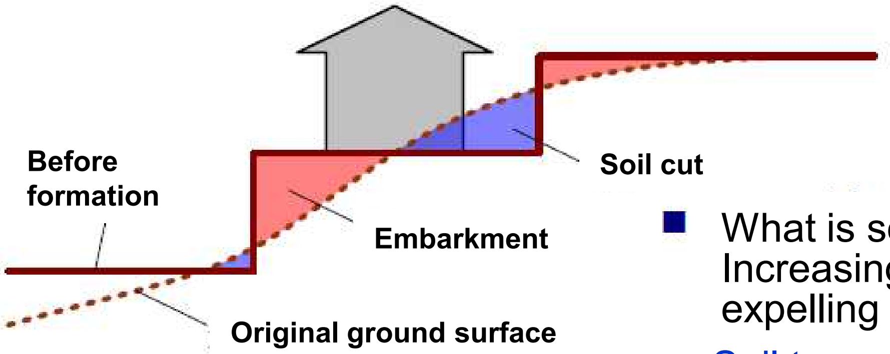



Fig. 3 Example of deformation of embankment on soft ground

## 2. What is soil compaction?
### 1) The concept of soil compaction

- Road construction (Creating residential area): earth fill (embarkment) and soil scrape (soil cut)

→ Forming roads: make it tight and resistant to deformation
(Railroads, residential area, dams, levees, etc.)




- What is soil compaction?
Increasing the density by applying force to the soil and expelling the air in the soil.

- Soil type and compaction method are important to make good embankment.
  - Compaction characteristics vary greatly depending on the soil type.
  - Compaction energy and moisture content (water content ratio) have major influence.

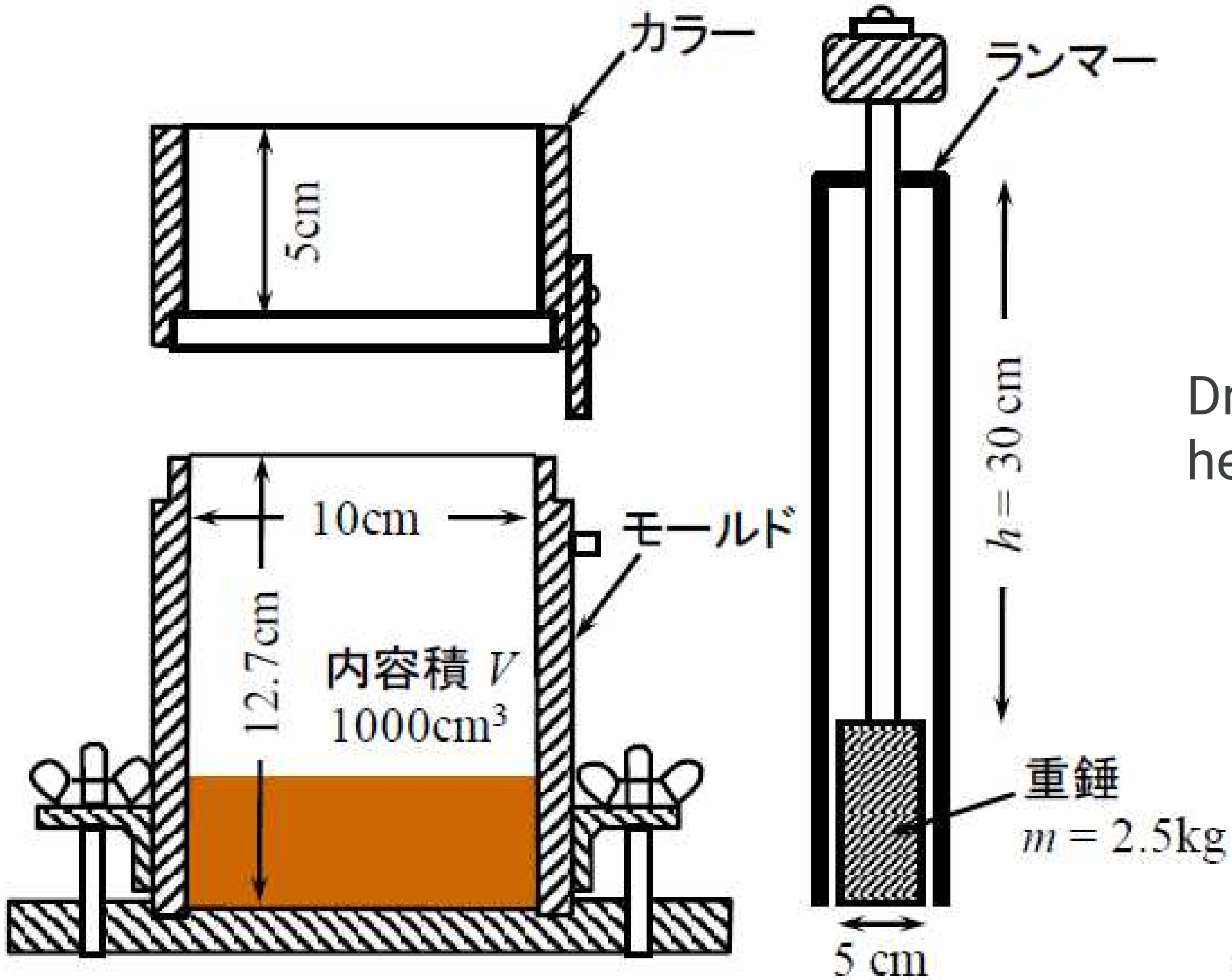
- Compaction effect
  - Reduced compaction: harder to settle
  - Reduced compaction: harder to settle
  - Increased shear stiffness and strength: less likely to break
Reduced permeability: difficult for water to pass through

- Basic concepts of compaction by Proctor (1933)
When compacted with a certain amount of energy, there is an optimum water content at which the density is maximum. (The content ratio controls the degree of compaction.)

From the website of Associate Professor Tadashi Kikumoto, College of Urban Science, Yokohama National University

## 2) Soil compaction test methods

### Soil compaction test





1) Divide the soil into 3 layers and tamp each layer 25 times.
2) Measure the wet density and water content ratio.
3) Calculate dry density.
4) Adjust the water content ratio and perform 1) - 3).

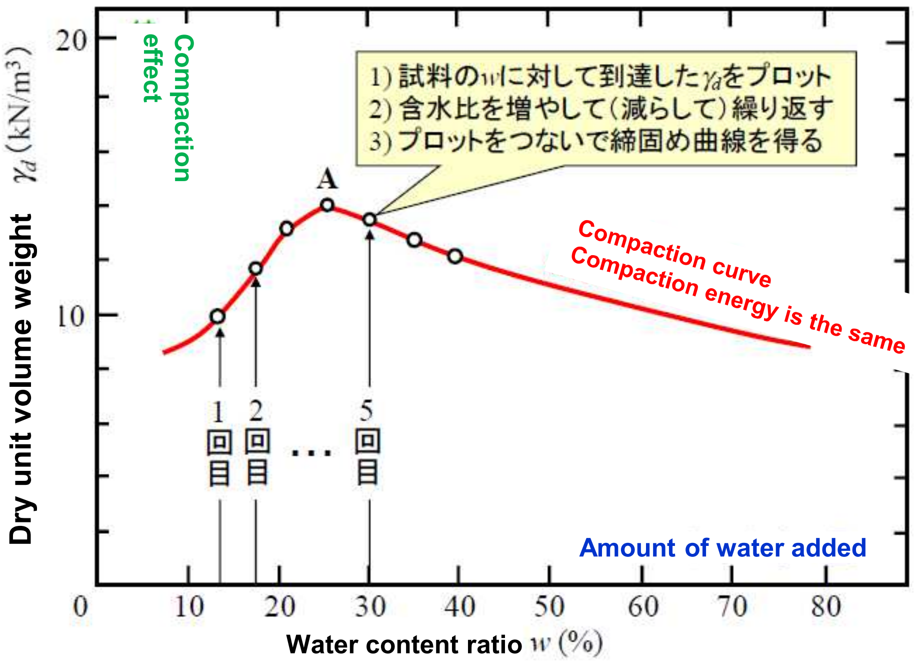
**Energy given to a unit volume of soil**

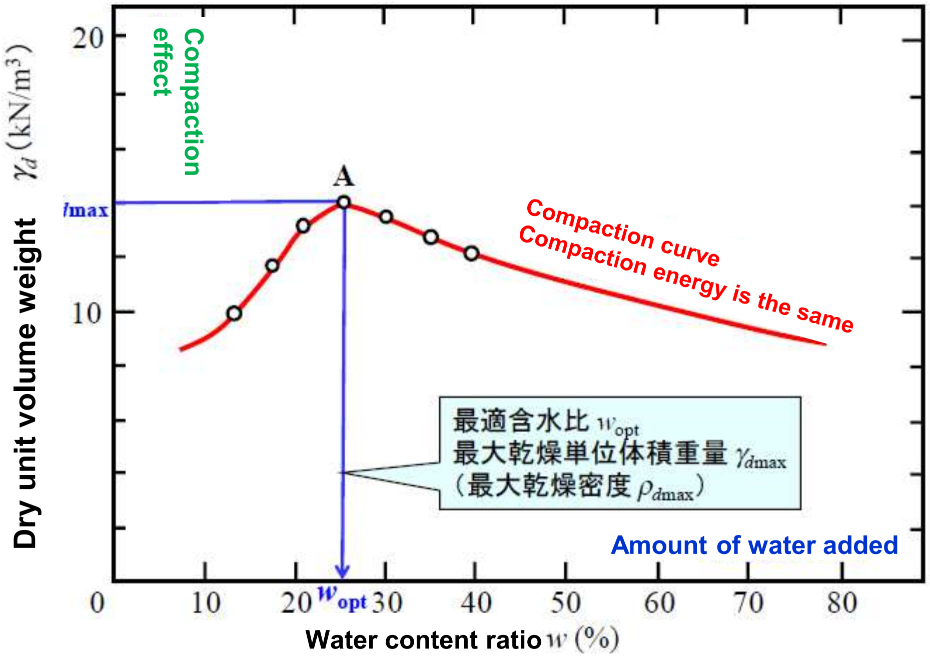
$$E_c = mgh \cdot 25 \cdot 3 / V = 5.6\ \mathrm{cm \cdot kgf/cm^3}$$

From the website of Associate Professor Tadashi Kikumoto, College of Urban Science, Yokohama National University

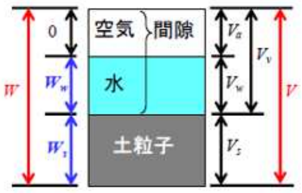
# 3) Soil compaction test results

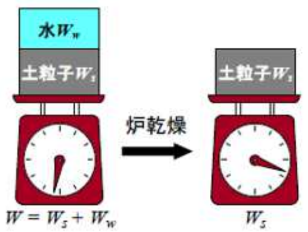
**Soil compaction test （$w$-$\gamma_d$ relation)**




**Compaction tests (optimum water content ratio and maximum dry density)**



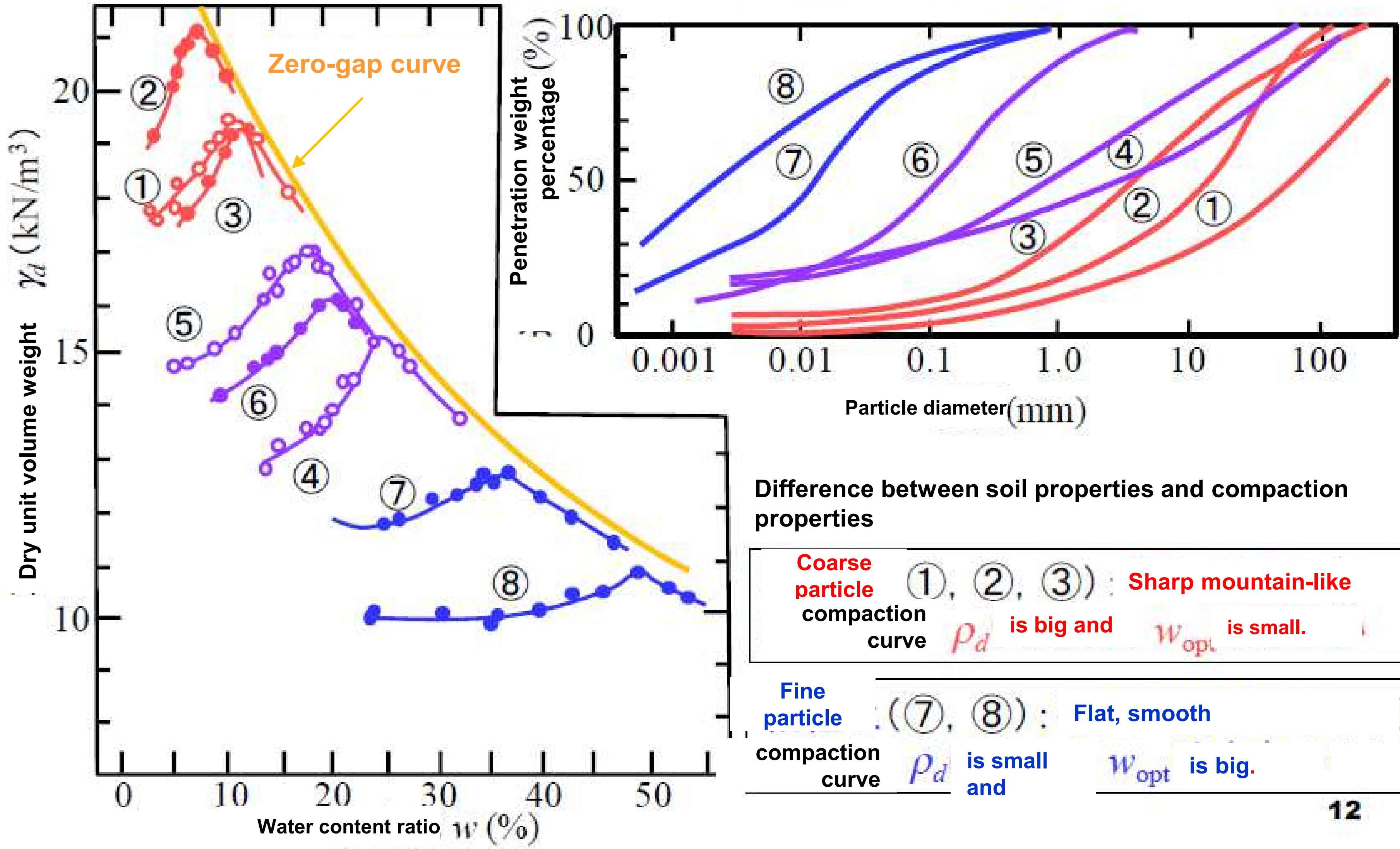




- **Wet unit volume weight** : $\gamma_t = \dfrac{W}{V}$
- **Water content ratio** $w = \dfrac{W_w}{W_s}$
- **Dry unit volume weight** : $\gamma_d = \dfrac{W_s}{V} = \dfrac{\gamma_t}{1+w}$

From the website of Associate Professor Tadashi Kikumoto, College of Urban Science, Yokohama National University

# 4) Characteristics of soil compaction

## Differences in soil types and compaction characteristics




Difference between soil properties and compaction properties

Coarse particle compaction curve (①, ②, ③) : Sharp mountain-like $\rho_d$ is big and $w_{opt}$ is small.

Fine particle compaction curve (⑦, ⑧) : Flat, smooth $\rho_d$ is small and $w_{opt}$ is big.

12

From the website of Associate Professor Tadashi Kikumoto, College of Urban Science, Yokohama National University

## 5) Embankment compaction management method

- Sediment becomes stronger when the density of the sediment is packed. (See Figure 1)
- This property is used to increase the strength of the embankment itself. This action is called “sediment compaction“.
- “Compaction management" is the process of constructing embankment to approach the optimum dry density determined for each embankment material.

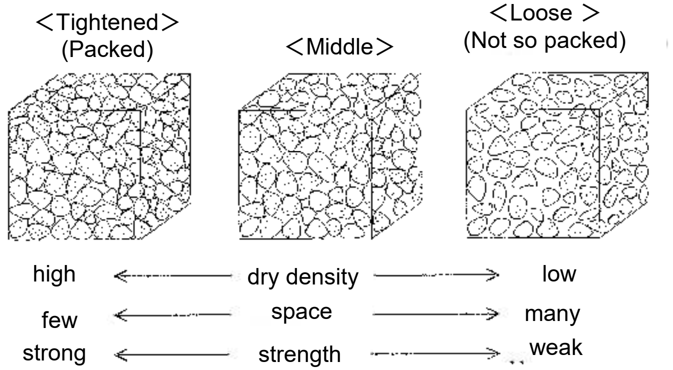


Fig. 1 Relationship between sand condition and density

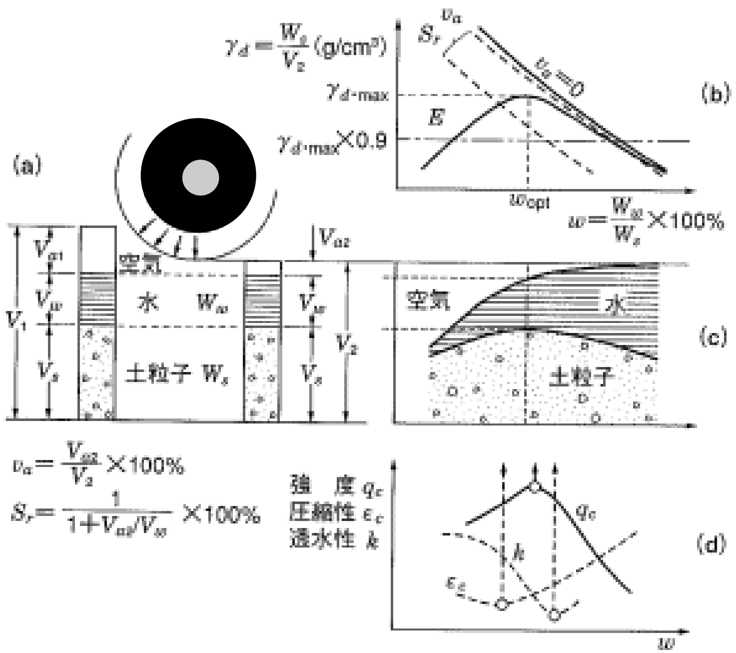


図4　砂の状態と密度の関係

# ＜List of soil classification and compaction equipment for embankments and roadbeds＞

| 盛土の構成部分 | 土質区分 | 仕上がり厚さ cm | 締固め機械 振動ローラ 自走式 転圧力(kN) 転圧力320kN級 | 振動ローラ 自走式 転圧力200kN級 | 振動ローラ 非牽引式 転圧力130kN級 | 振動ローラ 非牽引式 転圧力50 kN級 | 自走式ソイルコンパクタ | 被けん引式タンピングローラ | ロードローラ | 振動コンパクタ | ランマ・コンパクタ | タイヤローラ 自走式 | タイヤローラ 被牽引式 | ブルドーザ 普通型 | ブルドーザ 湿地型 | 備考 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 盛土・路体 | 岩塊などで、転圧によっても容易に細粒化しない | 100～60 | ◎ | ◎ | | | | | | | | | | | | 硬岩 |
| | | 60～30 | ◎ | ◎ | ○ | | | | | | | | | | | |
| | | 30 | ◎ | ◎ | ○ | ○ | | | | 大□ | 大□ | | | | | |
| | 風化した岩・土丹などで部分的に細粒化してよく締固まる岩など | 60～30 | ◎ | | | | | | | | | | | | | 軟岩<br>脆弱岩 |
| | | 30 | ○ | ◎ | ○ | ○ | | | | □ | 大□ | 大○ | 大○ | | | |
| | 単粒度の砂、細粒分の欠けた切込砂利、砂丘の砂など | 60～30 | ○ | | | | | | | | | | | | | 砂<br>礫混じり砂 |
| | | 30 | ○ | ○ | ○ | ○ | | | | □ | □ | ○ | ○ | | | |
| | 細粒分を適度に含んだ粒度のよい締固め容易な土、まさ土、山砂利など | 60～30 | ○ | | | | | | | | | | | | | 砂質土<br>礫混り砂質土 |
| | | 30 | ○ | ○ | ○ | ○ | | | | □ | □ | 大○ | ○ | | | |
| | 細粒分は多いが鋭敏性の低い土、低含水比の関東ローム、くだきやすい土丹など | 30 | | | | ○ | ◎ | ◎ | | | □ | 大○ | ○ | | | 粘性土<br>礫混り粘性土 |
| | 含水比調節が困難でトラフィカビリティが容易に得られない土、シルト質の土など | 30 | | | | | | | | | | | | ● | ● | 水分を過剰に含んだ砂質土 |
| | 関東ロームなど、高含水比で鋭敏性の高い土 | 30 | | | | | | | | | | | | ● | ● | 鋭敏な粘性土 |


図5　土砂の締固め重機・機械

# 6） Actual on-site embankment compaction management

At the construction site, one of the following three types ① - ③ of “compaction management” is carried out.

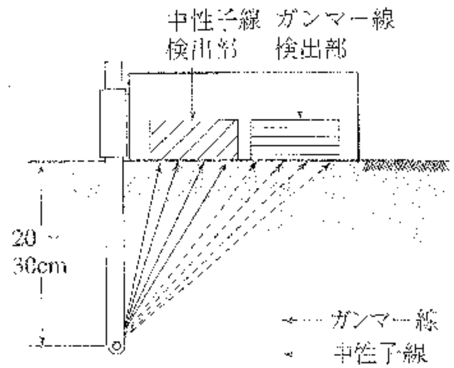
① In the in-situ test, determine the wet density and water content ratio of the embankment by conducting an in-situ density test (sand replacement method, water replacement method) and current water content ratio test. (Figures 1 and 2)

② Determine the density and water content ratio of the embankment using a radioisotope RI tester. (When radioisotope gamma rays pass through soil, the amount of transmission changes depending on the density of the soil, and the property that neutron beams collide with hydrogen atoms and change into thermal neutron beams is used. (Method of measuring the wet density water ratio.) (Figures 3 and 4)

Figure 1 On-site density test

Fig. 2 On-site water content test

Figure 3 RI testers



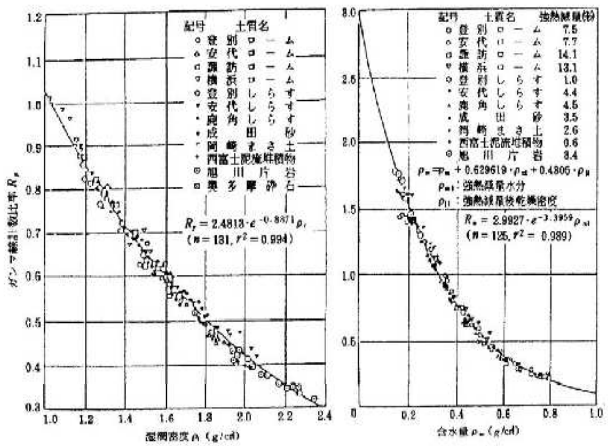



Figure 4 Wet density and water content of embarkment material and RI coefficient values

## ③ At the site, conduct an on-site compaction test using the rolling compaction machine and embankment material that will actually be used, and determine the rolling thickness, the heavy machinery to be used, and the number of compactions.

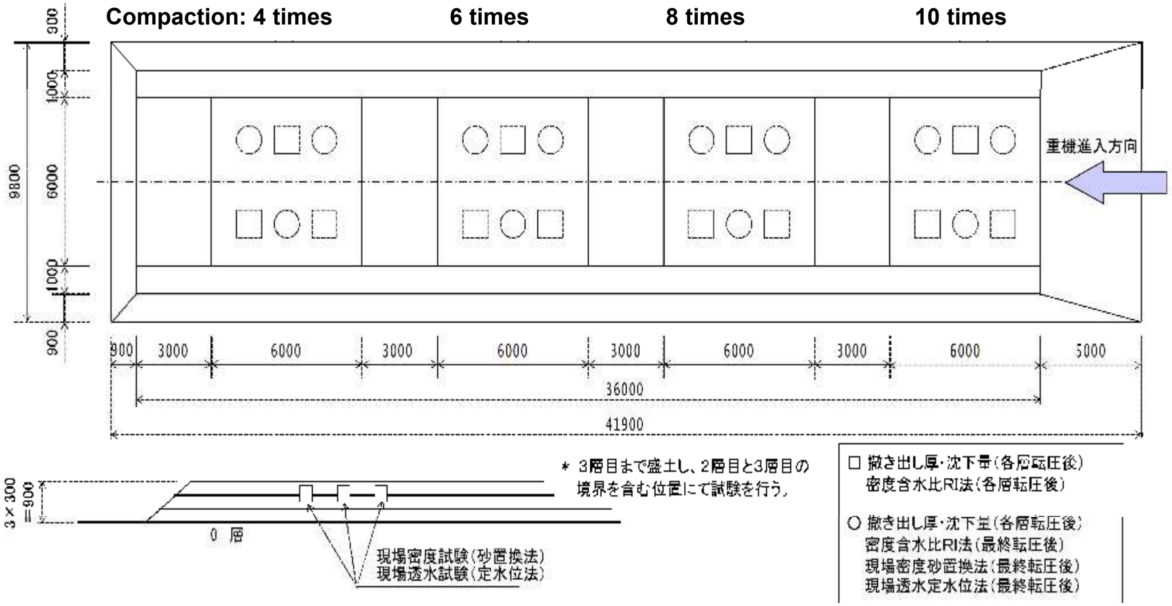


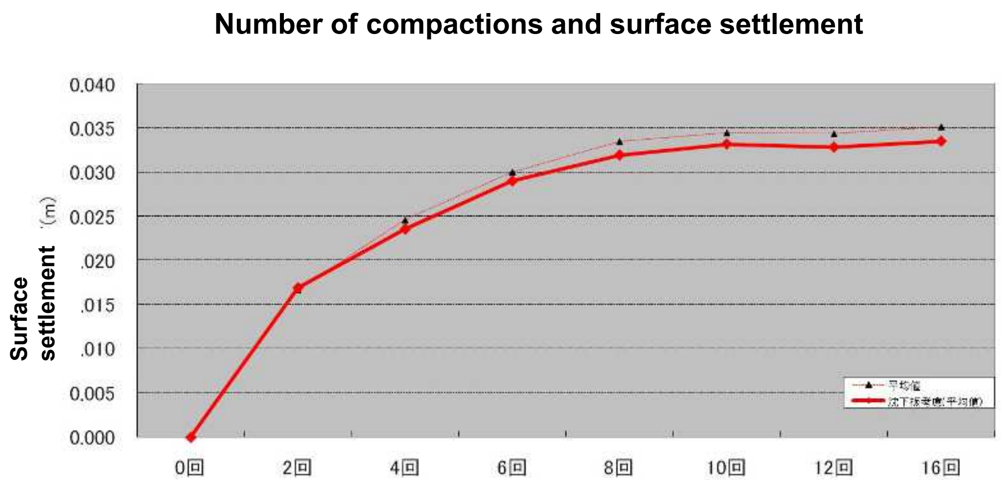

Figure 1 Embarkment test yard diagram

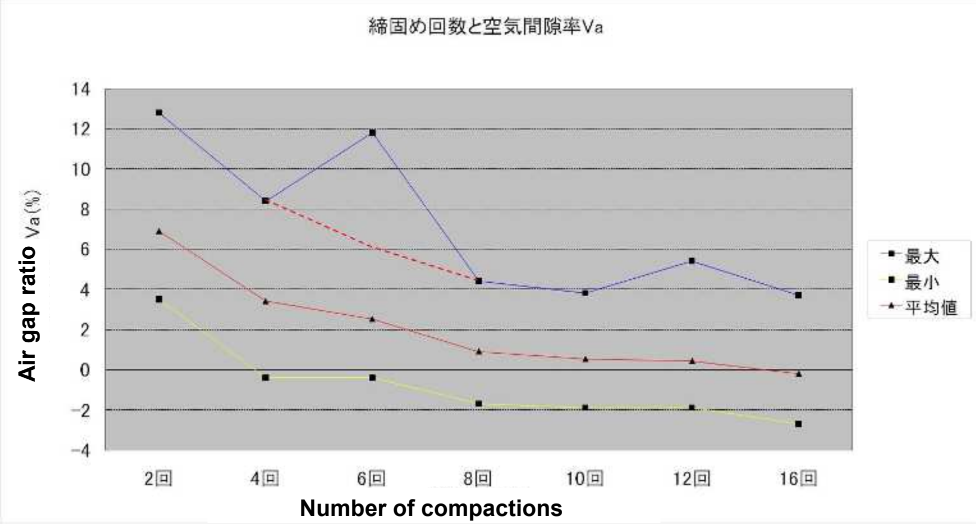

A heavy 20t vibrating roller actually used on site

<Example of implementation specifications>

・Rolling thickness: 30cm

・20t vibrating roller, number of rolling pressure: 3, 4, or 5 times



## 3. Stability of foundation ground

When embankment is carried out, the ground bearing capacity of the foundation ground and the degree of compaction of the embankment itself are important factors for the stability of the embankment.

① Ground bearing capacity of foundation ground, subsidence

② Stable embankment: arc wandering, embankment subsidence

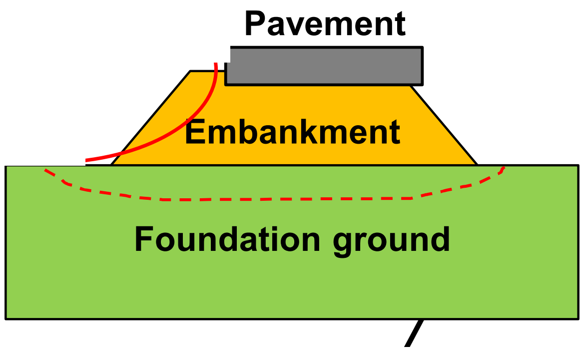



Fig. 1 Embankment section

**<Check the strength of the foundation ground>**

- **Conduct uniaxial and triaxial compressive strength tests of the foundation ground.**
- **Directly conduct a flat plate loading test on the ground.**

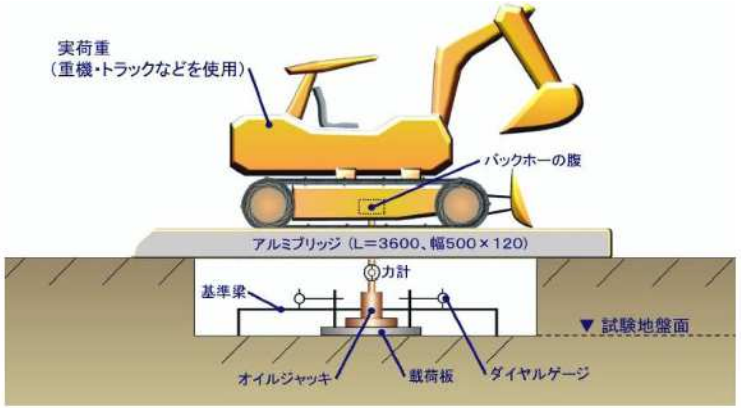



**Figure 2 Flat plate loading test method**

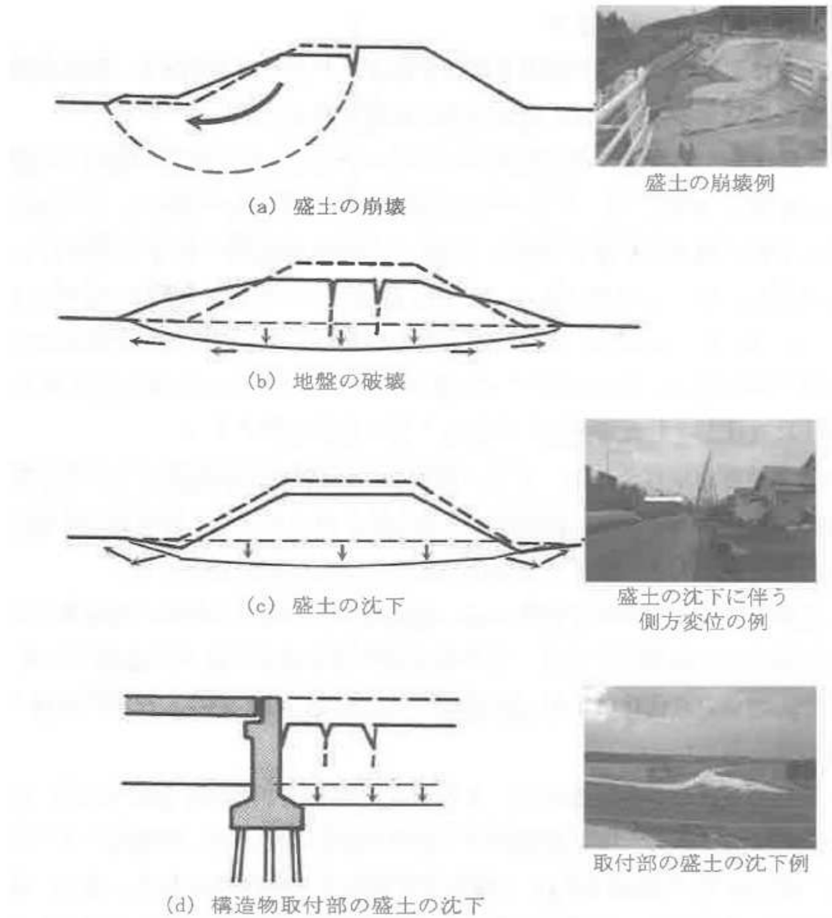



**Figure 3:Example of embankment deformation on soft ground**

# 1) Groundwater flow caused by rainfall

**→ Increased possibility of landslides**

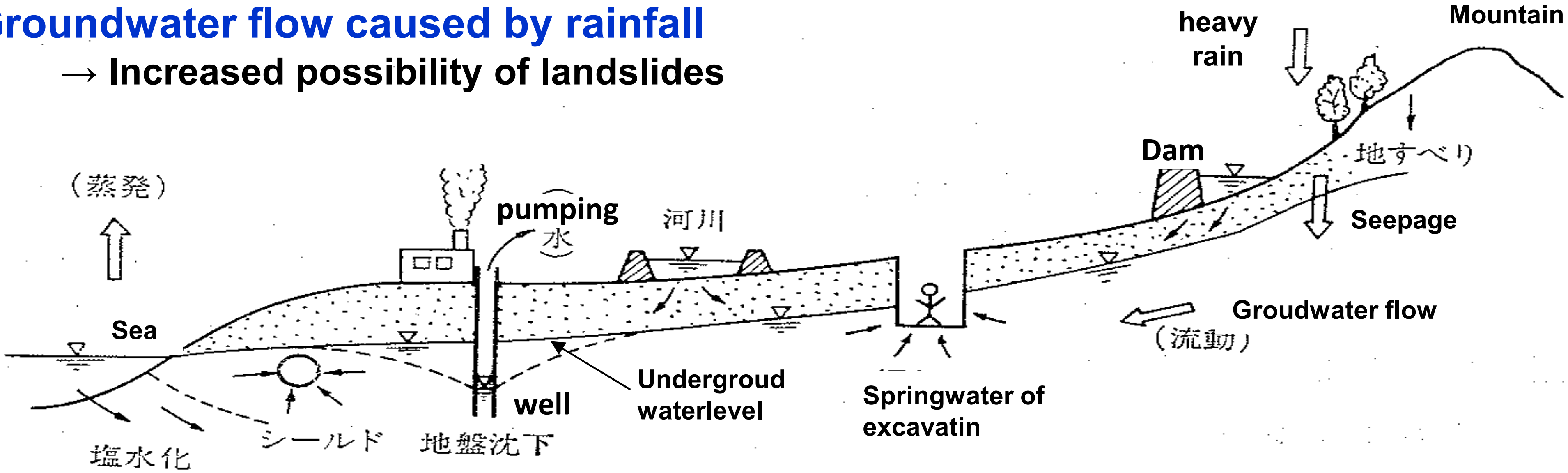



Figure 1 Groundwater circulation and civil engineering work

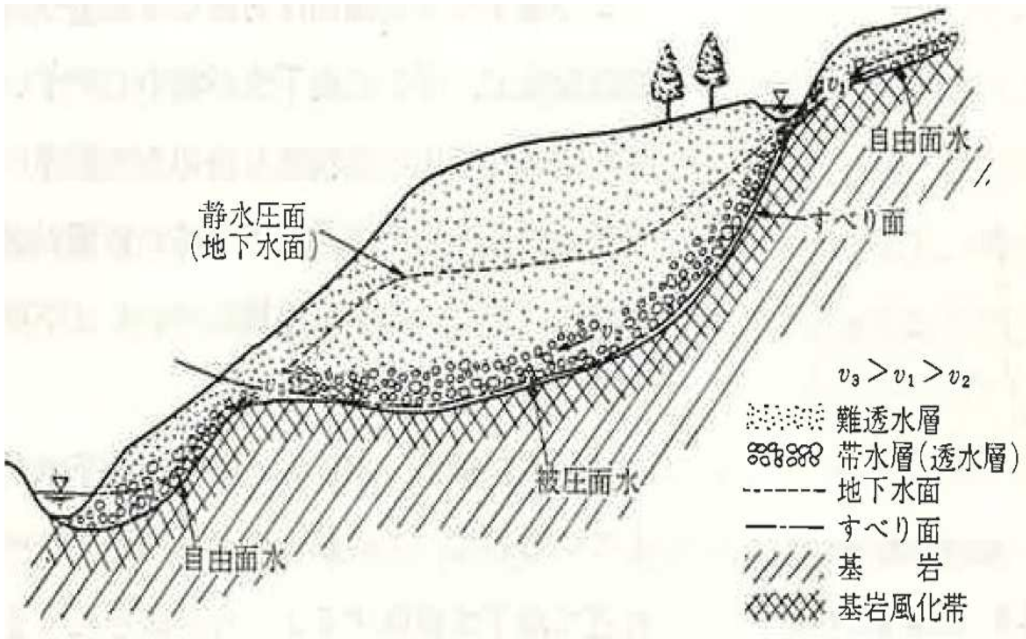



Fig. 2 Groundwater distribution in landslides

## 2) Deformation of embankments caused by groundwater

**Rise of groundwater leads to "collapse of slope, collapse of embankment."**

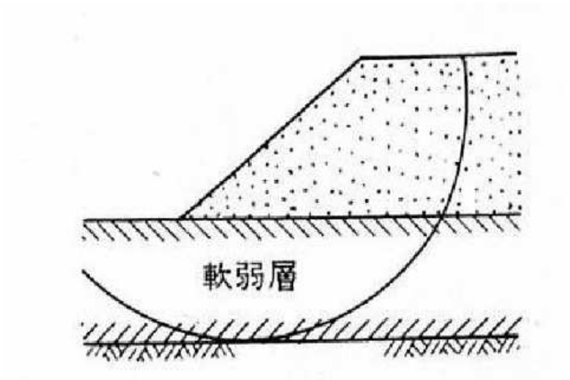



**Fig. 1 Deep slide including foundation**

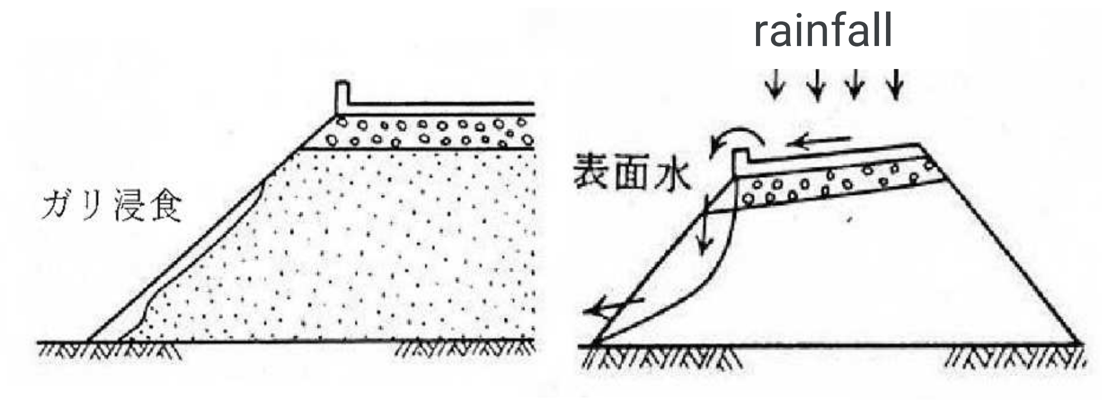



**Fig. 2 Shallow slide of direction layer**

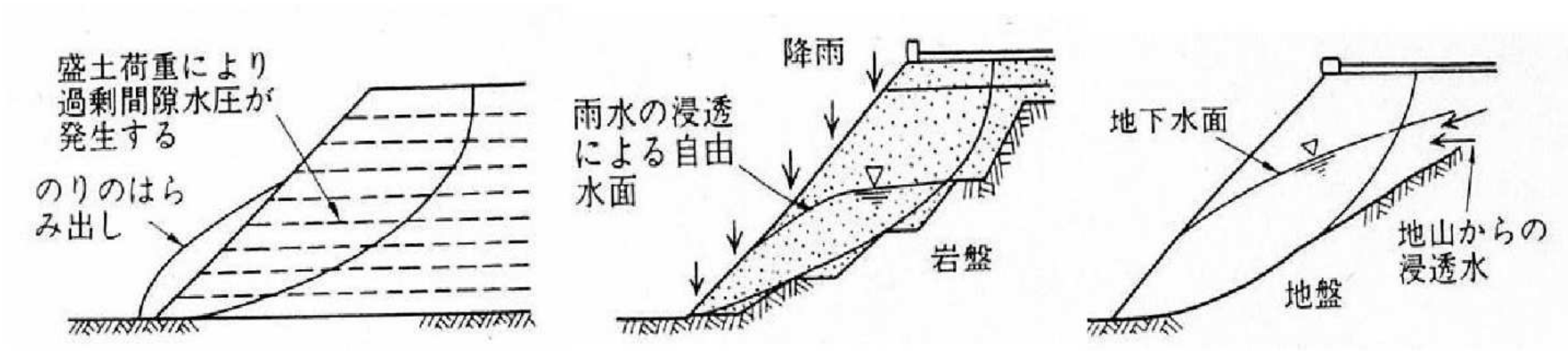



**Fig. 3 Sliding including inside of embankment**

## 3) Why are slopes prone to collapse when it rains?

**Landslide case 01:**

**Asajimachi, Bungo-Ono City, Oita Prefecture**
**Landslide in the Masuda area (May 2017)**
**Landslides occurred in deep underground due to heavy rainfall of 100 mm / hr.**

豊後大野市朝地町綿田の地割れの状況


※市の資料を基に作成

写真1■上空から見た様子。5月24日にドローンを使用して撮影（写真:下も大分県）

**Image of emergency measures**

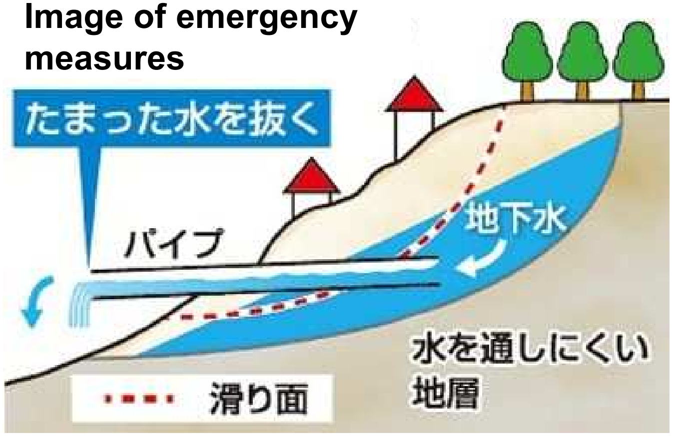



写真2■土木研究所の専門家チームによる現地調査の様子。右の写真も5月24日に撮影

## Landslide example 02: Landslide in the Shiraya district of Kawakami Village, Otaki Dam, Nara Prefecture (around 2002)

Otaki Dam: 100m high concrete gravity dam

・After the completion of the dam body, the groundwater level in the Shiraya area rose due to flooding, causing a large-scale landslide.

・Although large-scale landslide countermeasures (ground improvement, legal framework, anchor) were taken, 37 residents were finally settled by moving to adjacent land.



**Photo 1 Full view of  landslide**

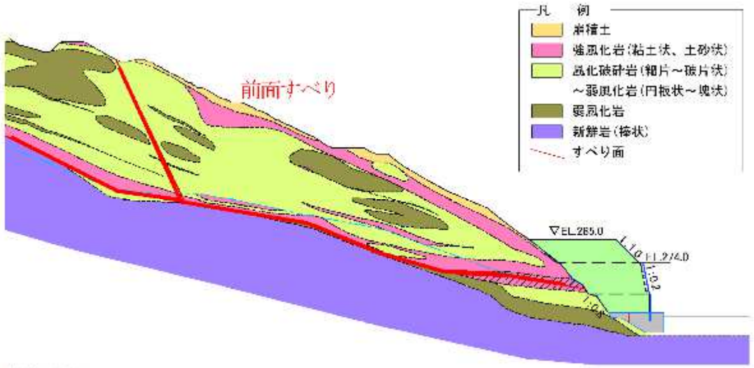



**Fig. 3 Cross-sectional view of weathered division**

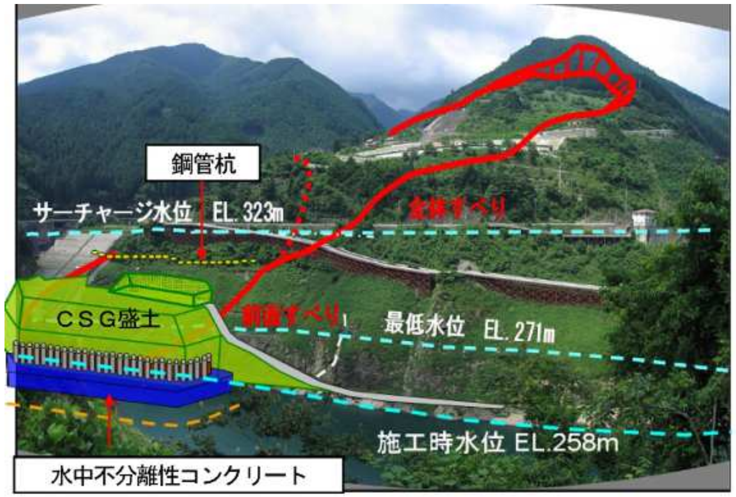



**Fig. 4 Image of countermeasures**

## 1) Landslides on roads

**Causes: ① Landslides caused by earthquakes ② Landslides and debris flows caused by heavy rain ③ Landslides that occur at the boundaries of strata**

**Mountain collapse caused by Hokkaido earthquake**

**Collapse of road embankment caused by earthquake**

**Cliff collapse caused by earthquake**

**Cliff collapse caused by heavy rain that loosened the ground**

**Mudslides caused by heavy rain**

## 2) Characteristics and signs of landslide topography

### Indicators of landslide activity

① **Steep cliffs, steps, and cracks are sharp and angular.**
② **Cracks and depressions are not filled with secondary sediments.**
③ **Uplift and small-scale collapse at end of slope.**
④ **Interview survey of local activity history**

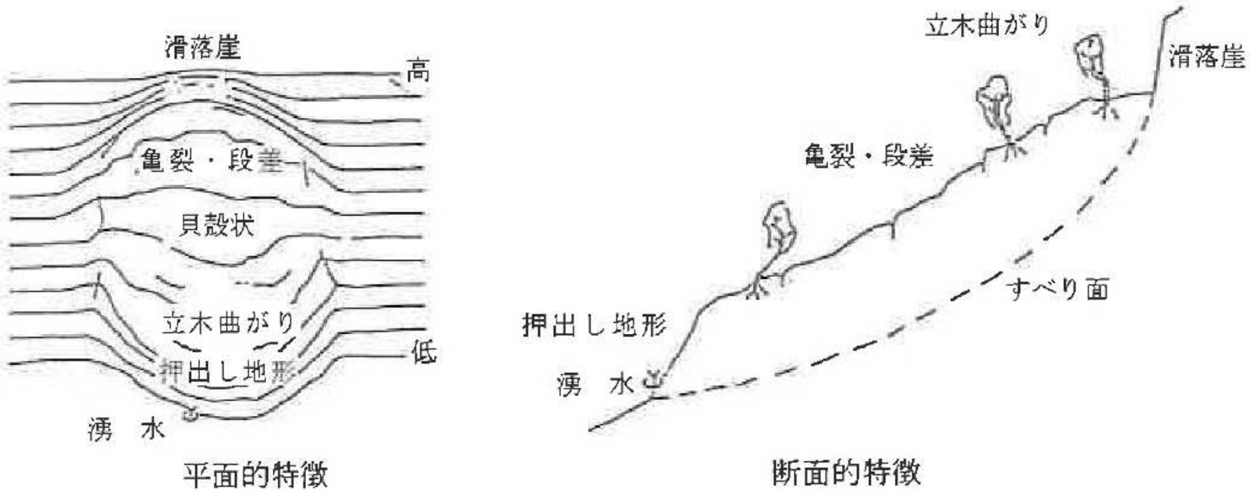



**Fig. 1: Landslide features**

### （1）Good example

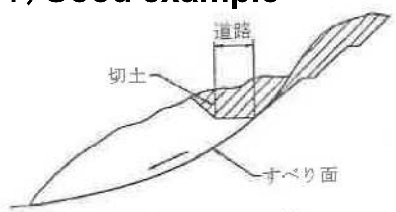



**Fig. 2 Cuttings at head**

**Landslide force is reduced by cutting the head of the landslide area.**

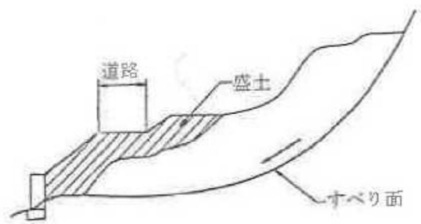



**Fig. 3 Embankment at end**

**By embankment at the end of the landslide, it becomes a restrained embankment and stabilizes the landslide.**

### （2）Bad example

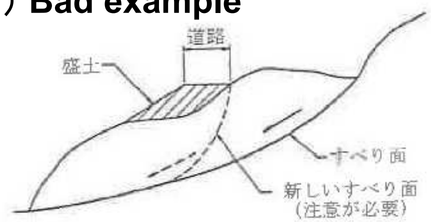



**Fig. 4 Embankment in middle part**

**Embankment in the middle of the landslide may induce a landslide.**

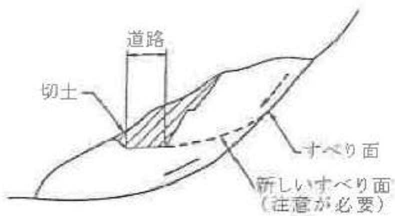
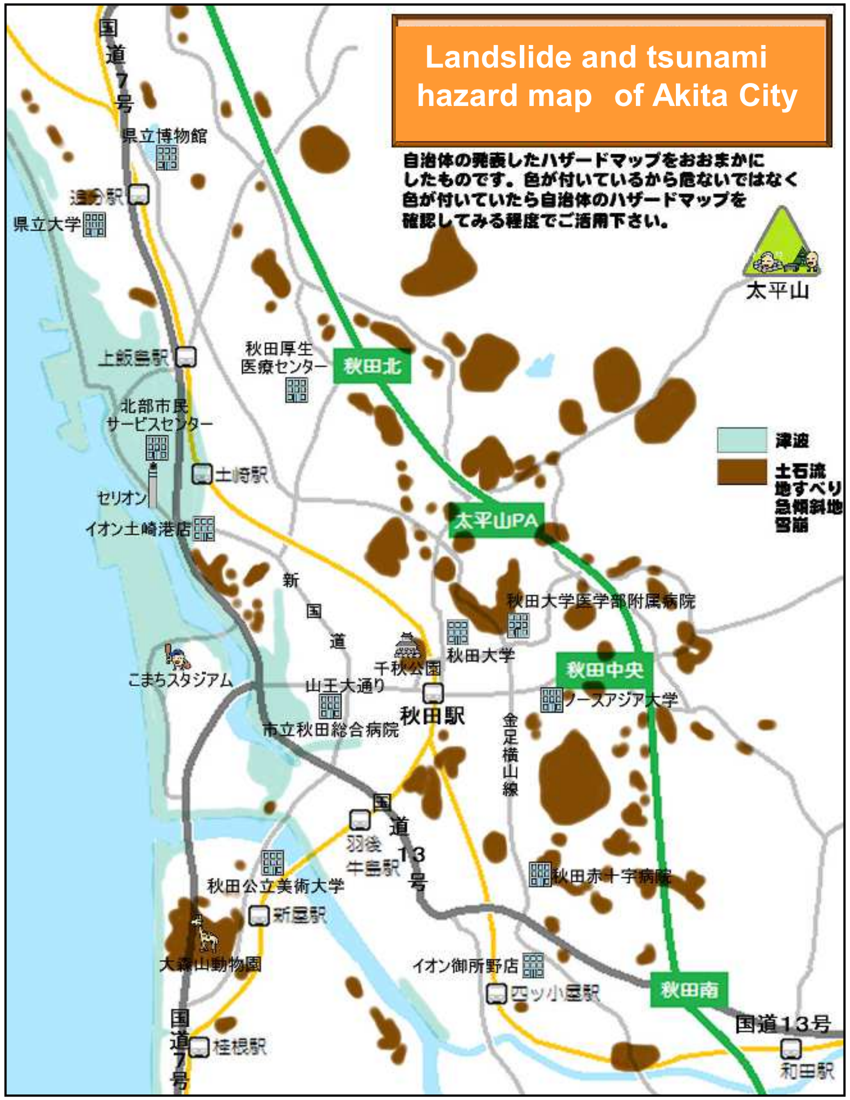



**Fig. 5 Cuttings in middle part**

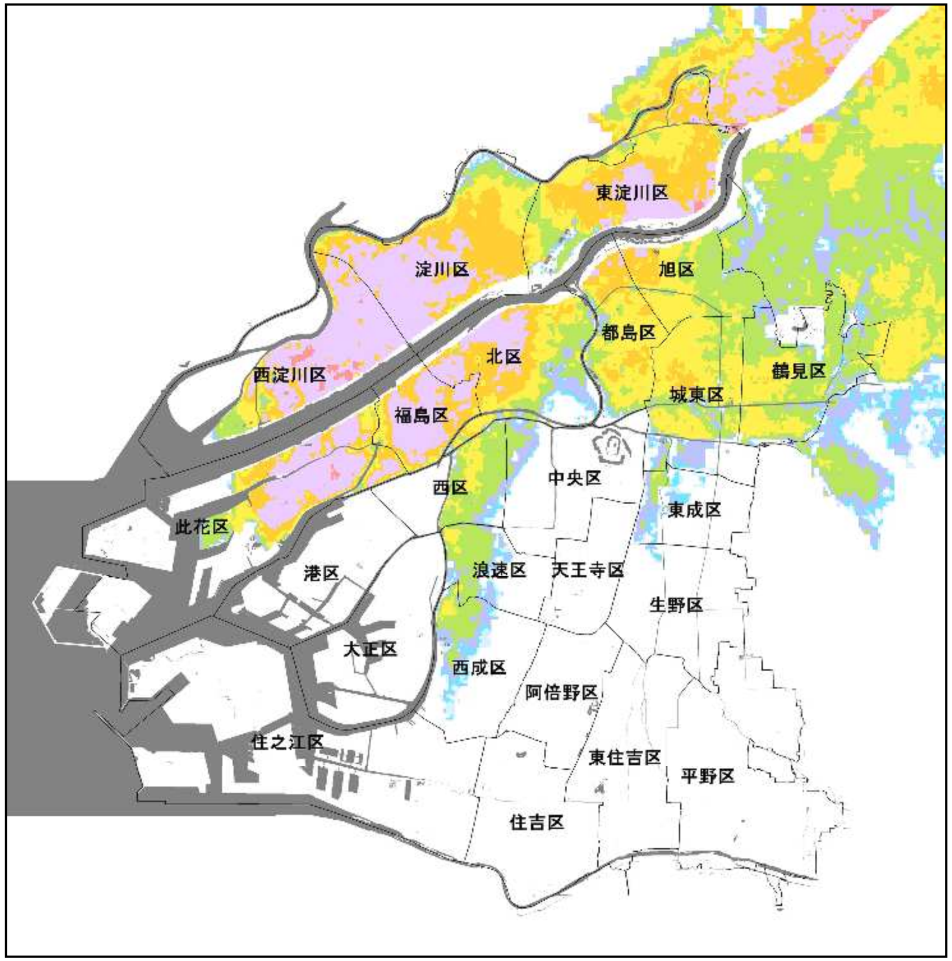
**Cuttings in the middle part of the landslide may induce a landslide.**

# 3) Disaster hazard maps along road routes

**Road maintenance and management requires the prediction of possible disasters on the road and preparation for road disasters. For this purpose, various disaster hazard maps must be prepared.**



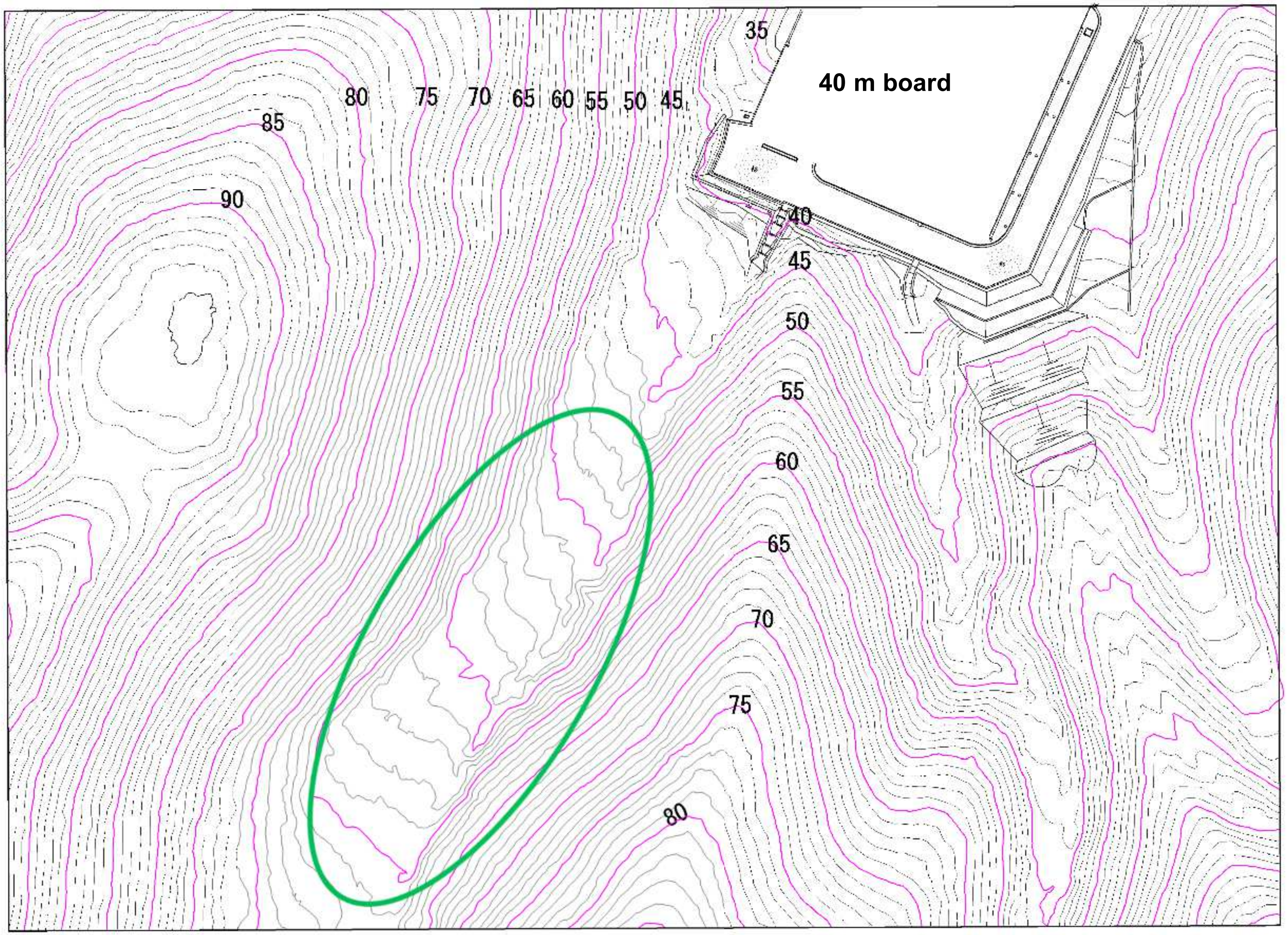

**Example ①: Landslide/tsunami hazard map**

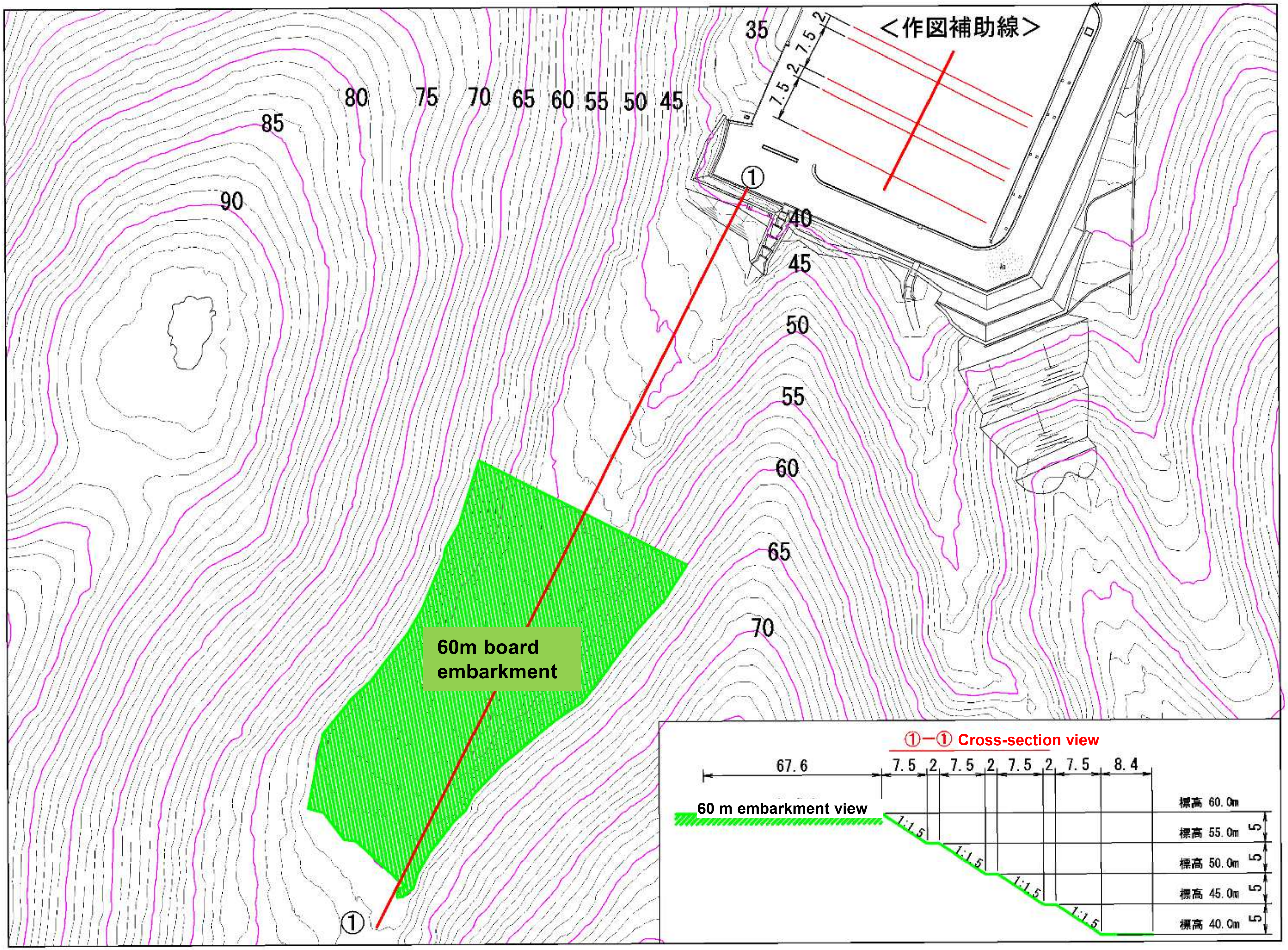



**Example ②: River flood hazard map**

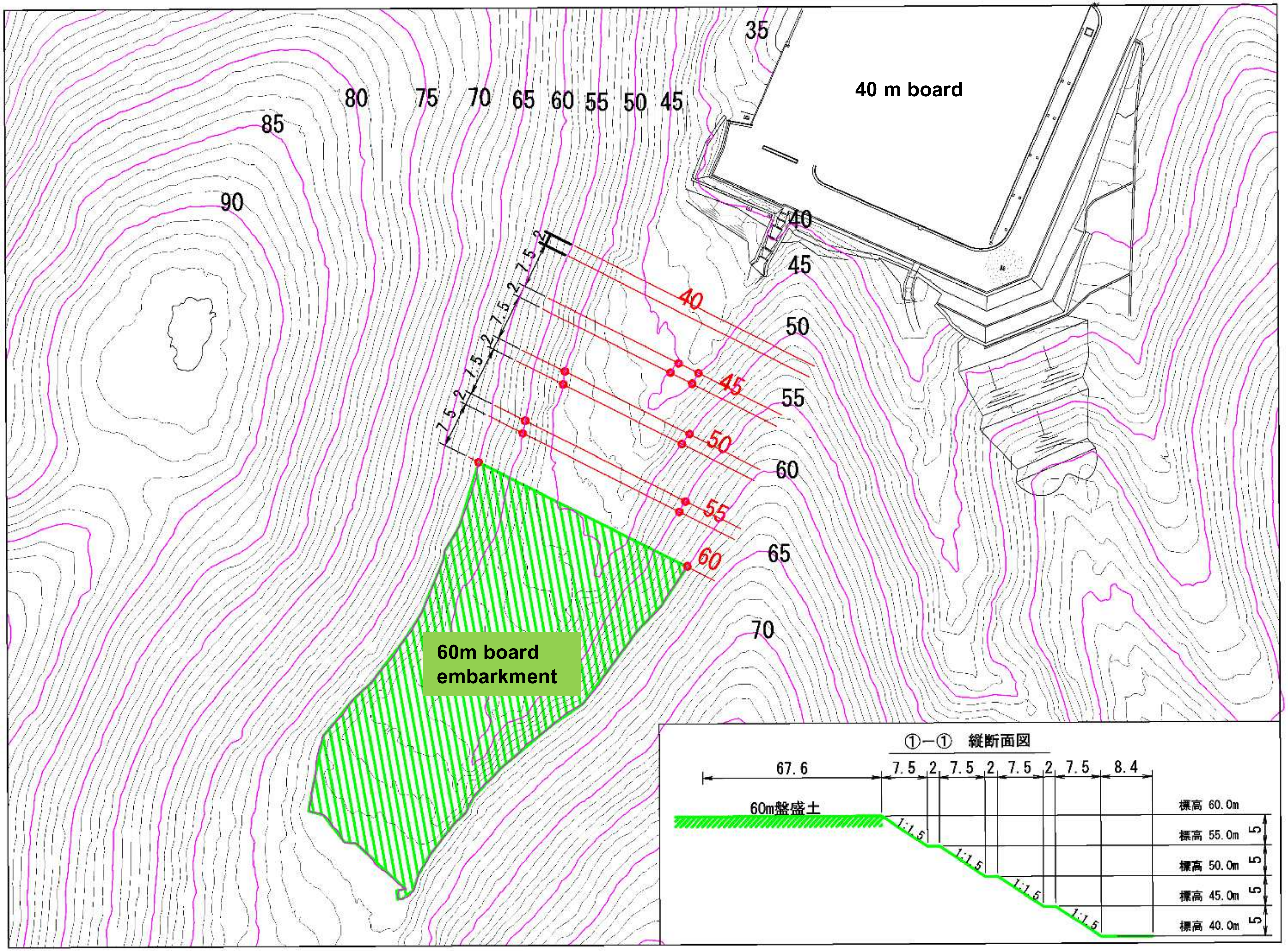
## 1) Creating embankment plans

**Please create an embankment on the 60m board area shown in the figure below. Write its shape. The slope of the embankment is 1.5%.**

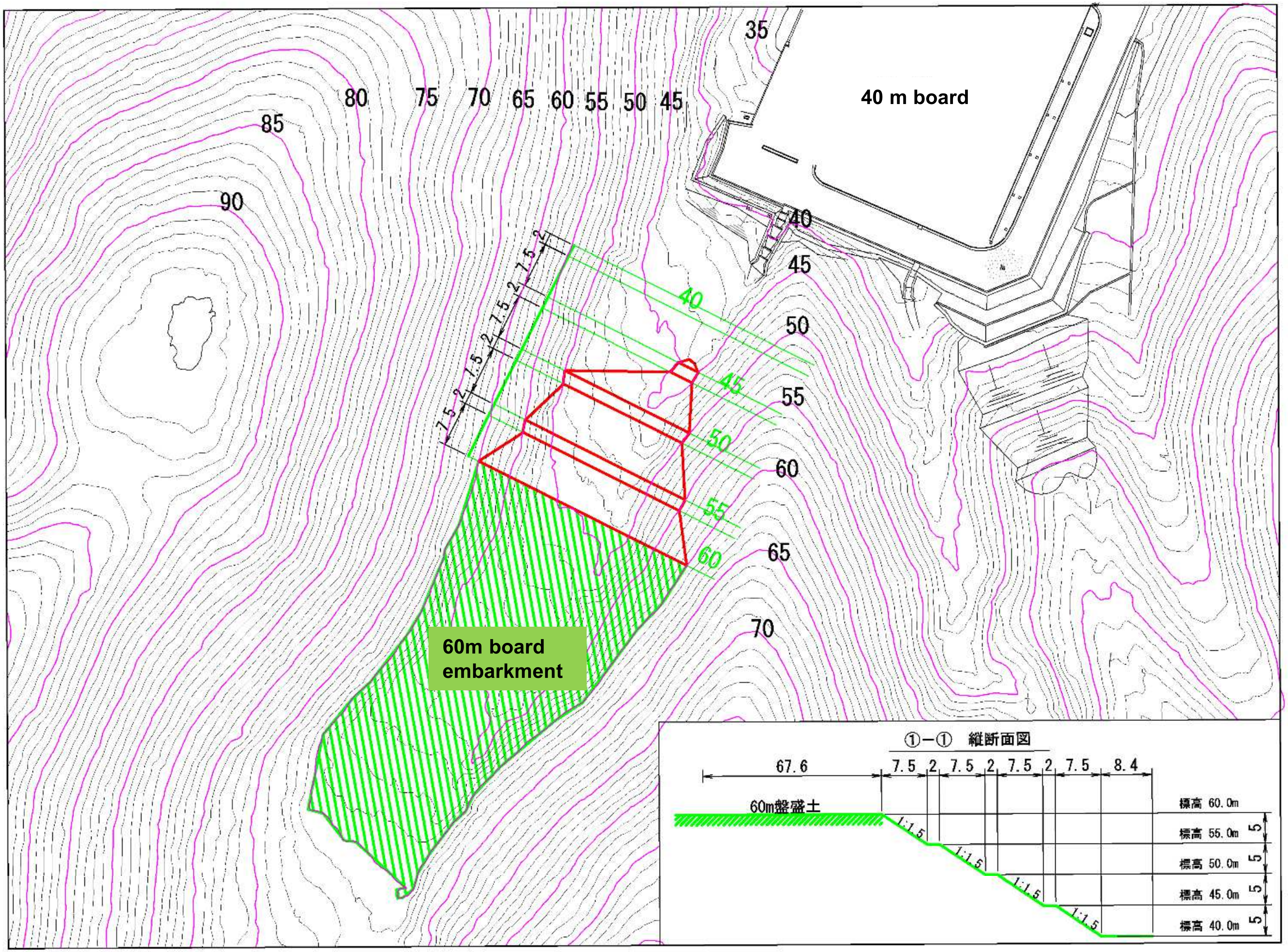


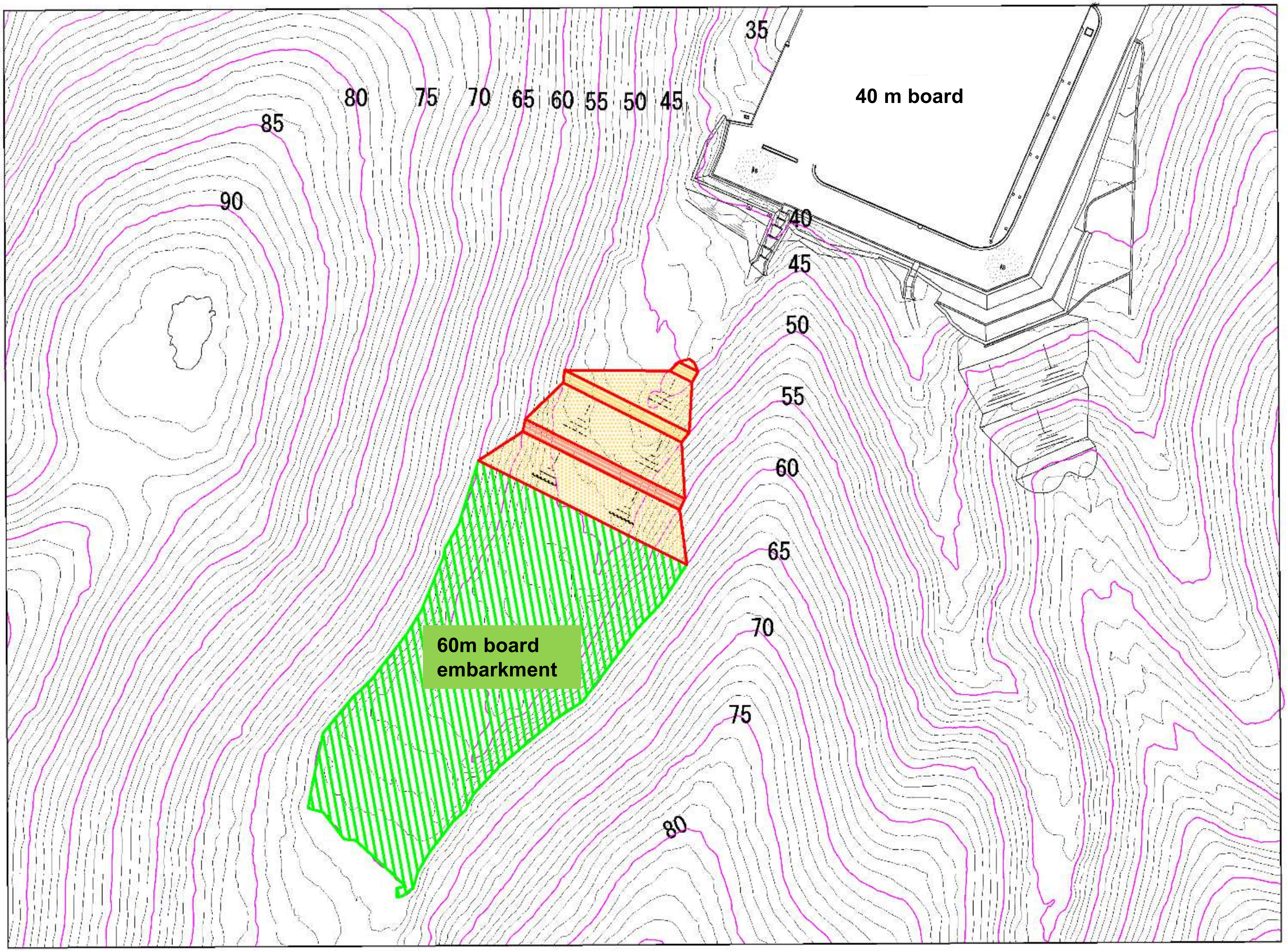


＜作図補助線＞
35
80
75
70
65
60
55
50
45
85
90
①
40
45
50
55
60
65
70
7.5
2
7.5
2
60m board embarkment
①
①ー① Cross-section view
67.6
7.5
2
7.5
2
7.5
2
7.5
8.4
60 m embarkment view
1:1.5
1:1.5
1:1.5
1:1.5
標高 60.0m
標高 55.0m
標高 50.0m
標高 45.0m
標高 40.0m
5
5
5
5



40 m board
60m board embarkment
35
80
75
70
65
60
55
50
45
85
90
40
45
50
55
60
65
70
①－① 縦断面図
67.6
7.5
2
8.4
60m盤盛土
1:1.5
標高 60.0m
標高 55.0m
標高 50.0m
標高 45.0m
標高 40.0m
5

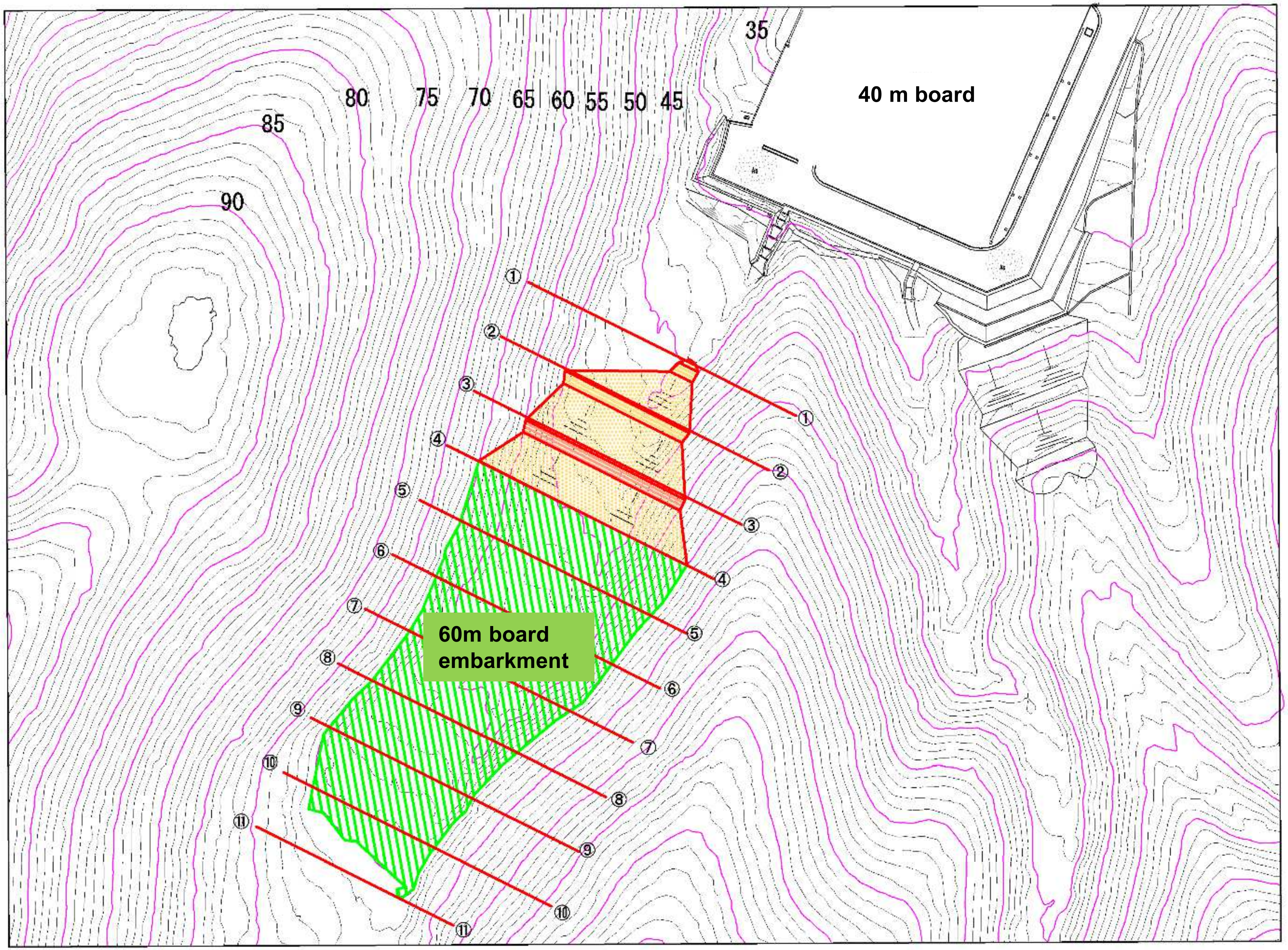

40 m board
60m board
embankment
①−① 縦断面図
67.6
7.5
2
8.4
60m盤盛土
1:1.5
標高 60.0m
標高 55.0m
標高 50.0m
標高 45.0m
標高 40.0m
5



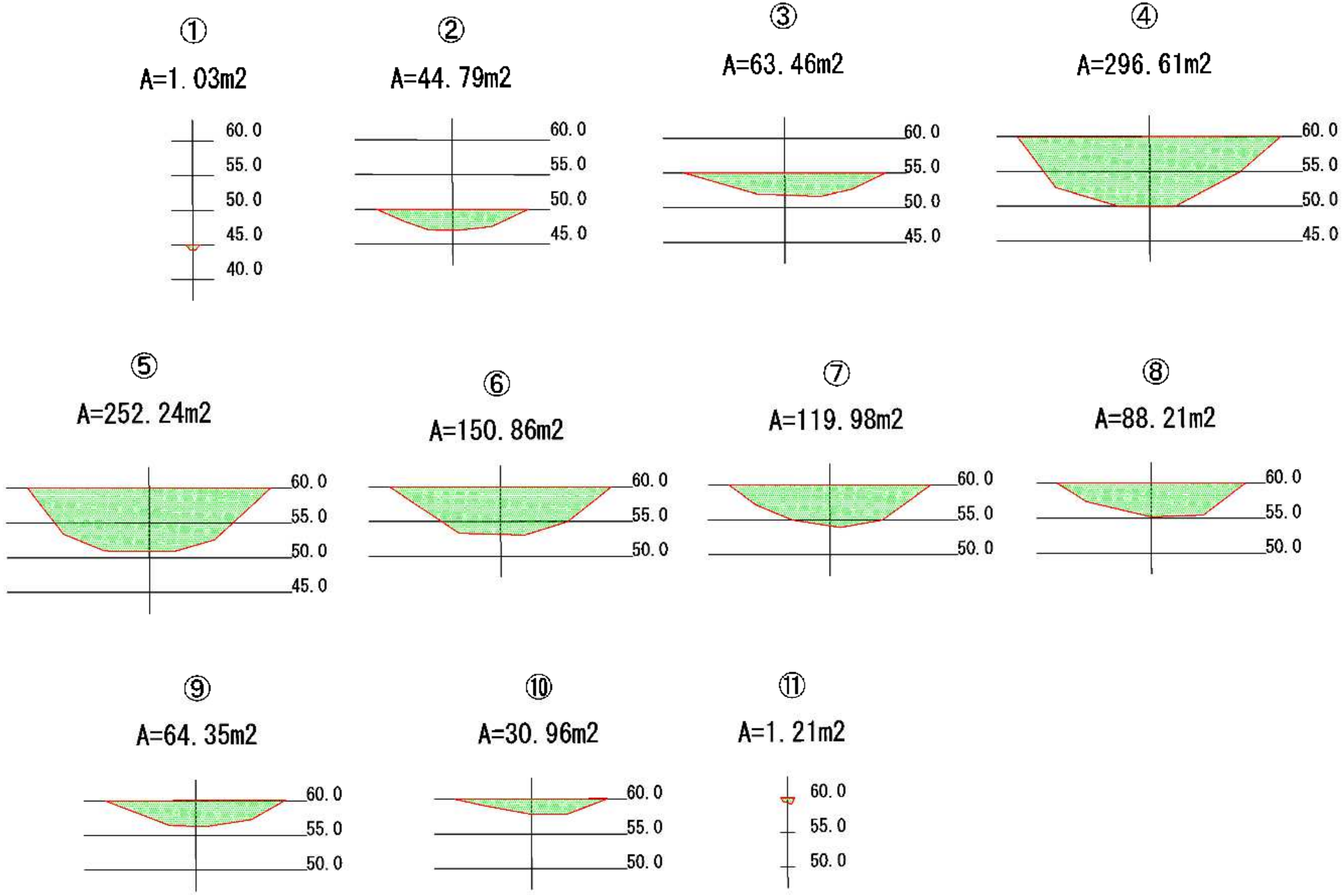
35
40 m board
80
75
70
65
60
55
50
45
85
90
40
45
50
55
60
65
70
60m board
embarkment
75
80

## 2) How to calculate the volume of earthwork

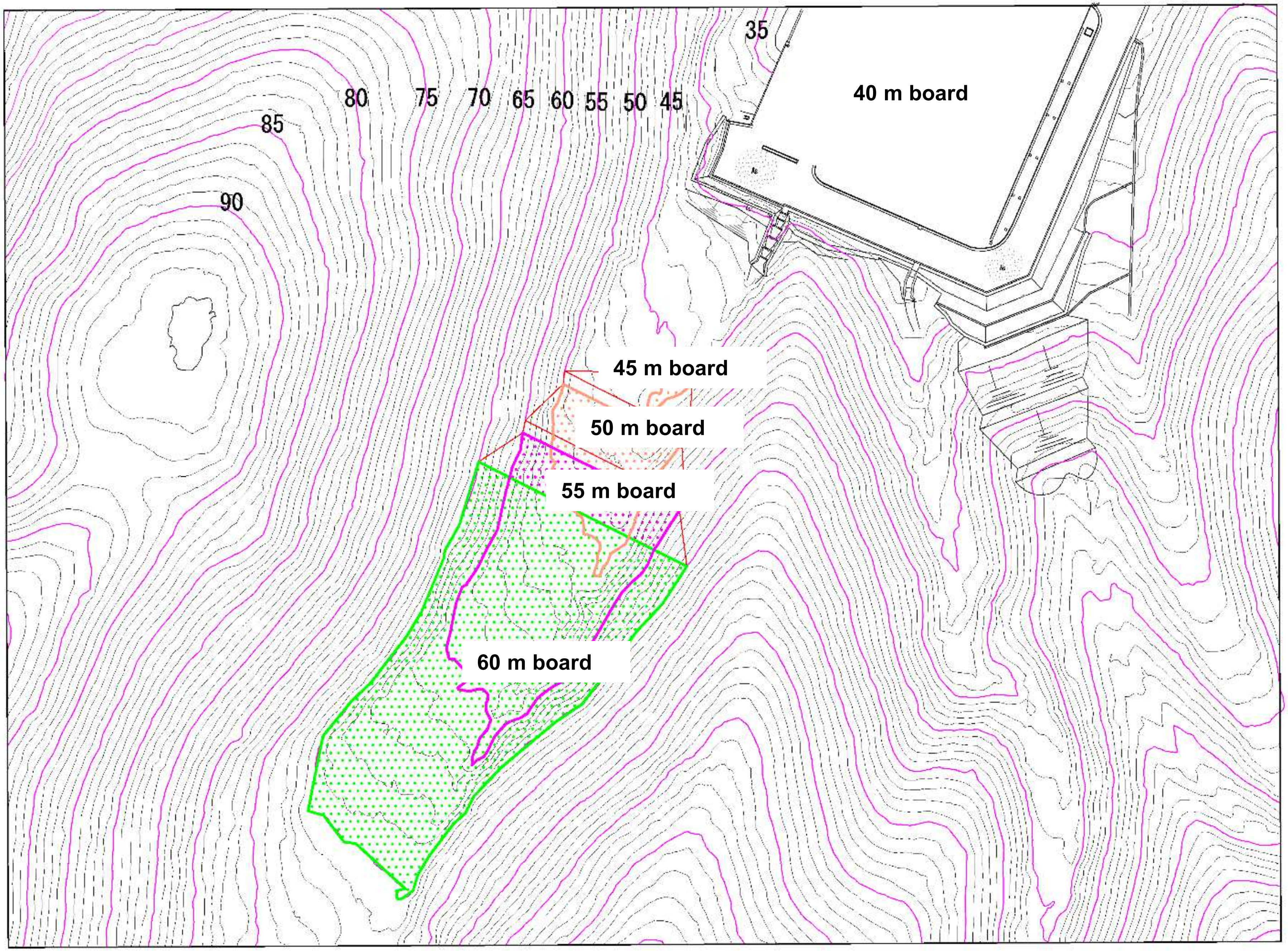
### ① Soil volume calculation by cross-sectional slice method



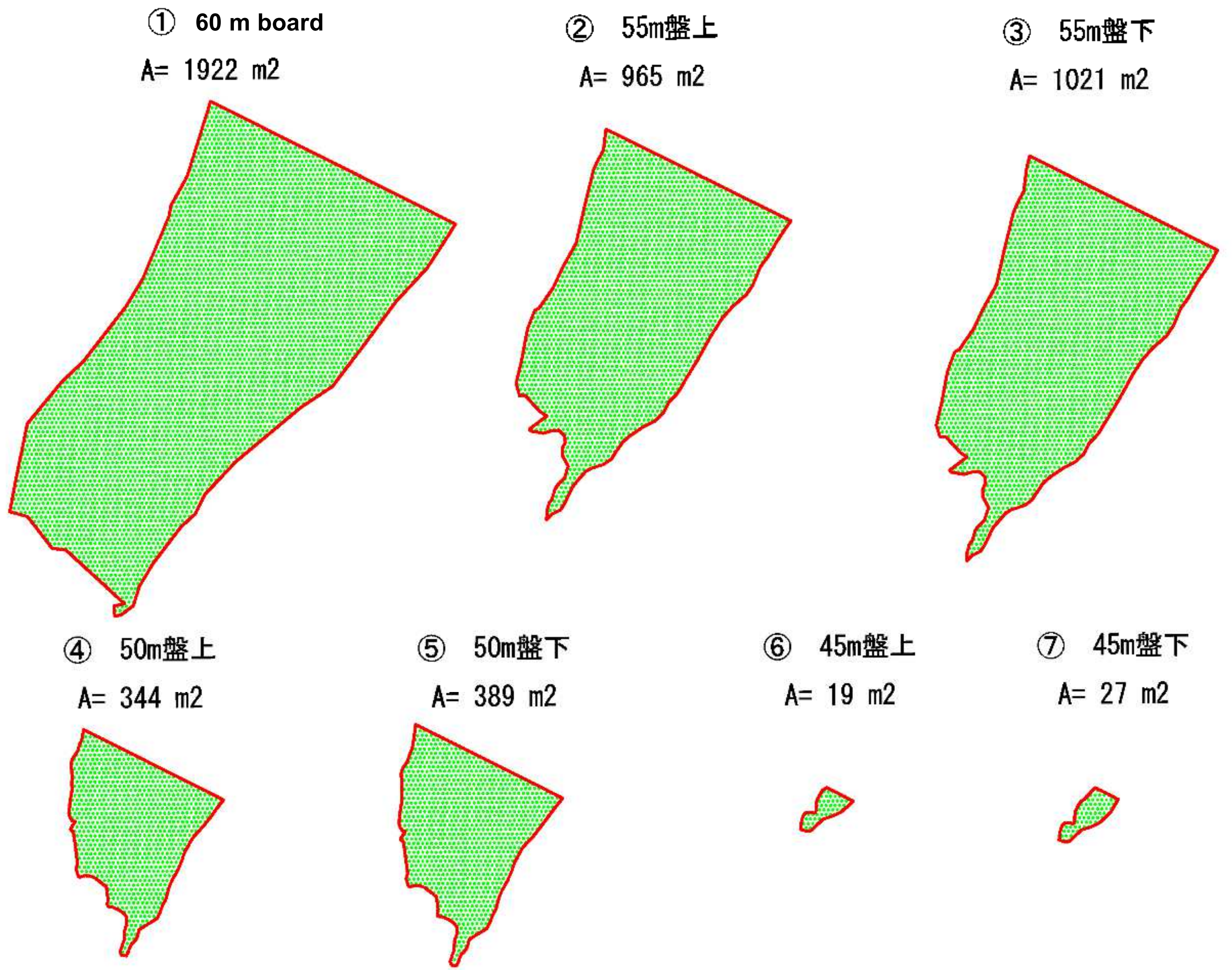
# Cross-sectional view of cross-sectional slices



## ② Soil volume calculation by plane slice method



## Plan view of plane slice



## 1） Cross-sectional slice method

V1＝（A①＋A②）／2 × 10m

∑V＝ V1＋V2＋・・・・＋Vi・・・・・・・・＋V11

| 断面<br>Cross section | 断面積<br>Cross section area | ①②平均<br>1 and 2 average | 延長<br>Extension | 区間体積<br>Section volume |
|---|---|---|---|---|
| | (m2) | (m2) | (m) | (m3) |
| ① | 1.03 | 22.91 | 10.00 | 229.10 |
| ② | 44.79 | 54.13 | 10.00 | 541.30 |
| ③ | 63.46 | 180.04 | 10.00 | 1800.40 |
| ④ | 296.61 | 274.43 | 10.00 | 2744.30 |
| ⑤ | 252.24 | 201.55 | 10.00 | 2015.50 |
| ⑥ | 150.86 | 140.42 | 10.00 | 1404.20 |
| ⑦ | 129.98 | 109.1 | 10.00 | 1091.00 |
| ⑧ | 88.21 | 76.28 | 10.00 | 762.80 |
| ⑨ | 64.35 | 47.66 | 10.00 | 476.60 |
| ⑩ | 30.96 | 16.09 | 10.00 | 160.90 |
| ⑪ | 1.21 | – | – | – |
| 計 | | | | 11226.10 |

## 2） Planar slice method

V1＝（A①＋A②）／2 × 5m

∑V＝ V1＋V2＋・・・・＋Vi・・・・・・・・＋V11

| 断面<br>Cross section | | 断面積<br>Cross section area | ①②平均<br>1 and 2 average | 延長<br>Extension | 区間体積<br>Section volume |
|---|---|---|---|---|---|
| | | (m2) | (m2) | (m) | (m3) |
| ① | 60m | 1922 | 1444 | 5.00 | 7220.00 |
| ② | 55m盤上 | 965 | | | |
| ③ | 55m盤下 | 1021 | 682.5 | 5.00 | 3412.50 |
| ④ | 50m盤上 | 344 | | | |
| ⑤ | 50m盤下 | 389 | 204 | 5.00 | 1020.00 |
| ⑥ | 45m盤上 | 19 | | | |
| ⑦ | 45m盤下 | 27 | 13.5 | 5.00 | 67.50 |
| ⑧ | 44m盤 | 0 | | | |
| 計 | | 1.21 | – | – | 11720.00 |

※） **Error in calculation method: If the cross-section calculation pitch is made finer, the final value will be the same.**

# 3) Changes in the volume of earthwork during construction

The amount of soil varies depending on the construction conditions.

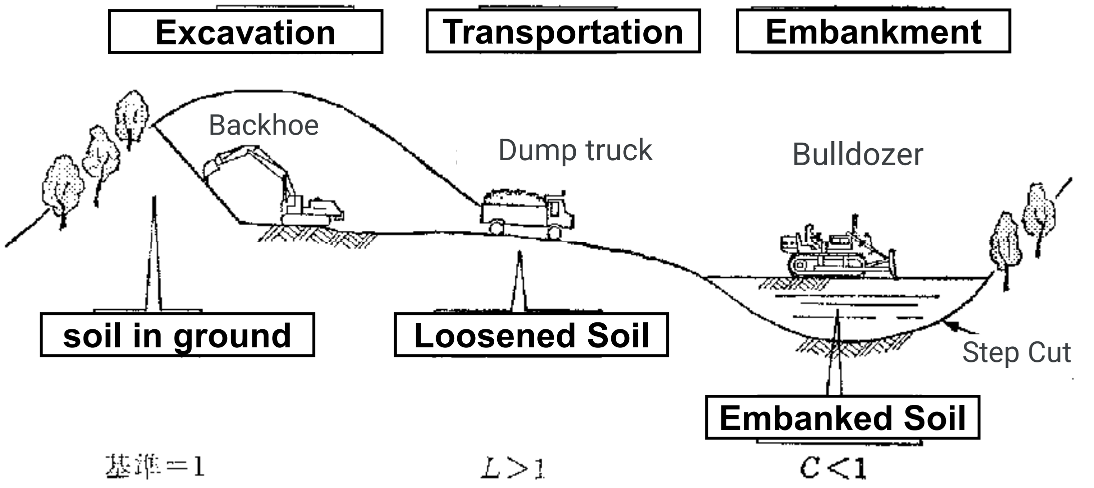



**Table 1 the rate of change in soil volume**

| soil | | L ; Rate of loosened soil | C ; Rate of embanked soil |
|---|---|---|---|
| rock | hard rock | 1.70~2.00 | 1.30~1.50 |
| | medium hard rock | 1.55~1.70 | 1.20~1.40 |
| | soft rock | 1.30~1.70 | 1.00~1.30 |
| gravelly soil | gravelly soil | 1.15~1.20 | 0.90~1.00 |
| | compacted gs | 1.25~1.45 | 1.10~1.30 |
| sand | | 1.10~1.20 | 0.85~0.95 |
| sandy soil | | 1.20~1.30 | 0.85~0.90 |
| clay soil | | 1.25~1.35 | 0.85~0.95 |
| clay | | 1.20~1.45 | 0.85~0.95 |

**This ratio of volume change is called the rate of change in soil volume and is usually expressed as L and C.**

$$L = \frac{\text{Loosened soil } (m^3)}{\text{Amount of soil in ground } (m^3)} \qquad C = \frac{\text{Amount of soil after compaction } (m^3)}{\text{Amount of soil in ground } (m^3)}$$

**【Actual soil volume change】( General earth and sand : when L＝1.2、C=0.95 )**

**① Ground excavation amount：V＝1，000m3** ↓

**②Volume of soil transported：V＝1，200m3 （unraveled amount）**

**⇒ A larger number of dump trucks are required than planned based on the amount of excavated soil.** ↓

**③Embankment amount：　V＝950m3（amount after compaction）**

**⇒ Not enough soil for embankment.**

## Thank you for listening for such a long time.

I hope that by listening to this seminar you will have gained more knowledge about soil quality and that it will be of use to you in road maintenance and repair.

Seminar lecturer: Takashi Horita