MINISTRY OF PUBLIC WORKS AND TRANSPORT

General Directorate of Techniques
Road Infrastructure Department

Bridge Repair Manual

February 2018

Contents

CHAPTER 1 INTRODUCTION

1.1 Purpose of bridge repair ---------- 1-1
1.2 Process of bridge maintenance ---------- 1-3
1.3 Glossary ---------- 1-4
1.3.1 Types of bridges ---------- 1-5
1.3.2 Basic Bridge Configuration ---------- 1-8
1.3.3 Glossary of bridges ---------- 1-10

CHAPTER 2 ORGANIZATION FOR BRIDGE REPAIR

2.1 Outline ---------- 2-1
2.2 Schedule ---------- 2-3
2.3 Jurisdiction ---------- 2-4
2.3.1 Bridge repair ---------- 2-4
2.3.2 Bridge Repair Record ---------- 2-10
2.3.3 Bridge Repair Seminar and Workshop ---------- 2-12

CHAPTER 3 SAFETY AND MAINTENANCE WORK

3.1 For keeping safety repair work ---------- 3-1
3.1.1 Introduction of safety work ---------- 3-1
3.1.2 Confirmation before repair work ---------- 3-4
3.1.3 Confirmation during repair work ---------- 3-7
3.2 Routine maintenance ---------- 3-11
3.2.1 Purpose of Routine maintenance ---------- 3-11
3.2.2 Application Criteria ---------- 3-12
3.2.3 Work Sequence ---------- 3-13

CHAPTER 4 MAINTENANCE ROOM AND BASIC KNOWLEDGE OF CONCRETE

4.1 Maintenance Room ---------- 4-1
4.2 Concrete Material ---------- 4-6
4.2.1 Composition of Concrete ---------- 4-6
4.2.2 Aggregate ---------- 4-7
4.2.3 Cement ---------- 4-8
4.3 Damages due to construction failures ---------- 4-9

4.3.1 Honeycombing and Cavity -- 4-9
4.3.2 Bubble and Sand Texture -- 4-11
4.3.3 Cracking --- 4-12
4.3.4 Cold Joint --- 4-14
4.4 Concrete Work --- 4-16
4.4.1 Requirements of Fresh Concrete materials -- 4-16
4.4.2 Storage --- 4-17
4.4.3 Concrete work --- 4-18
4.4.4 Work and placement of reinforcement -- 4-22
4.5 Concrete quality verification test --- 4-23
4.5.1 Slump test -- 4-23
4.5.2 Air content test -- 4-25
4.5.3 Compressive strength test --- 4-27
4.5.4 Chloride Ion Content Test --- 4-29

CHAPTER 5 REPAIR OF CONCRETE STRUCTURE

5.1 Planning of Concrete structure repair --- 5-1
5.2 Case of Concrete structure repair -- 5-2
C-1 Concrete crack -- 5-2
C-2 Carbon Fiber Cloth (CFC) Reinforcement Method ------------------------------------- 5-12
C-3 Corrosion of reinforcement in concrete pier column ----------------------------------- 5-65
C-4 Damages on concrete pier plinth --- 5-67
C-5 Cavity in the lower flange -- 5-70
C-6 Water leakage from the lower flange -- 5-71
C-7 Cracking damage on slab --- 5-73
C-8 Fracture damage -- 5-77
C-9 Corrosion of man Re-bars in concrete railing -- 5-82
C-10 Vehicle Collision Damage on Concrete Railing -- 5-86
C-11 Longitudinal Crack in the Lower Flange of PC Girder -------------------------------- 5-91
C-12 Concrete Pier Damaged by Alkali-Aggregate Reaction ------------------------------- 5-94

CHAPTER 6 REPAIR OF STEEL STRUCTURE

6.1 Planning of Steel structure repair -- 6-1
6.2 Case of Steel structure repair -- 6-2
S-1 Corrosion on steel girder due to water leakage -- 6-2
S-2 Cracks the jammed part connecting cross beam and vertical stiffener of I-girder - 6-6
S-3 M-Cracks on connected part of gusset or lateral bracing around support of steel I-girder -- 6-10

S-4 Crack at haunch girder -- 6-13
S-5 Steel pier corrosion -- 6-17

CHAPTER 7　REPAIRE OF FOUNDATION OR OTHER STRUCTURE

7.1　Case of other bridge structure repair --- 7-1
J-1 Damage on Expansion joint -- 7-1
J-2 Bridge scour -- 7-12

Attachment

BRIDGE REPAIR WORK JOB SHEET

Code : 1-0001　Concrete Crack Repair
Code : 1-0002　Concrete Defect repair
Code : 1-0003　Carbon Fiber Cloth (CFC) Reinforcement method
Code : 1-0004　Reinforcement by Steel Plate (Concrete structure)

Code : 2-0001　Steel Corrosion Repair
Code : 2-0002　Reinforcement by Steel Plate (Steel structure)

CHAPTER 1 INTRODUCTION

1.1 Purpose of bridge repair

Using a metaphor, the road network which serves for the national socio-economic activities such as logistics, travels and communications, is compared to the vascular network in a human-body (**Fig. 1.1.1**). To maintain a healthy human body, people may check their physical condition daily, and may have some advices from their doctors periodically and then keep their body condition in well, and sometimes people may receive medical treatment or surgery.

It is same manner for road infrastructure for logistics. Therefore, the road infrastructure is essential for Cambodia economy.

Bridges are important parts of road infrastructure. Bridges crossing rivers are vital components of the road network that contribute greatly to the national development and people's daily lives. And damages or collapses of bridges can risk the lives of road users as well as create serious influence to the entire country. Furthermore, the reconstruction of bridges needs considerable amount of money and time. In fact, Ethiopia has experienced many cases of bridge collapse and their serious consequences remain over decades.

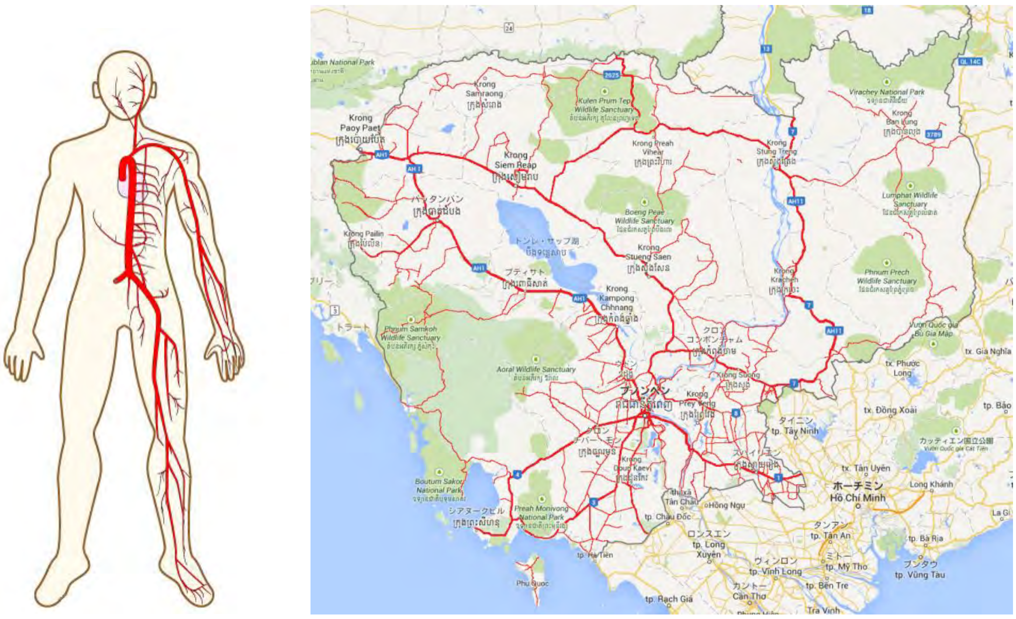


Fig. 1.1.1 Road Network is Equivalent to Blood Vessels

Structure's lifespan is a period of keeping the performance level it is required. And the length of lifespan largely depends on design, quality of construction, with or without the implementation of repair and reinforcement. Although maintenance-free is ideal during the designed lifespan, the period when maintenance is needed is very long. Health of structure is reduced by age, but the lifespan is extendable by appropriate maintenance. Hence, maintenance gives a significant effect on the structure's performance level and lifespan.

It is important for prolonging the lifespan to conduct systematical inspection according to structural type, designed function and required performance level, as well as to detect damage in its earlier stage, to diagnose the cause, to estimate the future progress damage, and to repair it preventively. It is also significant to accumulation the data collected during the maintenance activities.

'**Fig. 1.1.2**' shows a concept of preventive maintenance. Generally, the soundness of structures goes down over years but their condition can be recovered by repair work. If the current condition and the progress of deterioration can be monitored and identified in the early stage, the recovery can be made with minor repairing. However, if the deterioration is neglected until reaching to the minimum standard, major repair work is needed for the whole recovery. In order to reduce the burden of future maintenance to minimize the life cycle cost consequently, constant and timely inspection and repair work are essential.

The purpose of this manual is to describe and introduce **standard repair methods** against defects commonly found in bridges owned and managed by MPWT (Ministry of Public Work and Transport) and DPWT (Department of Public Work and Transport).

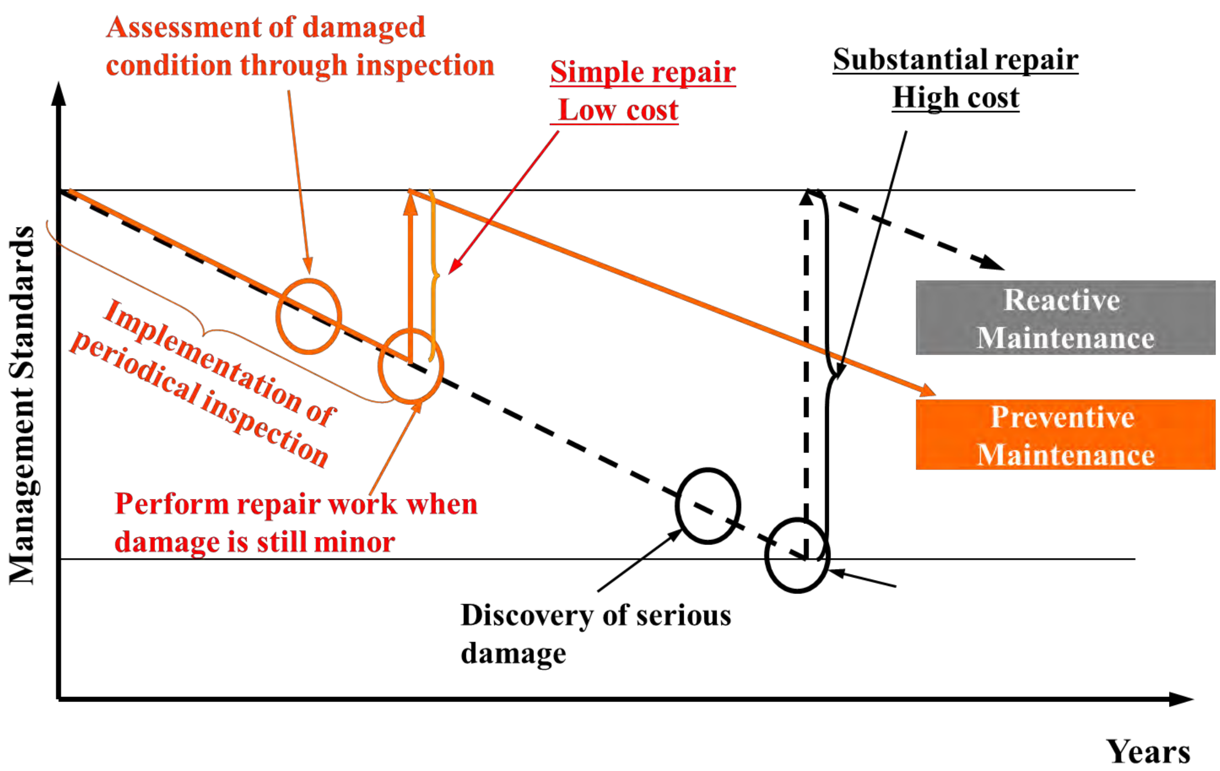


Fig. 1.1.2 Concept of Preventive Maintenance

1.2 Process of bridge maintenance

Structural maintenance is a series of actions which consists of inspection, performance evaluation (diagnosis of defect cause, deterioration prediction), determination of necessity of repairing, work implementation and data recording They all should be carried out promptly based on maintenance plan to ensure structural performance throughout the lifespan.

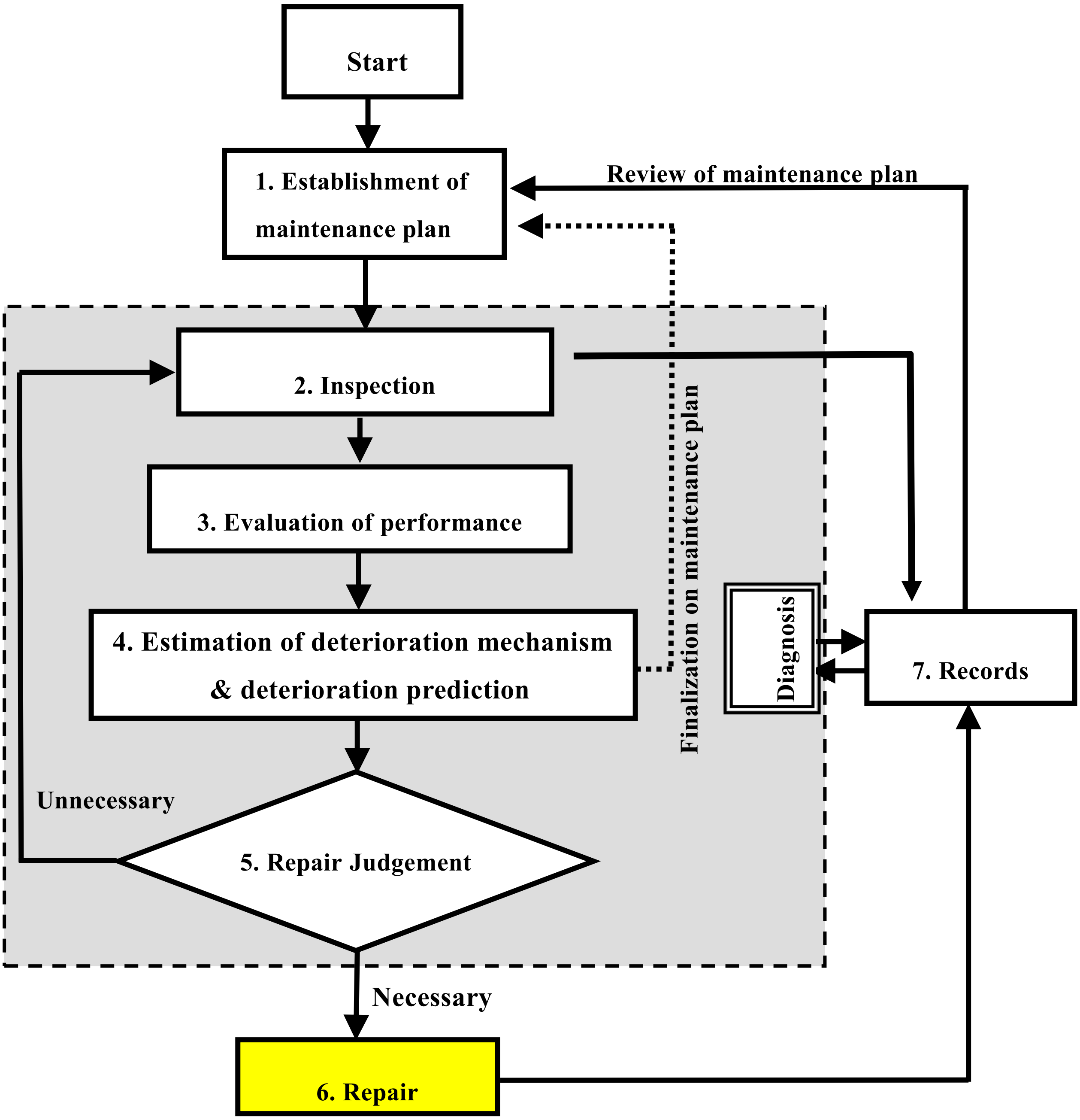


Fig. 1.2.1 Basic Procedure of Bridge Maintenance

1.3 Glossary

Bridge component consists of deck slab, superstructure, bearing and substructure (pier, abutment and foundation) as shown in **Fig.1.3.1** and **Fig.1.3.2.**

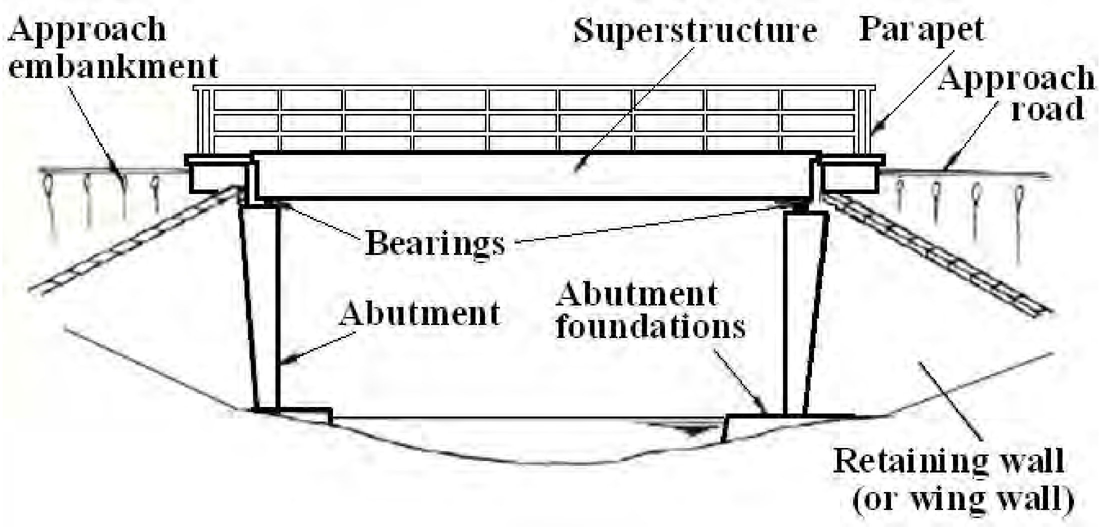


Fig. 1.3.1 Single Span Bridge

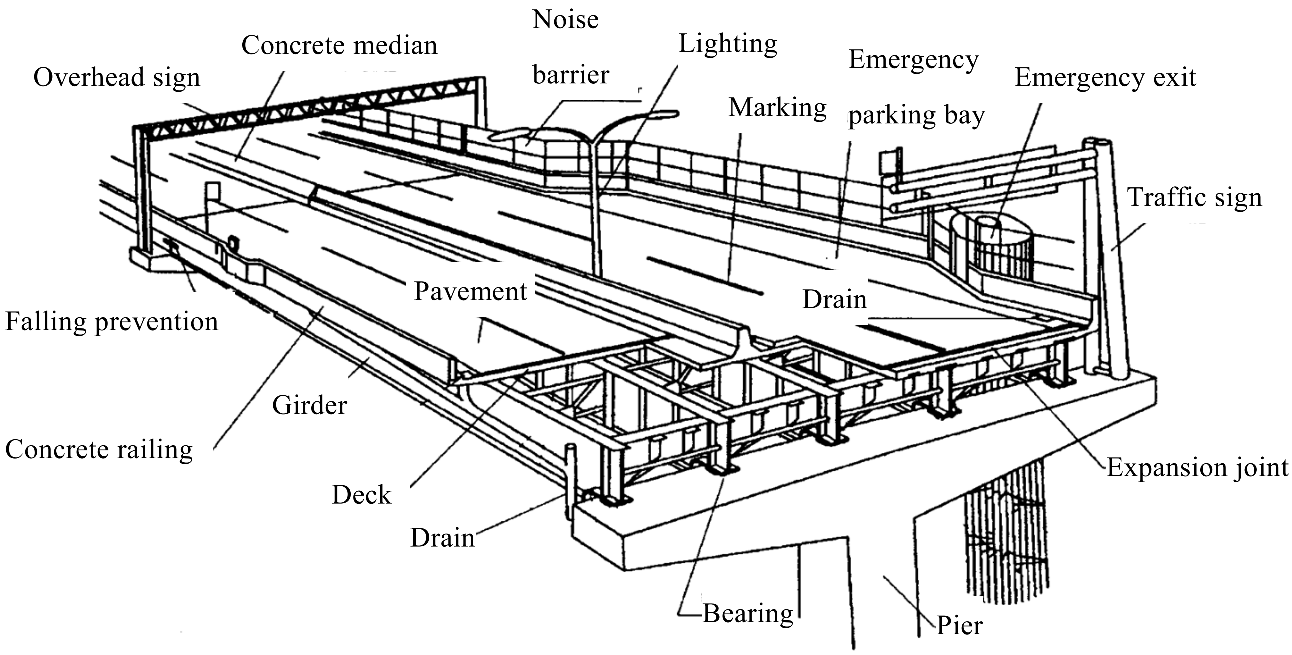


Fig. 1.3.2 Glossary of Bridge Structure

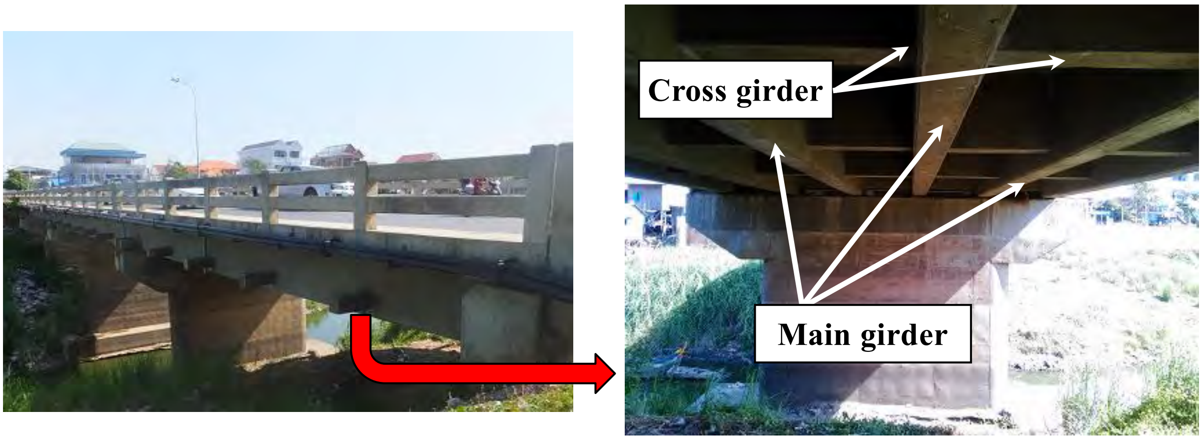


Photo 1.3.1 Girder Components

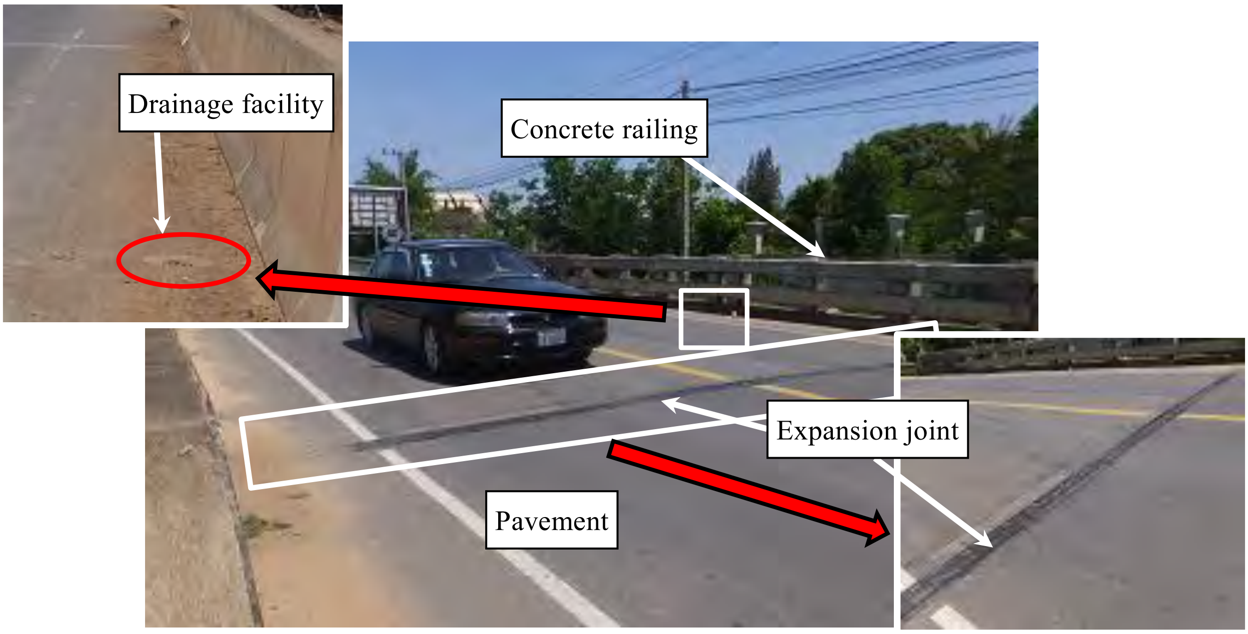


Photo 1.3.2 Superstructure Component on Road Surface

1.3.1 Types of bridges

Bridge configuration consists of two sections: superstructure comprising deck/floor and girder/beam, and substructure supporting superstructure. Type of superstructure is categorized in terms of material and structural feature as follows.

(a) Category by material

1) Steel bridge: Bridge mainly made by steel
2) Reinforced concrete (RC) bridge: Bridge mainly made by reinforced concrete
3) Pre-stressed concrete (PC) bridge：Bridge mainly made by pre-stressed concrete

(b) Category by structural feature

1) Girder bridge

Photo 1.3.3 Box girder bridge

Mechanical feature of girder bridge is that girder is utilized as sole resisting element against bending moment and shear force. I-shaped steel and H-shaped steel are most commonly used for steel bridge and called "Plate girder bridge" (**Photo 1.3.1**). "Composite girder bridge" is the combination of reinforced concrete deck and steel girder resisting integrally against vehicle load.

Bridge with box-shaped girder is called "Box girder bridge" (**Photo 1.3.3**).

2) Concrete deck bridge

Concrete deck bridge is applied for relatively short span bridge since dead load becomes heavier due to its span length. Also, it is advantageous to shortening construction period and saving workload at the site because of its structural simplicity and workability.

Photo 1.3.4 Concrete deck bridge

3) Bailey Bridge

Photo 1.3.5 Bailey Bridge

The Bailey bridge is portable and pre-fabricated truss bridge type. It was invented in UK during the World War II for military use and widely used by both British and the American military engineering units.

It has "through" type of steel deck girder which is situated between and supported by two main girders. The main girders are consisted of 3m-long modular elements each of which can be pinned together for quick assembly

4) Cable stayed bridge

Cable stayed bridge applies pre-stress to continuous girders by cables set up between tower on center pier and girder. Compressive force to the girder and tensile force to the cable are equilibrant on both sides of tower. Though this bridge type used to be most economical for center span of up to 400m, recently it is applicable to the span length of more than 800m. Orthotropic plate members are usually adopted for its deck structure in case of steel girder.

Photo 1.3.6 Cable stayed bridge (Tsubasa bridge)

5) Truss bridge

Truss is a frame structure with members arranged in triangle-geometry and connected each other with pins. Its mechanical feature is that truss members are designed to carry only axel compression or tension force assuming no bending moment generated on them.

Photo 1.3.7 Truss bridge

6) Arch bridge

Arch structure rigidly supports girders from both sides with truss beam with chamber. Arch rib is principal resisting against compressive axle force and bending moment. Bridge which is supported by arch structure is called as “Arch bridge”.

Photo 1.3.8 Arch bridge

1.3.2 Basic Bridge Configuration

(a) Superstructure and substructure

Configuration of bridge is shown in **Fig. 1.3.3**

Superstructure is the main bridge part comprise deck/floor and girder/beam. Substructure supports superstructure and transmits its load to the ground. It comprises abutment, pier and foundation.

Layer of asphalt or Double Bituminous Surface Treatment (DBST) or concrete provides smooth riding surface. (Wearing Surface)

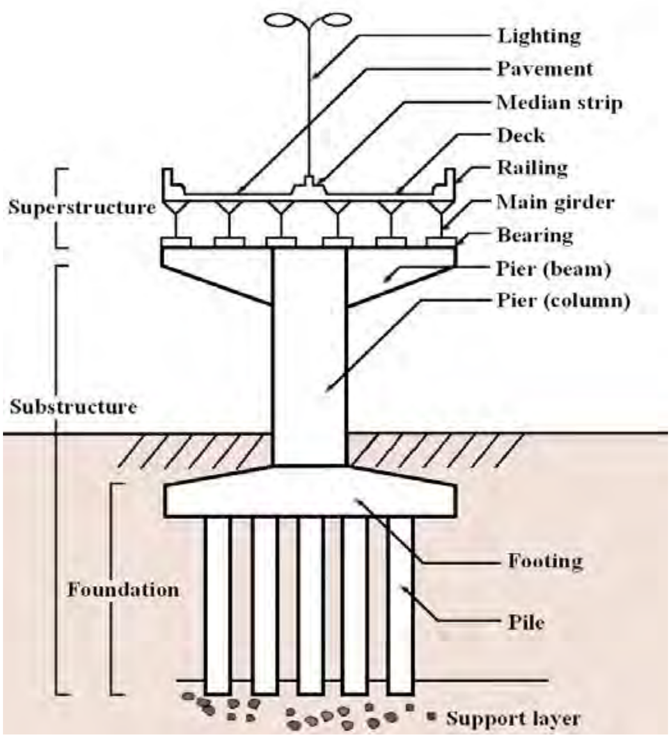


Fig. 1.3.3 Configuration of bridge

(b) Bearing

Generally, bearing intermediates connection of bridge girder and pier. Bearings sustain vertical load such as dead load or live load from the superstructure as well as lateral load by wind or earthquake.

Photo 1.3.9 Bearing

(c) Deck plate and floor system

Deck plate is one of the structural components sustaining live load directly and transmitting it to girder directly or through floor system. It comprises reinforced concrete deck slab, pre-stressed concrete deck slab or orthotropic steel deck slab. Pavement is applied on it.

(d) Lateral bracing and sway bracing

Girders are connected each other with truss structure such as lateral bracing on lateral direction and sway bracing on vertical direction. Lateral bracing resists against wind and seismic force and sway bracing avoids cross-sectional deformation.

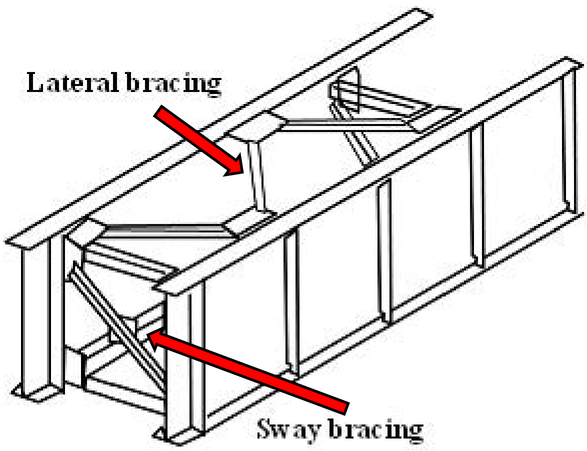


Fig. 1.3.4 Bracing

(e) Road furniture

1) Drainage facility

Photo 1.3.10 Drainage facility

In order to collect and smoothly lead rainwater on the bridge down to the ground, drainage pits are set on a certain interval on the bridge surface. Rainwater is induced from the drainage pit to ground along girder and pier with polyvinyl chloride drainage pipe.

2) Expansion joint

Photo 1.3.11 Expansion joint

Expansion joint allows displacement of girder due to temperature change and keeps flatness of road surface. In addition, it has a function of drainage. Generally, joint type is selected depending on the assuming girder displacement. Rubber and steel finger type are mainly used.

1.3.3 Glossary of bridges

There is a list of engineering words that are used in this manual and their meanings.

(______ : Important Word)

Abutment – end support of the superstructure of bridges and usually have the additional functions of retaining earth fill for the bridge approaches**. (Fig. 1.3.1)**

Approach Embankment – the earth work or earth fill that forms a transition road up to the bridge abutment. **(Fig. 1.3.1)**

Approach Road – the road near abutting the bridge. **(Fig. 1.3.1)**

Bank Seat Abutment – an abutment set well up the river bank; above the usual river level.

Barrel – the main part of an arch which supports fill and roadway.

Beam – a narrow structural member such as girders, stringers, floor beams, cross beams (diaphragms), edge beams, etc.

Bearing – the part between the superstructure and the coping of pier or abutment. It transmits the load from the superstructure to the substructure and may be movable or fixed depending on the allowed degree of movement. (**Photo 1.3.9**)

Bearing Bolt – type of fixing for joints in steel or timber.

Bearing Shelf – part of the abutment, where the superstructure rests.

Boom – the upper (top chord) and lower (bottom chord) longitudinal members extending the full length of a truss.

Box Girder – a hollow beam with box shape**. (Photo 1.3.3)**

Bracing – parts of a bridge which help to resist lateral forces and keep it stiff so as not to change shape, e.g., lateral braces and sway braces in steel truss and steel Deck Girders.

Bulging – where a flat place changes shape and is bent.

Camber – the slight convexity (curve) required for construction of bridges, provided to compensate for the dead load deflection.

Caissons – type of masonry or concrete foundations, built like a tube**.**

Cantilever – a beam, fixed at one end and free to move at the other**.**

Compression – being pushed together.

Corrosion

Corrosion - It is the gradual destruction of materials (usually metals) by chemical reaction (more stable oxide).

Corrugated Steel – thin sheet of steel which have been shaped to make strong**.**

Cross Beam – commonly called FLOOR BEAMS, the beams that connect two trusses wherein the stringers are connected.

Debris – rubbish and other unwanted things.

Decay – rotting of wood, making it soft and weak; caused by dampness and fungus.

Deck Slab – top of bridge superstructure. This allows bear vehicular loads directly. (**Fig. 1.3.3**)

Deformation - Permanent deformation of steel members can take the form of bending, buckling, twisting or elongation, or any combination of these.

Delamination - defined as a discontinuity in the surface concrete which is substantially separated but not completely detached from concrete below or above it.

Diaphragm – a beam connecting the girders of concrete and steel deck girder bridge

Disconnection - Loose or defected joints can seriously affect the strength of the timber bridge.

Disintegration - the physical deterioration or breaking down of the concrete into small fragments or particles.

Downstream – where the river flows away from a bridge.

Drainage – system for taking away water (usually rainwater) **(Photo 1.3.9)**

Embankment – soil bank which supports the roadway pavement.

Fill – soil placed in front of the abutment.

Fixed (Fixed Bearing) – not able to move.

Flange – the top and bottom plates of a girder; the enlarged top/bottom portion of a concrete Deck Girder e.g., an AASHTO Standard I-section and steel I-Beam for steel girder bridge.

Foundations – the lowest part of the bridge which sits or in the ground. (**Fig. 1.3.3**)

Fretting -This defect is caused by the loss of cementing or binding agents by leaching due to the percolation of water through the structures.

Gabion – wire basket filled with stones.

Galvanizing – a thin layer of zinc on steel to protect it against corrosion.

Gabion

Girder – a beam usually made of steel and reinforced concrete. **(Fig. 1.3.2)**

Groyne (or Spurdike) – a wall built to change the flow of a river and protect the river bank from scour.

Headwall – a wall at the end of a culvert to hold the soil fill above the culvert pipe.

Honeycombing – badly made concrete with lots of holes.

Honeycombing

Impact – to hit hard, as when a vehicle hits a bridge parapet.

Curb – the step between the road and Sidewalk.

Landslide – soil and rocks slipping down a mountain or hill.

Loose connections - Loose tightening or missing in bolted or riveted connections

Lubrication System – a system to supply oil or grease to a mechanical bridge bearing.

Curb

<u>Maintain (as in Well Maintained)</u> - to look after carefully and repair when it is necessary

Masonry – bricks or stones set together with mortar.

Mass Concrete – concrete without any steel in it.

Moisture – some water or dampness.

<u>Overloaded</u> – carrying too much weight.

Overloading

Panel – a flat frame or plate**.**

Parapet – a wall or rail along the edge of bridge.

<u>Rebar</u> – steel bars in reinforced concrete, to make it stronger.

<u>Pier</u> – a support between abutments for bridges with more than one span. (**Fig. 1.3.2**)

<u>Pile</u> – a long, thin, foundation driven deep into the ground; bored pile - a cast-in-place pile. (**Fig. 1.3.3**)

Piled Walls – walls made of long pieces of material driven into the ground.

<u>Plate</u> – a flat, stiff piece of steel.

Pointing – the mortar between bricks or stones on masonry.

Pre-stressed – a way of making concrete stronger with pre-stressing steel bars or cables.

PTFE – a slippery white material used in bearings.

Rendering – a thin layer of mortar put on masonry or brickwork to protect it.

Reno Mattress – a long thin gabion.

Retaining Wall – a wall to hold back soil.

River Bed – the bottom of the river.

Riprap – layer of loose rocks to protect the river bank from scour.

<u>Rust</u> - Usually red oxide formed by the redox reaction of iron and oxygen in the presence of water or air moisture.

Safety Pins – the small clips on a bailey bridge, that stop the panel pins from falling out.

<u>Scaling</u> - the local flaking or loss of the surface portion of concrete or mortar.

Scaling

<u>Scouring</u> – erosion of the river bed or bank caused by the flow of the river.

Scouring

Seating – the place where one-part rest on another part. For example, the place where a bearing is set on a pier or abutment.

Services – cables and pipes for service facilities and utilities such as water, electricity and tele-communication belonging to other authorities.

Settlement – small movement downwards of a structure.

Sheet Piled Wall - a wall made from steel panels, concrete piles or timber bored hammered into the ground to form a wall.

Shrinkage (in Timber) - Shrinkage happens when the timber dries up below its fiber saturation point.

<u>Slab</u> – a large piece of concrete (For example a bridge deck).

Spacer Plates – plates which are put between two other parts.

Spall – to break off in a piece.

Spalling – an area where concrete has broken away; e.g. due to corrosion of reinforcing steel bars.

<u>Span</u> – the part of a bridge, or the distance, between the supports; span length refers to the length of a bridge.

Spandrel Walls – the side walls of a masonry arch bridge.

Splitting - Splitting happens when the interior member remains above the fiber saturation point while the outer layers shrink.

Spread Foundations – wide base to a pier or abutment, usually made of reinforced concrete.

<u>Stiffener</u> – in a steel plate girder, in prevents buckling of the web due to bending; also bearing stiffeners which are provided directly over the bearing in a steel plate Deck Girder to prevent buckling of web as well as to prevent bending failure of the bottom flange.

Stone Pitching – stones set in cement mortar to cover a sloping or an invert.

Stringer – a horizontal deck member.

Structural Member – all members which contribute to the structural integrity of a bridge.

Substructure – all parts of a bridge below the bridge seats, or below the springing line of arches, and including abutments, piers, wingwalls and bents below the level of the top of cap. (**Fig. 1.3.3**)

Superstructure – all of the deck, including parapets, trusses, beams and running surface. (**Fig. 1.3.3**)

Suspended Span (or Drop-in Span) – the middle span of a cantilever bridge.

Tension – pulling apart.

Upstream – the direction where the water is coming from.

Vibration – repeated small movements caused by a heavy vehicle or perhaps an earthquake.

Web – the part of a girder that joins the top and bottom flanges**.**

Weephole – a hole to allow water to come through.

Wingwalls – walls which are at the side of the abutments and part of it.

【Definition of Terms】

Maintenance – All engineering work provided to maintain structures' performance at the required level or higher, sometimes simply called, "maintenance"

Required Performance – Performance required for structures based on the purpose and the function

Scheduled Maintenance – Necessary measures are selected in accordance with the evaluation and determination that are made based on the inspection and the examination of maintaining the structure's required performance so as to optimize LCC (life cycle cost). Maintenance is scheduled so as to prevent it from being concentrated in a certain period of time. (Preventive maintenance and corrective maintenance are included.)

Life Cycle Cost (LCC) – Total costs required for future maintenance and operation (This is abbreviated to LCC.)

Preventive Maintenance – Operation and maintenance that are implemented for the purpose of preventing deterioration which results in the degradation of structure performance

Corrective Maintenance – Operation and maintenance that are implemented in accordance with the degradation of structure performance

Scheduled In-service Period – Planned period that a structure is intended to be in service, which is subject to change in accordance with the reviewed maintenance plan.

Design Service Period – Period that a structure or member should fully carry out its function.

The period is decided during the design phase.

Remaining Scheduled In-service Period – Period from inspection or study to the end of scheduled in-service period

Remaining Design Service Period – Period from inspection or study to the end of design service period

Function of Structure (Member) – Function that the structure (member) carries out in accordance with the purpose or requirement

Performance of Structure (Member) – Performance that the structure (member) exercises in accordance with the purpose or requirement

Durability – Resistance held by the structure against degradation over time, caused by deterioration of materials in the structure under normal conditions

Safety – Structure performance that prevents lives and property of users and third parties from being harmed

Usability – Structure's Performance that enables users to use the structure problem free or that prevents negative impacts to the surrounding environment, and performance for the purpose of properly maintaining other functions required for the structure

Impact on Third Parties – Degree of impact on property or injury of a person caused by falling concrete pieces that separated from the structure

Inspection – Collective term for diagnostic examinations to discover any abnormalities on the structure or members

Monitoring – To observe conditions of structures and members through sensors mounted on structures and members

Repair – Measures intended to remove impact to a third party or, restore/enhance structure's aesthetic appearance or durability, including measures to restore safety or usability (mechanical performance) to a degree that the structure had when constructed

Reinforcement – Measures to restore safety or usability (mechanical performance) to a higher degree than when originally constructed

Defect – Collective term for initial flaw, damage, and deterioration

Initial Flaw – Cracks, honey comb, and cold joint which occur during construction

Damage – Damage that occurs in a short period time by an earthquake or a collision and does not progress as time passes

Deterioration – Deterioration that progress as time passes.

Soundness – Level of current performance against required performance for the structure

CHAPTER 2　ORGANIZATION FOR BRIDGE REPAIR

2.1　Outline

As described in CHAPTER1, it is important to conduct a routine maintenance of bridge structures for keeping their sound condition and prolong their lifespan, and it is necessary to establish a basic and feasible management cycle as shown in **Fig. 2.1.1** in the management entity.

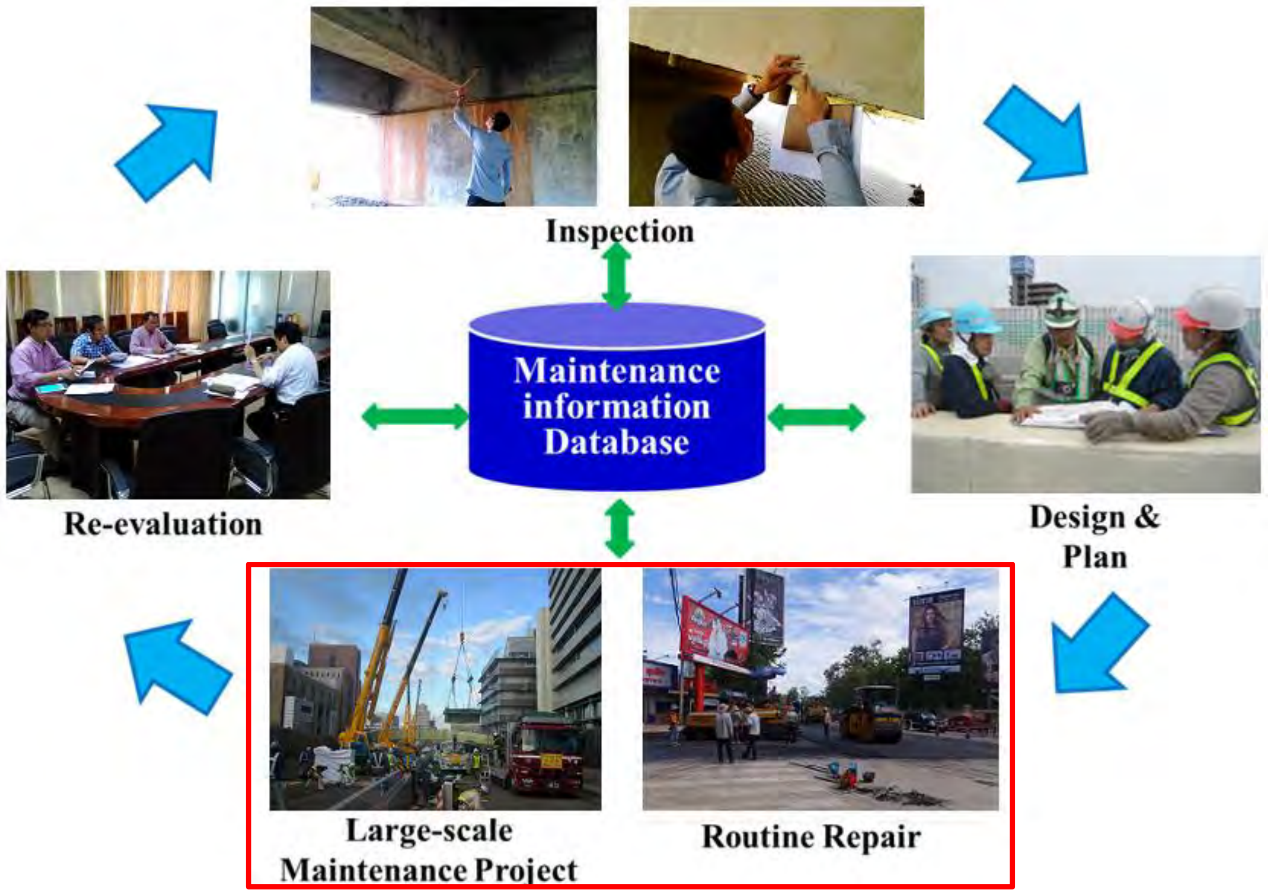


Fig. 2.1.1 Routine Bridge Maintenance Cycle

In order to implement this routine bridge maintenance cycle in a sustainable manner, it is essential to determine in advance the unit in charge in the relevant departments for each segment of the cycle. Furthermore, the range of responsibility and the relevant annual schedule should be prescribed in an official document is useful for sharing the understandings among units.
The following chapters prescribe the field of inspection as a core portion of bridge maintenance and clarify the units in charge of each inspection work and its standard procedures.

It should be noted that each unit is not independent from others and the mutual cooperation is the key for smooth flow of this inspection cycle. Each unit should respond any request from the correspondent units accordingly and sincerely. Also, the request should be given with the deadline and be as concrete as possible.

In addition, in order to exchange and share information, challenging issues, and necessary actions taken in the next step among the relevant units, it is highly recommended to organize regular joint meetings. Here, information on inspection technology is shared, identified damages are briefed and necessary type of repairing intervention is planned.

The organization charts of RID and DPWT are shown in **Fig. 2.1.2**, and **Fig. 2.1.3** respectively.

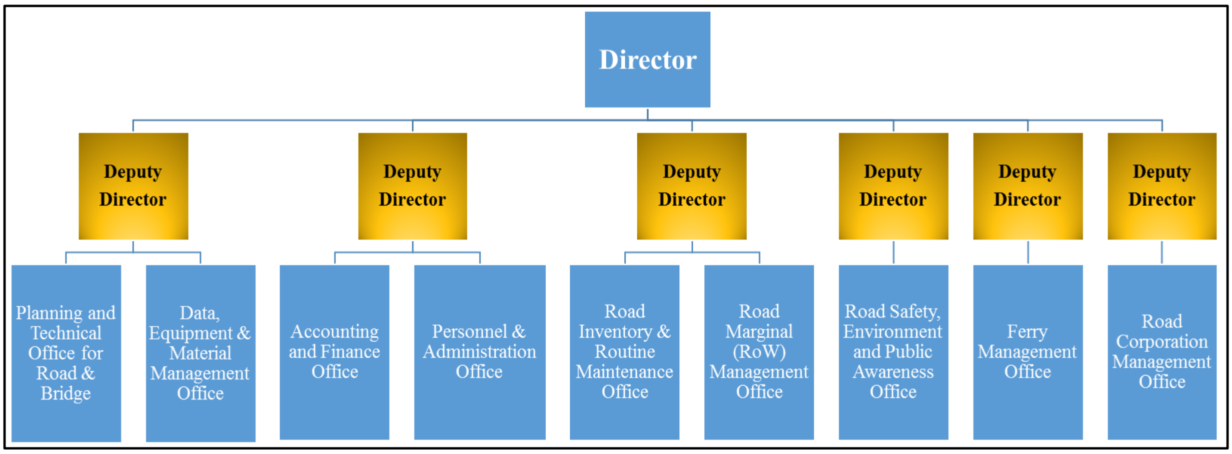


Fig. 2.1.2 Organization Chart of RID

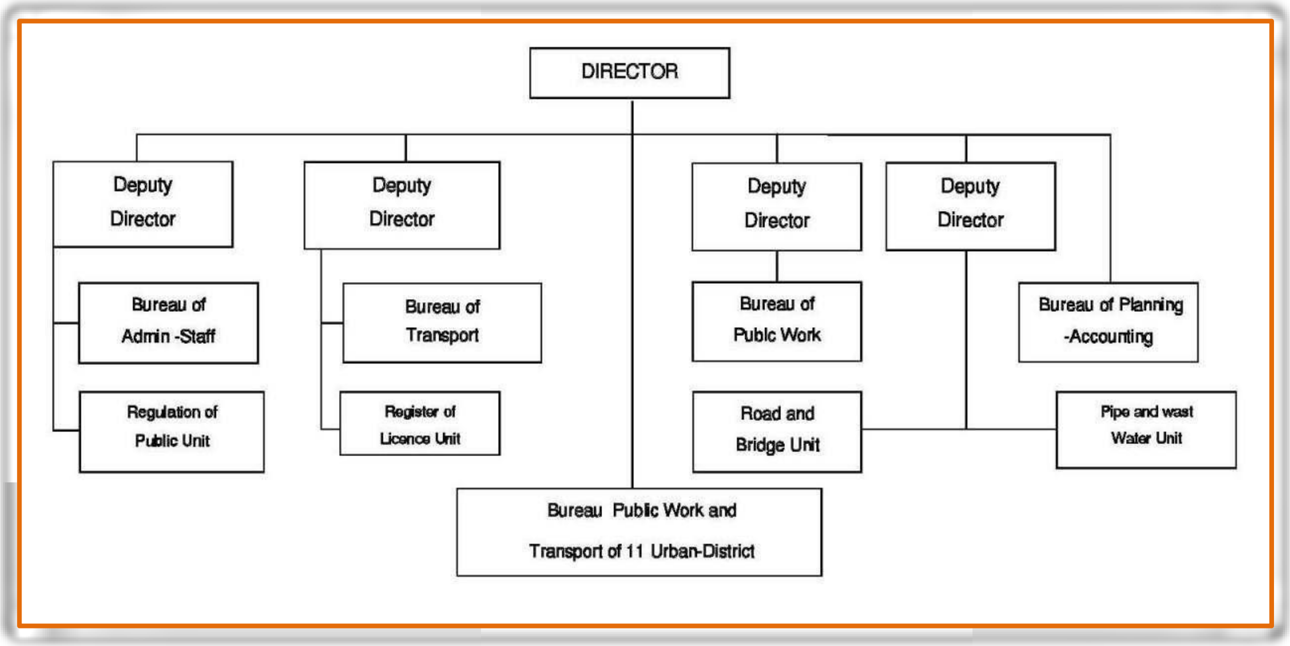


Fig. 2.1.3 Organization Chart of DPWT (In case of Kandal Province)

2.2 Schedule

Annual action plan for bridge repair is shown in **Fig. 2.2.1**. It is preferable to conduct each action by reflecting this schedule.

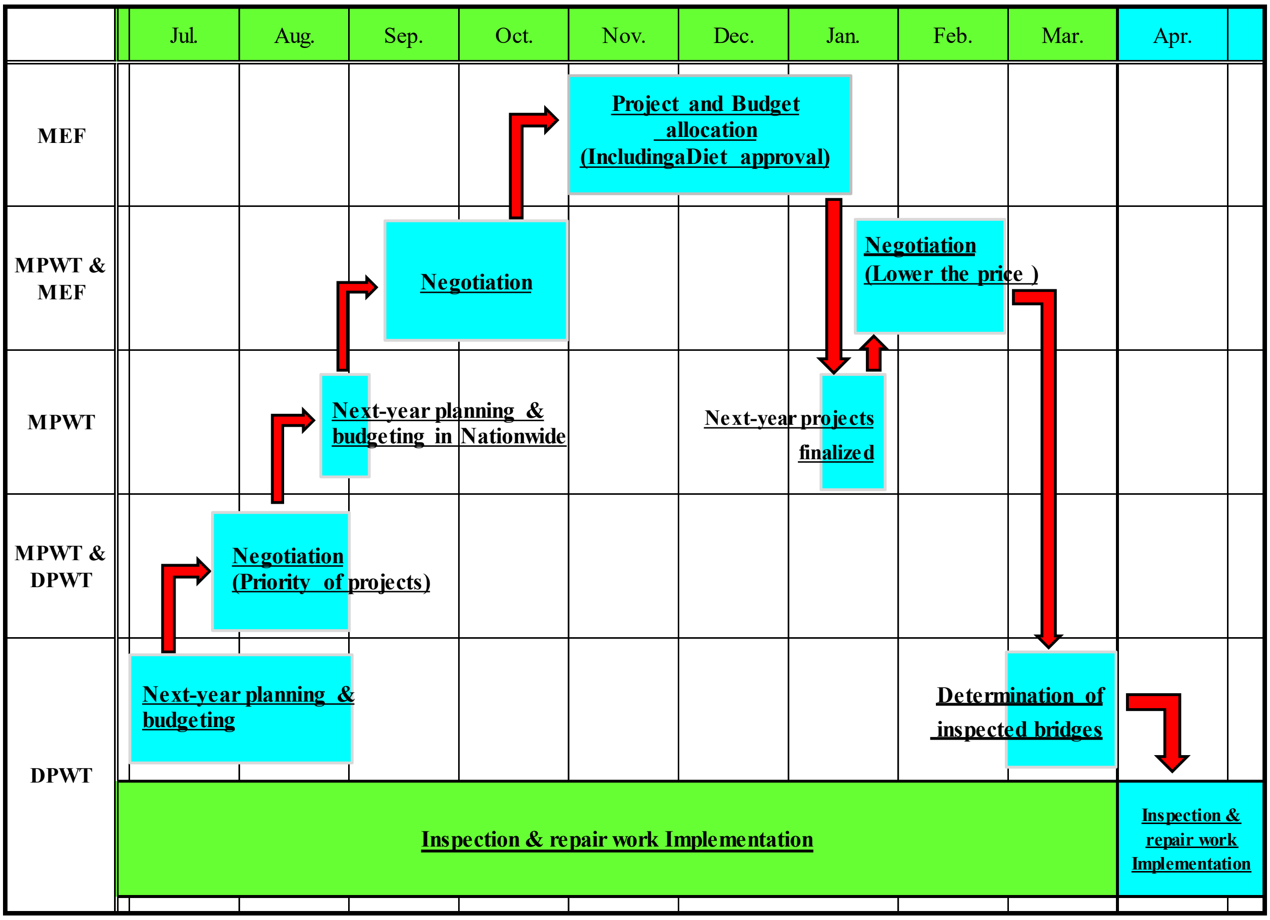


Fig. 2.2.1 Inspection and Maintenance Budgeting Schedule

MPWT: Ministry of Public Work and Transport

DPWT: Department of Public Works and Transportation

MEF: Ministry of Economy and Finance

2.3 Jurisdiction

2.3.1 Bridge repair

When bridge repair is carried out, the following responsibilities of bridge repair are necessary to be assigned to a certain unit.

(a) Annual Implementation Plan

(b) Cost Estimation

(c) Budget Management

(d) Implementation

(e) Technical advisory

(a) Annual Implementation Plan

Annual implementation plan includes bridge repair location, its volume, methodology and schedule. Along with repair budget estimates prepared in (b), the plan is used for budget request and negotiation with MEF. The plan should consider metrological condition like squall and flood and be prepared to secure the efficient implementation.

The unit in charge and the formulation process are as follows:

1) The annual implementation plan is prepared by each **Bureau of Public Work, DPWT** by referring to the inspection database and previous inspection record. The plan shall be sent to **Road Inventory & Routine Maintenance Office of RID, MPWT**.
2) In order to collect necessary information for the negotiation with MEF, **Road Inventory & Routine Maintenance Office** questions to and receives answer from each **Bureau of Public Work** on the content if any.
3) **Road Inventory & Routine Maintenance Office** summarizes the collected information and edited it as a plan.

The rough timing of the abovementioned actions is shown in **Fig. 2.2.1**. The specific deadline of submission shall be informed by **Road Inventory & Routine Maintenance Office** every year.

Table 2.3.1 The unit in charge of Annual Implementation Plan

Content	The unit in charge	Relevant division
1)To Prepare the annual implementation plan	Bureau of Public Work, DPWT	Road Inventory & Routine Maintenance Office of RID
2)To quest and to receives answer about the plan	Road Inventory & Routine Maintenance Office of RID	Bureau of Public Work, DPWT
3)The collected information and edited	Road Inventory & Routine Maintenance Office of RID	Bureau of Public Work, DPWT

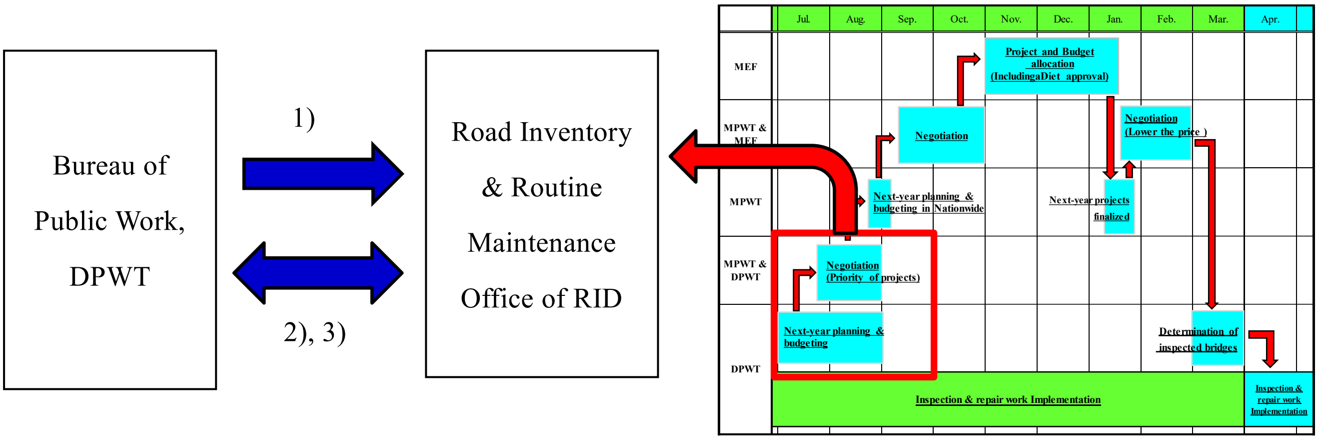


Fig. 2.3.1 Image of Annual Implementation Plan

(b) Cost Estimation

Properly estimated cost is a key reference for the negotiation with MEF. The unit in charge and the formulation process are as follows:

1) The cost shall be estimated by each **Bureau of Planning Accounting, DPWT** based on the annual implementation plan. The estimated cost shall be sent to **Road Inventory & Routine Maintenance Office of RID**.

2) **Road Inventory & Routine Maintenance Office** questions to and receives answer from each **Bureau of Planning Accounting** on cost-related matters if any.

3) **Road Inventory & Routine Maintenance Office** summarizes and edited the bill of quantity document.

The rough timing of the abovementioned actions is shown in **Fig. 2.2.1**. The specific deadline of submission shall be informed by **Road Inventory & Routine Maintenance Office** every year.

Table 2.3.2 The unit in charge of Cost Estimation

Content	The unit in charge	Relevant division
1) To estimate the cost	Bureau of Planning Accounting, DPWT	Road Inventory & Routine Maintenance Office of RID
2)To quest and to receives answer about the Cost Estimation	Road Inventory & Routine Maintenance Office of RID	Bureau of Planning Accounting, DPWT
3)To summarize and to edit the estimation	Road Inventory & Routine Maintenance Office of RID	Bureau of Planning Accounting, DPWT

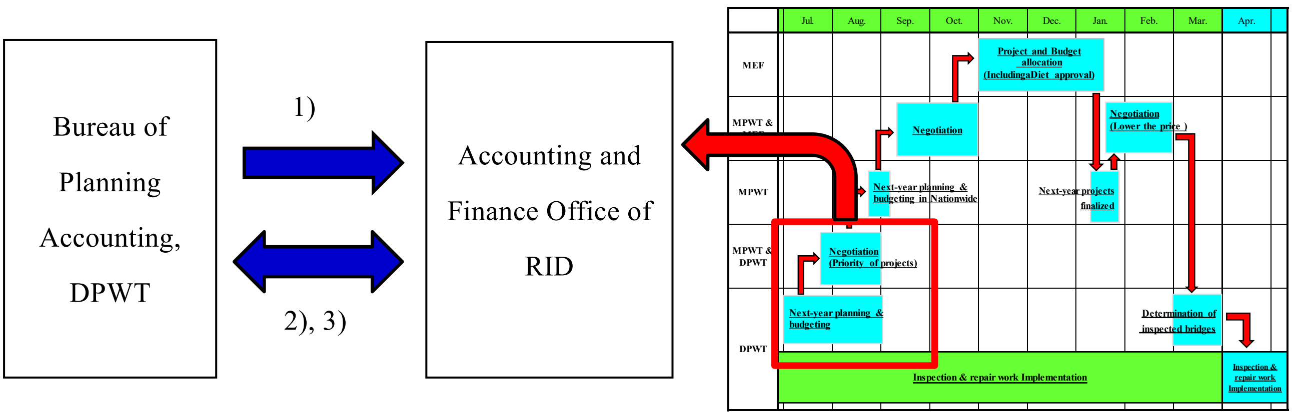


Fig. 2.3.2 Image of Cost Estimation

(c) Budget Management

Proper management of the given repair budget prevents from the shortage of repair payment and the consequent negative reaction from MEF, which may cause problems on the next budget request. Therefore, routine check and assurance of budget implementation should be made if any diversion or misuse of the budget to irrelevant purposes occurs. The unit in charge and the formulation process are as follows:

1) **<u>Road Inventory & Routine Maintenance Office of RID</u>** is responsible for the management of overall national budget. And each **<u>Bureau of Planning Accounting, DPWT</u>** manages the budget of jurisdiction in charge.

2) By the end of September, **<u>Road Inventory & Routine Maintenance Office</u>** checks and confirms the balance between budget and actual spending in each **<u>Bureau of Planning Accounting</u>**. If any shortage is identified, **<u>Road Inventory & Routine Maintenance Office</u>** shall conduct the budget reallocation.

Table 2.3.3 The unit in charge of Budget Management

Content	The unit in charge	Relevant division
1) Management of overall national budget	Road Inventory & Routine Maintenance Office of RID	Bureau of Planning Accounting, DPWT
2)To checks and to confirm the balance between budget and actual spending	Road Inventory & Routine Maintenance Office of RID	Bureau of Planning Accounting, DPWT

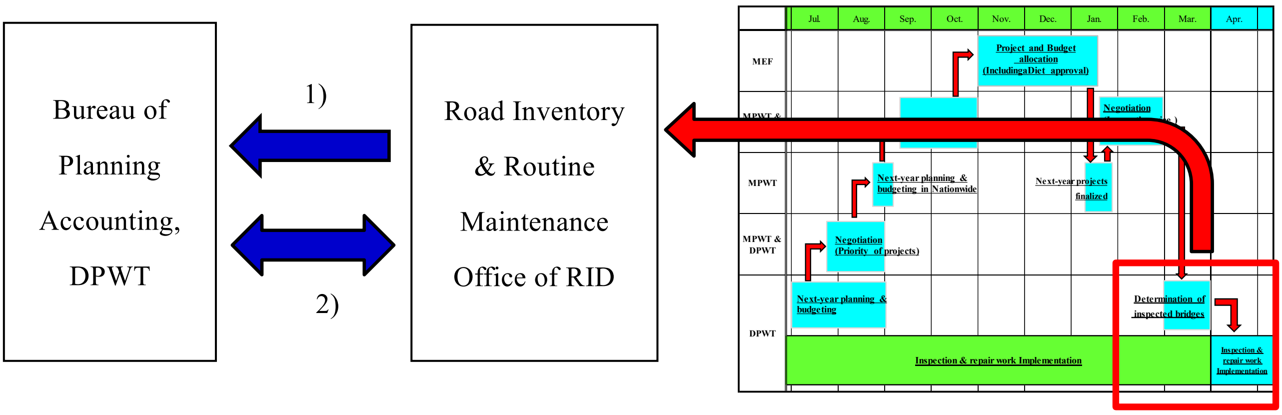


Fig. 2.3.3 Image of Budget Management

(d) Implementation

Repair methodologies are shown in '**CHAPTER, 3, 4, 5, 6, 7**'. The unit in charge and the formulation process are as follows:

1) Bridge repair is conducted by designated repair staffs belonging to each **Road and Bridge Unit, DPWT** regardless of the presence or absence of damages, **Repair workers** must register and input the inspection and repair results in the Bridge Inspection Database System.
2) For the repair budget management, each **Road and Bridge Unit** must report the actual repair cost to the **Bureau of Planning Accounting, DPWT** within one week after the payment.
3) If any excessive spending is assumed, the **Road and Bridge Unit** must report to the **Bureau of Planning Accounting** in advance.

Table 2.3.4 The unit in charge of Implementation

Content	The unit in charge	Relevant division
1) To conduct bridge repair	Road and Bridge Unit, DPWT	—
2) To report the actual repair cost	Road and Bridge Unit, DPWT	Bureau of Planning Accounting, DPWT
3) The report repair cost (In case of excessive spending)	Road and Bridge Unit, DPWT	Bureau of Planning Accounting, DPWT

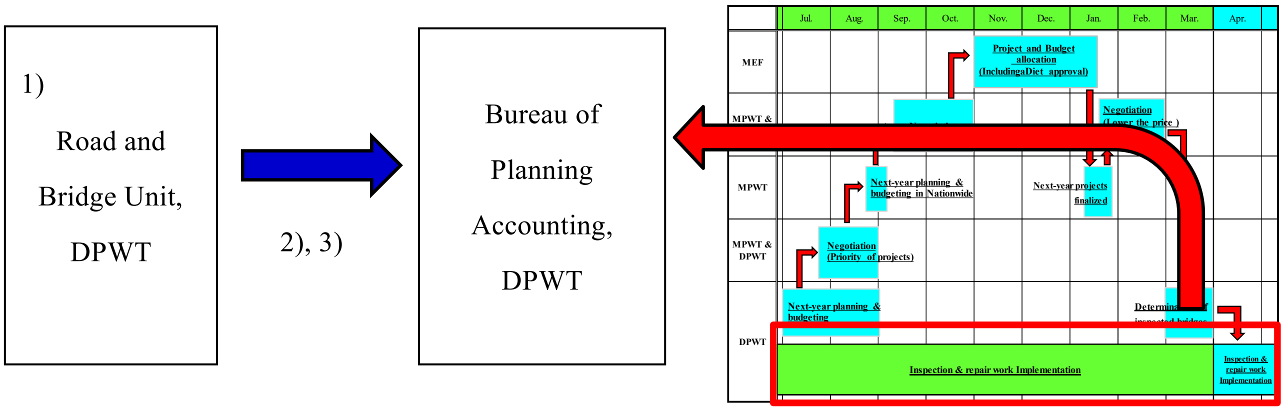


Fig. 2.3.4 Image of Implementation

(e) Technical Advisory

When a new structural material is introduced on a certain bridge and repair staffs need some technical guidance on the repair methodology, they can contact the designated department for technical advice. The unit in charge and the formulation process are as follows:

1) **Planning and Technical Office for Road & Bridge of RID** and **Road Inventory & Routine Maintenance Office of RID** are responsible for the technical advisory
2) **Planning and Technical Office** and **Road Inventory & Routine Maintenance Office** shall record the consultation contents for the future reference to the similar cases and the basic information for the revision of Bridge Repair Manual.

Table 2.3.5 The unit in charge of Technical Advisory

Content	The unit in charge	Relevant division
1) Technical advisory	Planning and Technical Office for Road & Bridge of RID / Road Inventory & Routine Maintenance Office of RID	DPWT, MPWT
2) To record the consultation contents	Planning and Technical Office for Road & Bridge of RID / Road Inventory & Routine Maintenance Office of RID	DPWT, MPWT

2.3.2 Bridge Repair Record

The results input in the Bridge Inspection Database System include not only inspection result but also repair result. If the updating of the Bridge Inspection Database System does not carry out for repaired bridges, they remain registered as the damaged ones. In this case, it may influence negatively on plan and bridges budget for bridge repair. Therefore, when bridge repair is carried out, the following responsibilities of bridge inspection are necessary to be assigned to a certain unit.

(a) Data Input of Repair Results
(b) Confirmation of the Data Input
(c) Database Management

(a) Data Input of Repair Results

The unit in charge and the formulation process are as follows:

1) Repair workers in each **Road and Bridge Unit, DPWT** shall be responsible for inputting the repair result data in the Bridge Inspection Database System. It is preferable that the input shall be done on the site right after the repair unless the site condition is not allowed

Table 2.3.6 The unit in charge of Data Input

Content	The unit in charge	Relevant division
1) Inputting the repair result data in the Bridge Inspection Database System	Repair workers (Road and Bridge Unit, DPWT)	—

(b) Confirmation of the Data Input

The confirmation is to make sure that the given budget is properly spent without diversions to any misappropriate cause. This process is helpful for gaining trust relationship with MEF and facilitating the future budget negotiations. The unit in charge and the formulation process are as follows:

1) **The chief of repair team** is responsible for input data confirmation. Intermediate check for the balance between the initial schedule in the repair implementation plan and the actual progress shall be conducted in every December.

Table 2.3.7 The unit in charge of Confirmation

Content	The unit in charge	Relevant division
1) Input confirmation	The chief of repair team	Repair workers

(c) Database Management

The database server of Bridge Inspection Database System shall be in the computer system of the RID. The unit in charge and the formulation process are as follows:

1) **Data, Equipment & Material Management Office of RID** is responsible for the database server management. The server shall be kept activated constantly so that anyone can access to the system and input and reference actions can be made at any time.

Table 2.3.8 The unit in charge of Database Management

Content	The unit in charge	Relevant division
1) The database server management	Data, Equipment & Material Management Office of RID,	—

2.3.3 Bridge Repair Seminar and Workshop

It is very beneficial to share information on new know-hows and technologies and the tendency of damage patterns through seminars and workshops which are held nationwide. Seminars and workshops shall be held in a regular basis in order to build partnerships and network among DPWT staffs.

In addition, it is preferable to establish and promote an information sharing mechanism in each DPWT. The unit in charge and the formulation process are as follows:

1) **Planning and Technical Office for Road & Bridge of RID** is responsible for the organization and implementation of national seminars and workshops.
2) Local workshop an information sharing are carried out by each **Deputy Director, Bureau of Public Work, DPWT** and **Deputy Director, Bureau of Road and Bridge Unit, DPWT.**

Table 2.3.9 The unit in charge of Bridge Inspection Seminar and Workshop

Content	The unit in charge	Relevant division
1) The organization and implementation of national seminars and workshops	Planning and Technical Office for Road & Bridge of RID	MPWT, DPWT
2) To carry out local workshop an information sharing.	Deputy Director, Bureau of Public Work, DPWT Deputy Director, Bureau of Road and Bridge Unit, DPWT	DPWT

CHAPTER 3 SAFETY AND MAINTENANCE WORK

3.1 For keeping safety repair work

3.1.1 Introduction of safety work

Construction site are often exposed to the risk of life compared to other industries.

Fig.3.1.1.1 shows the accident ratio of construction work for the all industries in Japan. Although accident rate of construction work is about 15% in all accidents (all injuries and deaths), it is more fatal and more than half of all accidents are caused by construction.

From this fact, it should be fully aware of the any danger hidden in construction works. Also it is necessary to consider safety measures for repair workers not only during the construction period but also before the commencement of construction. In addition to supervisors understanding it is important to share among and educate engaged workers about the danger of repair work and safety measures.

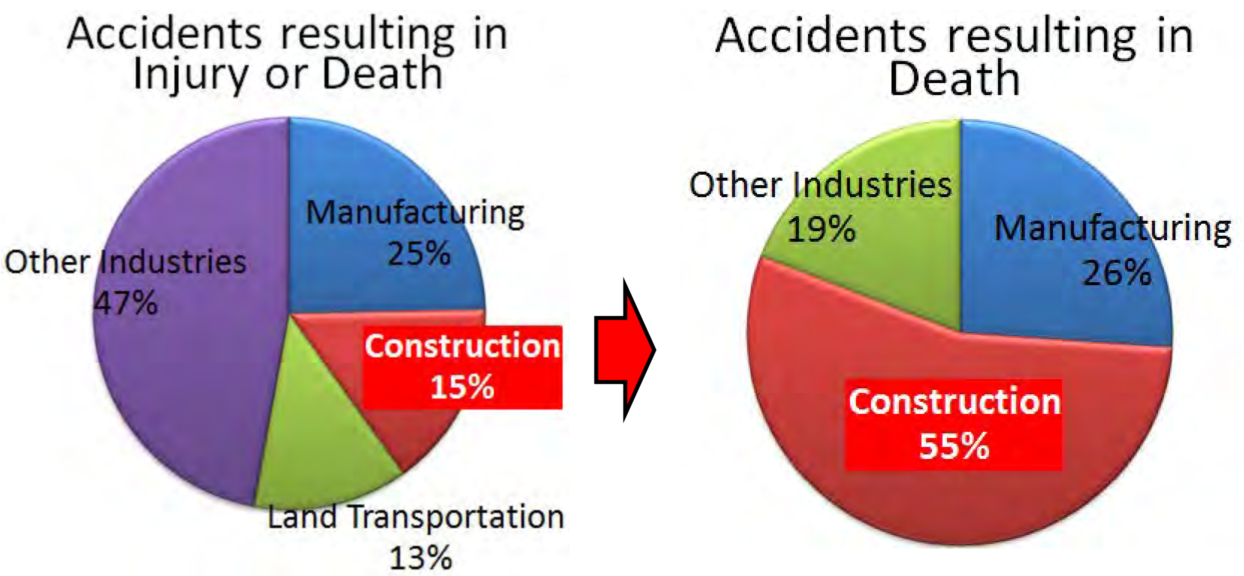


Fig 3.1.1.1 Accidents result in all industries (In Japan)

Fig 3.1.1.2shows the proportion of death cause in construction sites in Japan. Fall', and 'Traffic accident' are the main cause of fatality.

Fall accident of the construction site often occurs when workers are on the high place (**Photo 3.1.1.1**) or when workers are accessing to the vicinity of the bridge (**Photo 3.1.1.2**).

When scaffolding is needed, work floor must not have wide gaps (**Photo3.1.1.3**). In addition, handrails should be attached for fall prevention (**Fig.3.1.1.3**).

And, if possible, it is necessary to provide measures for easy accessing ice to bridge such as temporary step under the bridge (**Photo 3.1.1.2**) or bush clearing around bridge during routine maintenance (cleaning).

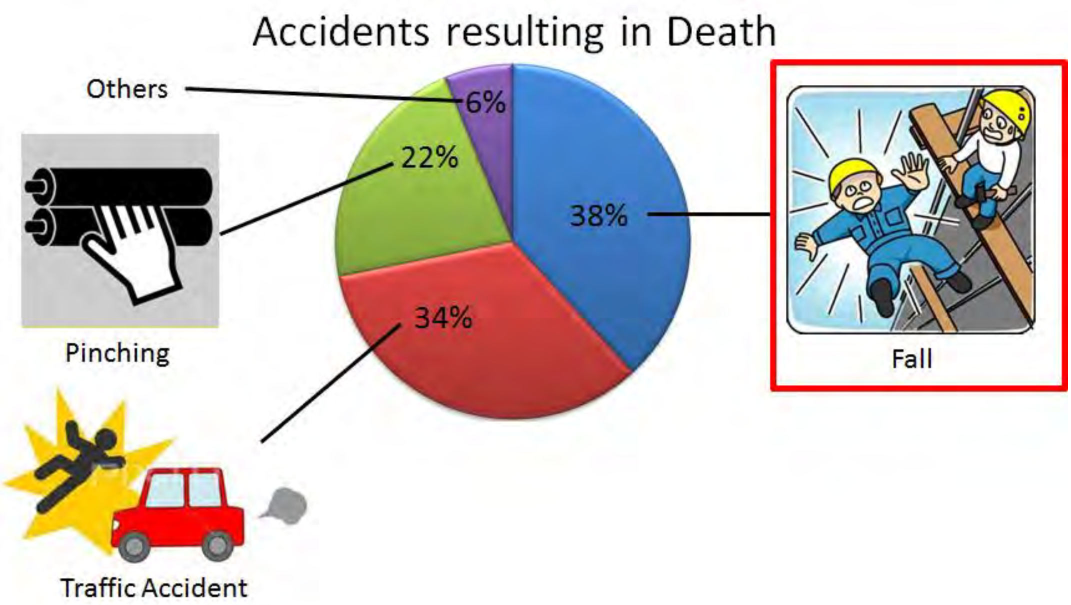


Fig 3.1.1.2 Accidents rate in death (In Japan)

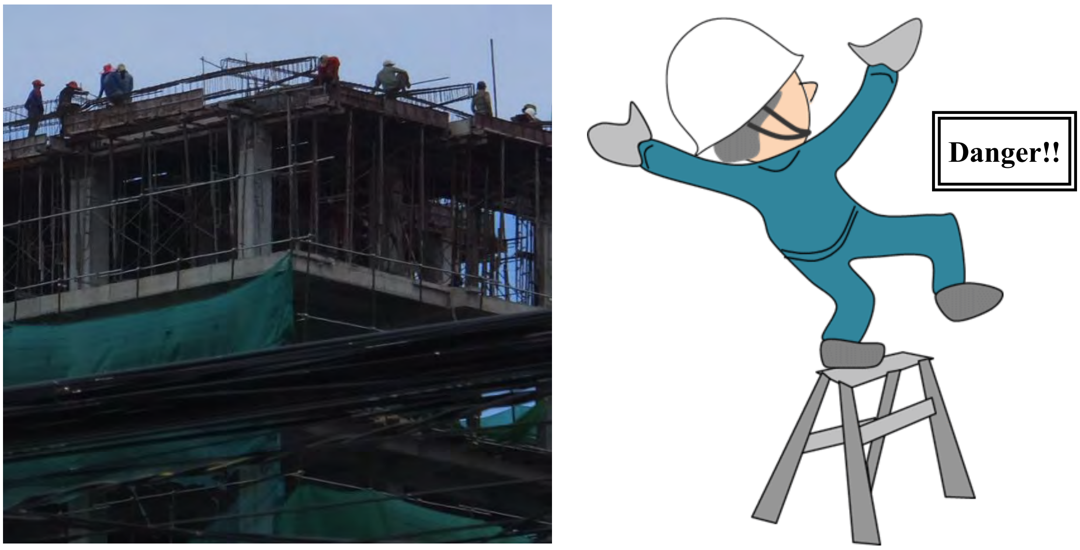
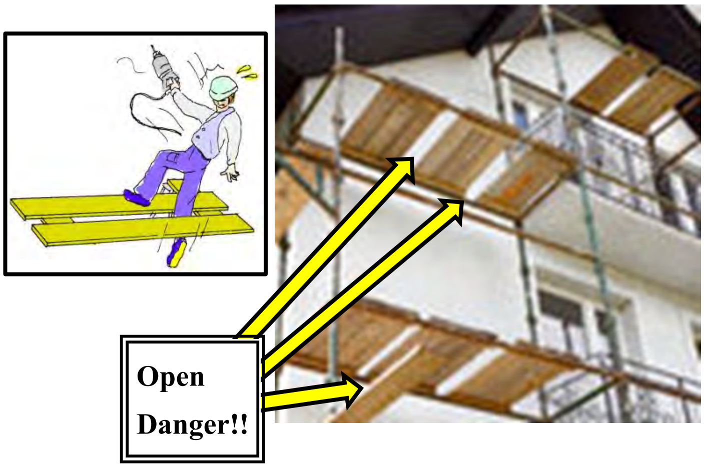


Photo 3.1.1.1 High place work

Photo 3.1.1.2 Steps on the slope



(a) Work floor opening

(b) Handrail of scaffolding

Photo 3.1.1.3 Scaffolding

Fatal traffic accidents occur more often in repair work than construction work because repair work is likely to be conducted near traffic flow (**Photo 3.1.1.4**). As a countermeasure of reducing traffic accident, it is effective to put a “men-at-work” signboard on the road for the extra attention to drivers (**Photo 3.1.1.5**).

Photo 3.1.1.4 Serviced road

Photo 3.1.1.5 Working signboard

Thus, the accident can be reduced substantially if appropriate safety measures are prepared in advance and arranged during the construction period. Also accident is likely to occur when workers get accustomed to work routines and start losing concentration. Supervisor should not be off guard and keep attention even if no accident period continues.

It is essential that repair work should be carried out under the condition where worker safety is completely ensured.
If the worker safety cannot be guaranteed, any work must not be carried out.

3.1.2 Confirmation before repair work

Before repair work is commenced, it is necessary to check the site (**Photo 3.1.2.1**) in order to confirm target damages to be repaired (making the inspection sheet (**Fig.3.1.2.1**)) and how to access to them. Based on the site check, temporary facilities such as scaffoldings, work schedule, tools and material shall be prepared. At the same time, it is necessary to plan the safety management during the work.

Photo 3.1.2.1 Site check (Before repair work)

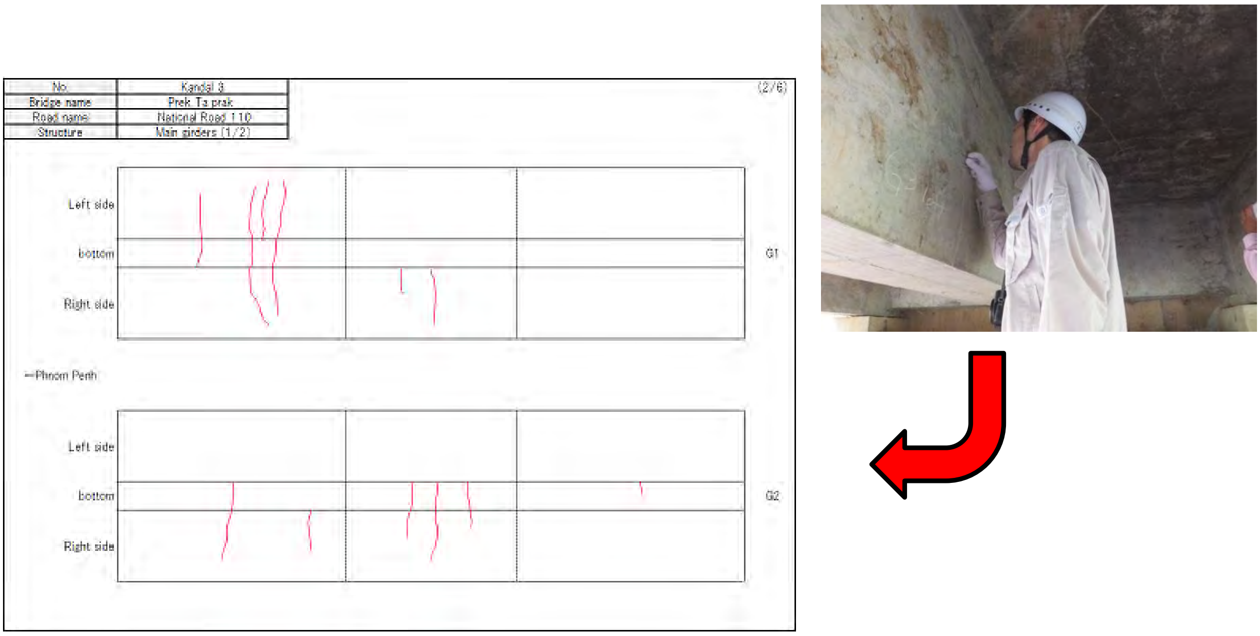


Fig 3.1.2.1 Inspection sheet

After the site check, in order to share the work proceedings and the relevant information among participants, it is better to have a preliminary meeting (**Photo 3.1.2.2**). In this meeting, detail work procedure, schedule, safety measures, number of workers dispatched, material, tools, and assignment of each worker are discussed and confirmed based on newly-obtained knowledge from site check and inspection sheet (**Fig. 3.1.2.1**).

Photo 3.1.2.2 Meeting for repair (Before repair work)

Weeds, bushes and trash on the work site sometimes cause workers to stumble or slip, and make scaffoldings unstable. Also some trash contains hazardous substances such as glass, cutlery and syringes, and they may be hidden under weeds and bushes (**Photo 3.1.2.3**). Therefore, it is important to remove weeds, bushes and trash before repair work. (**Photo 3.1.2.4**)
As it takes considerable time to remove them, this clearing period should be included in repair work schedule, and in some cases it should be done in a day before repair work is commenced.

Photo 3.1.2.3 Hazardous materials in repair site

Fig 3.1.2.2 Hidden holes under the grass

Photo 3.1.2.4 Cutting grass

3.1.3 Confirmation during repair work

All people entering the work site, not only the workers but also the supervisors, must wear the protection helmet (**photo 3.1.3.1**), working shoes or leather shoes (**photo 3.1.3.2**). Sandals are not allowed in the site. Rubber protection gloves (**Photo 3.1.3.3**) should be worn in case of using harmful material harmful to skin.

Photo 3.1.3.1 Protection helmet

(a) Sandal **(b) Working shoes**

Photo 3.1.3.2 Sandal and working shoes

Photo 3.1.3.3 Gloves

Before the repair work, the supervisor have to gather the all workers and have a meeting in order to confirm the procedure of the day's work and caution for safety (**Photo 3.1.3.4**).

Photo 3.1.3.4 Meeting on site before start of repair work

After the site meeting, all members carry out site cleaning at first if necessary (**Photo -3.1.3.5**). Ideally site cleaning should be carried out every day to keep its safe workable condition.

Photo 3.1.3.5 Site cleaning (During repair work)

When scaffolding is set up, ground around its columns should be leveled or column length should be adjusted so that its floorboards are kept horizontal and stable **(Photo 3.1.3.6)**. The floorboards are firmly fixed with the frame and level of different floorboards should be kept even in order to remove the risks of stumbling and falling (**Fig 3.1.3.1**).

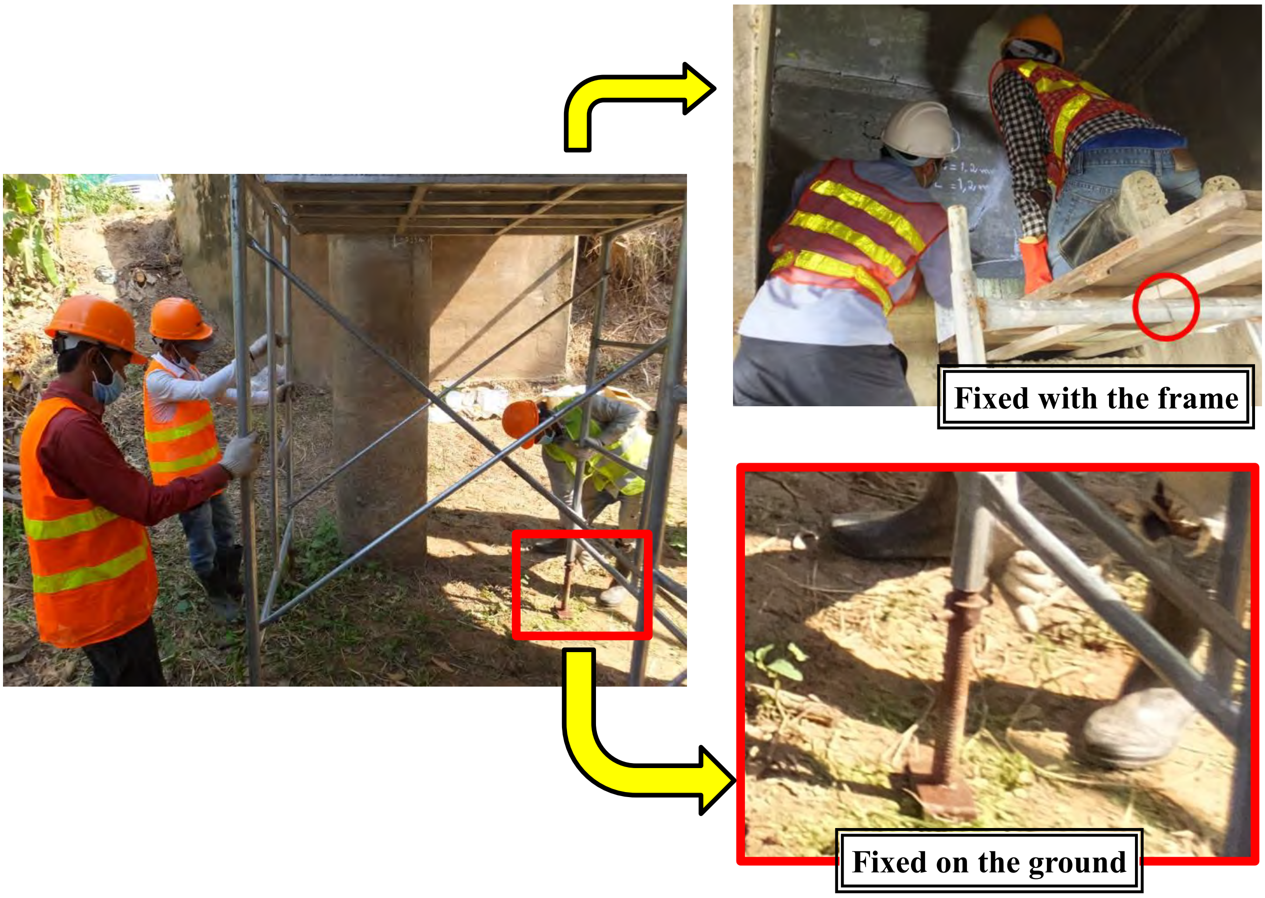


Photo 3.1.3.6 Fixed scaffolding

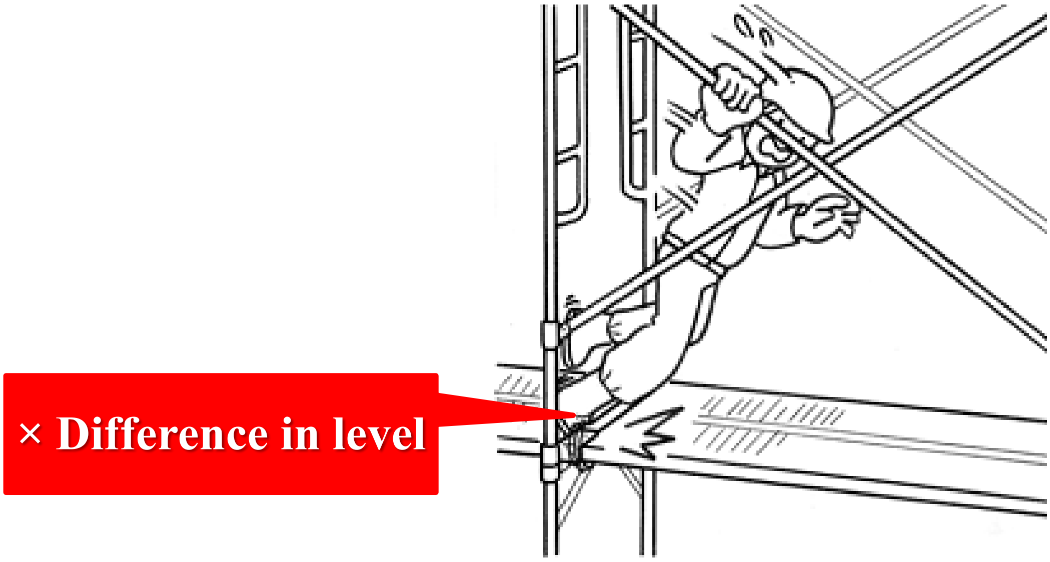


Fig 3.1.3.1 Accident by difference in level

Repair work is commenced after the scaffolding setting. Any worker is refrained from smoking in the work site because there is repair material is highly flammable.
Supervisor should monitor workers actions carefully to make sure there are obeying safety regulations.

The work of the day shall be finished and supervisor shall allow workers to dismiss after the confirmation of the contents of next-day work is done. It should be noted that any waste generated from the work should brought back without leaving in the site.

It is necessary to carefully use repair tools. And after the day's repair work, keep cleaning (Example: By using thinner and paper towel) and take care of repair tools (**Photo 3.1.3.7**).

Photo 3.1.3.7 Keep cleaning and take care of repair tools

3.2 Routine maintenance

3.2.1 Purpose of Routine maintenance

To prevent deterioration of the bridge structure, cleaning works should be performed including removal of all accumulated foreign materials from the entire areas of bridge such as deck, sidewalk, curbs, pier top, truss and web members, lower flanges of beams or girders, expansion joints, bearings, wind bracing and drain facilities. After the cleaning, it is better to be ensured that there is no remaining sand, gravel, dirt, and other foreign materials on the areas.

Especially drainage must be cleaned regularly to prevent from the remnant of rainwater which may often trigger the rusting of structural members.

3.2.2 Application Criteria

The bridge shall be kept clean and in good condition to prolong its service life, as well as to provide safety and comfort to road users. Recommended criteria for cleaning applied to the bridge including its steel surface, deck and substructure are as follows:

a) Bridge Deck Slab

All surface areas of the bridge deck should be cleaned, including the drain pits, curbs, expansion joints and railings. This could be performed using high pressure water blasting or manual shoveling/sweeping works.

b) Bridge Substructure

All areas under the superstructure should be cleaned, including the bearings, parapet wall, pier caps and concrete diaphragms. This could be executed using high pressure water blasting or manual shoveling/sweeping.

c) Surface of Steel Plate

All surface areas of a steel bridge should be cleaned, including the top and bottom part of flanges, web plates, diaphragms, lateral members and gusset plates. This should be washed using high pressure water blasting. Inspection vehicle is utilized effective to carry out cleaning of the high bridge soffit parts.

3.2.3 Work Sequence

a) Bridge Deck and Drainage Cleaning

All foreign materials such as dirt, dust, sand, rain water, and moss on concrete surfaces in the gaps between girders shall be completely removed manually and then washed using a high pressure water bluster. Drainage facilities and expansion joints on the deck should also be carefully cleaned:

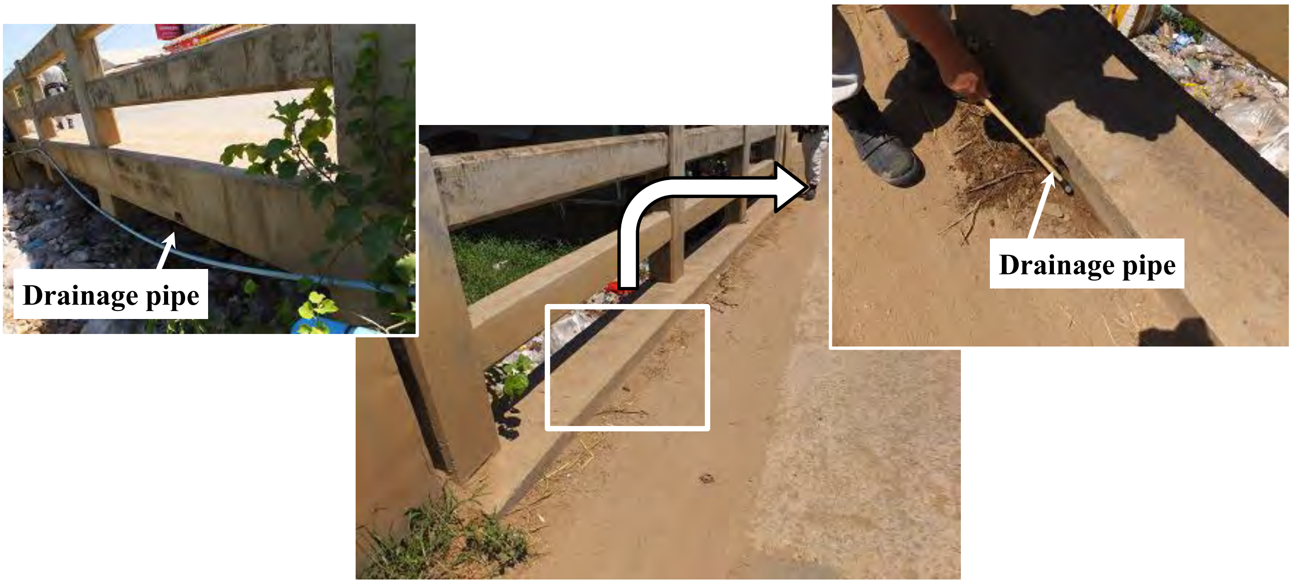


Photo 3.2.3.1 Clogged drainage facility

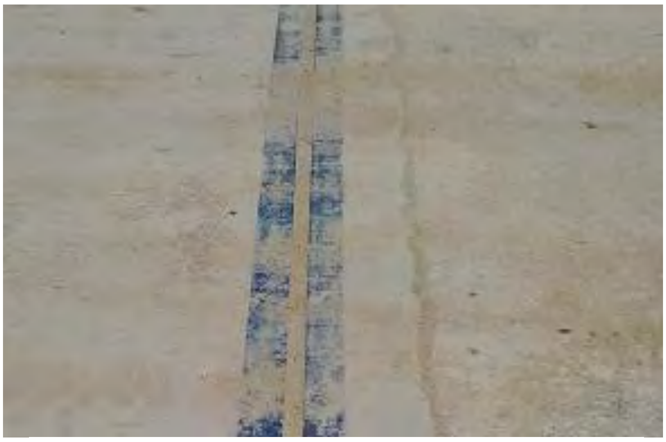


Photo 3.2.3.2 Expansion joint clogged with sand and dust

Photo 3.2.3.3 Drainage cleaning with water jet

Photo 3.2.3.4 Manual drainage cleaning

b) Cleaning of Bridge Substructure

All foreign materials such as dirt, dust, sand, rain water, and moss on surfaces of abutment and pier bearing seats and coping shall also be completely removed manually and then washed using a high pressure water bluster. Mud and sand deposits at the sides of abutment shall be excavated to maintain its original distance from the river bank.

Photo 3.2.3.5 Vegetation in the deck

Photo 3.2.3.6 Mud, debris and sand deposits around Bearing seat areas

Photo 3.2.3.7 Cleaning of pier bearing seat

Fig. 3.2.3.1 Removal of grass and shrubs around bridge

CHAPTER 4   MAINTENANCE ROOM AND BASIC KNOWLEDGE OF CONCRETE

4.1 Maintenance Room

Even for any bridge structure, it is advised that spatial allowance for maintenance activities be secured for sides of alignment and under the girders so that scaffolding can be installed properly. Except for long-span bridges, concrete bridges in general have a short span and small gap between girders. Also as there is a little girder expansion allowance and supporting load of substructure is relatively small, small size of expansion joints and bearings are generally used. Consequently, there is little space available for working on pier top and that makes inspection and repairing difficult to carry out.
Therefore, even for a concrete structure, it is essential to secure enough maintenance room (working and preliminary space) as defined hereafter.

Enough maintenance room should be secured for the following structures (**Photo 4.1.1**).

(a) Bridge structure over river and waterways
(b) Bridge structure over crossing road
(c) Bridge structure adjacent to immovable structures

(a) Over waterway

(b) Above road

Photo 4.1.1 Limited Maintenance

Expecting future requirement of inspection, repairing and strengthening by deterioration due to aging and unexpected causes, in the planning and design stages, any bridge structure is advised to secure enough maintenance room around the main structure.

Maintenance room includes the scaffolding space on both sides of and under the girders, working space for inspection, repair and strengthening, and any probable room as deemed necessary in the future. Scaffolding also needs enough spaces for suspension devices, worker's passage and staircase and protection panel.

Examples of maintenance room are shown in **Fig. 4.1.1**and **Table 4.1.1**.

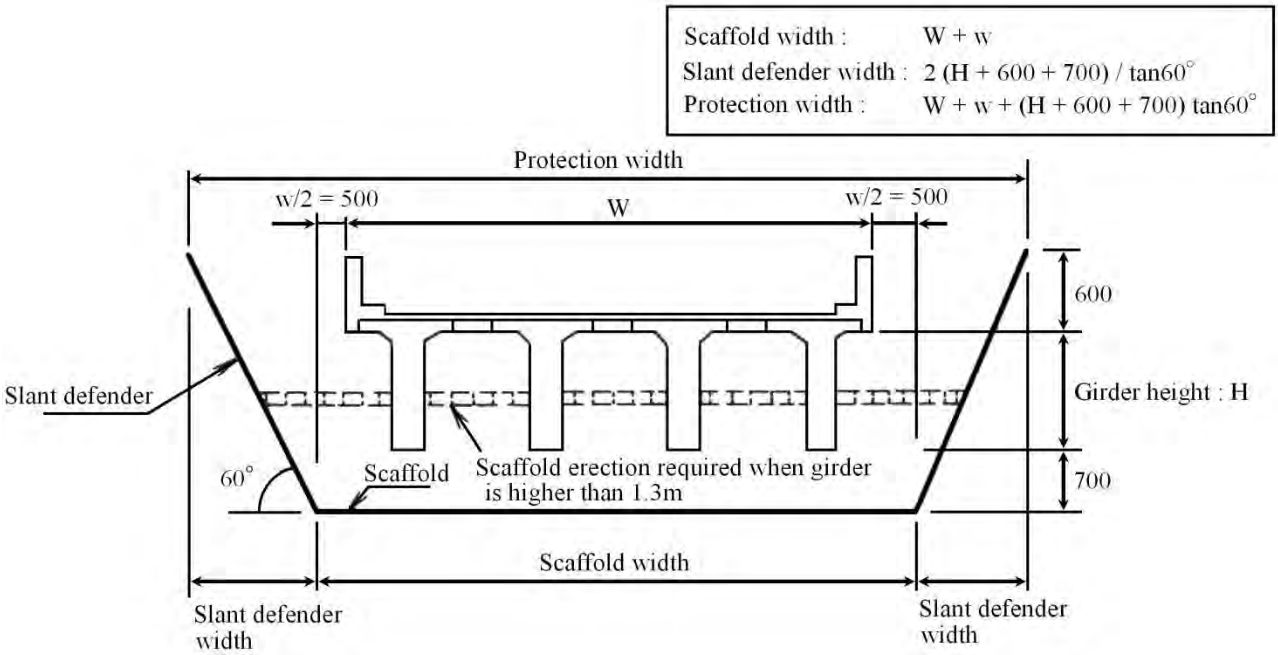


Fig. 4.1.1 Standard Setting of Scaffolding

Photo 4.1.1 Scaffold

Table 4.1.1 Standard Maintenance Space for Bridge Repairing

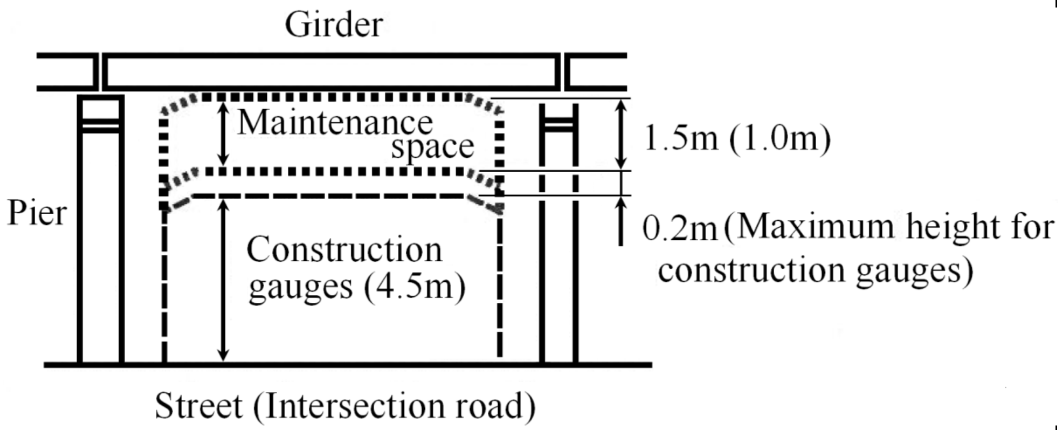
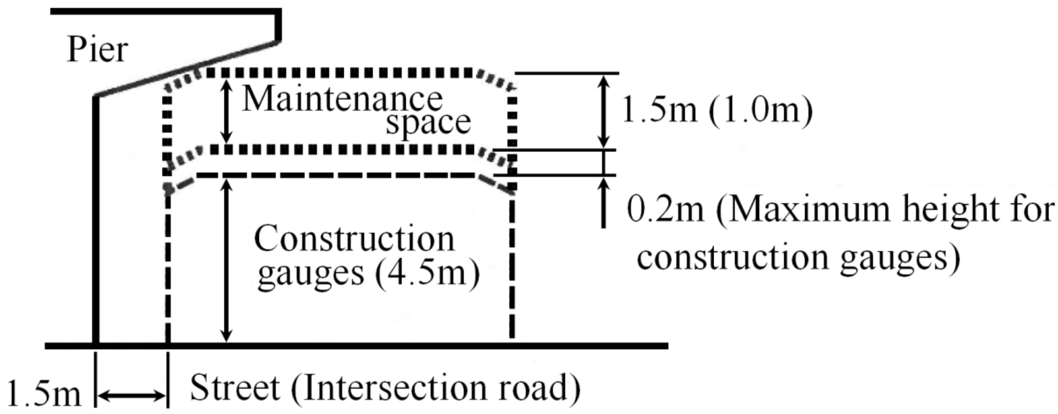
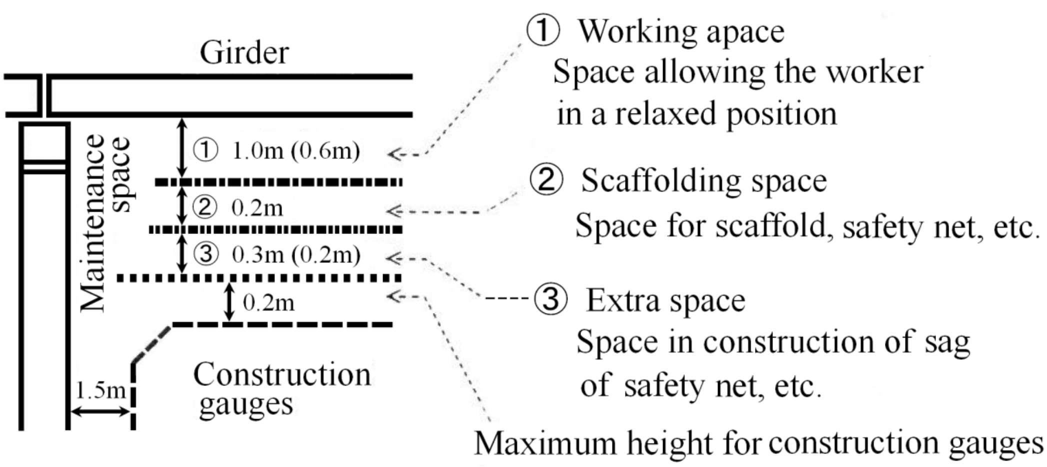
Maintenance space under girder	
Maintenance space under pier girder	
Details of maintenance space	

Table 4.1.2 compares worker's positioning and the associated fatigue level during maintenance work. When a worker works on the bottom side of lower flange of main girder near the bearing, his/her fatigue level may double. Enough working space should be provided as much as possible so that workers can work and move without physical hindrance.

As shown in **Fig 4.1.2**, in the case of a structure layered with other roads, enough space between right-of-ways of parallel roads and adjacent pier girder and column should be generally kept for maintenance room.

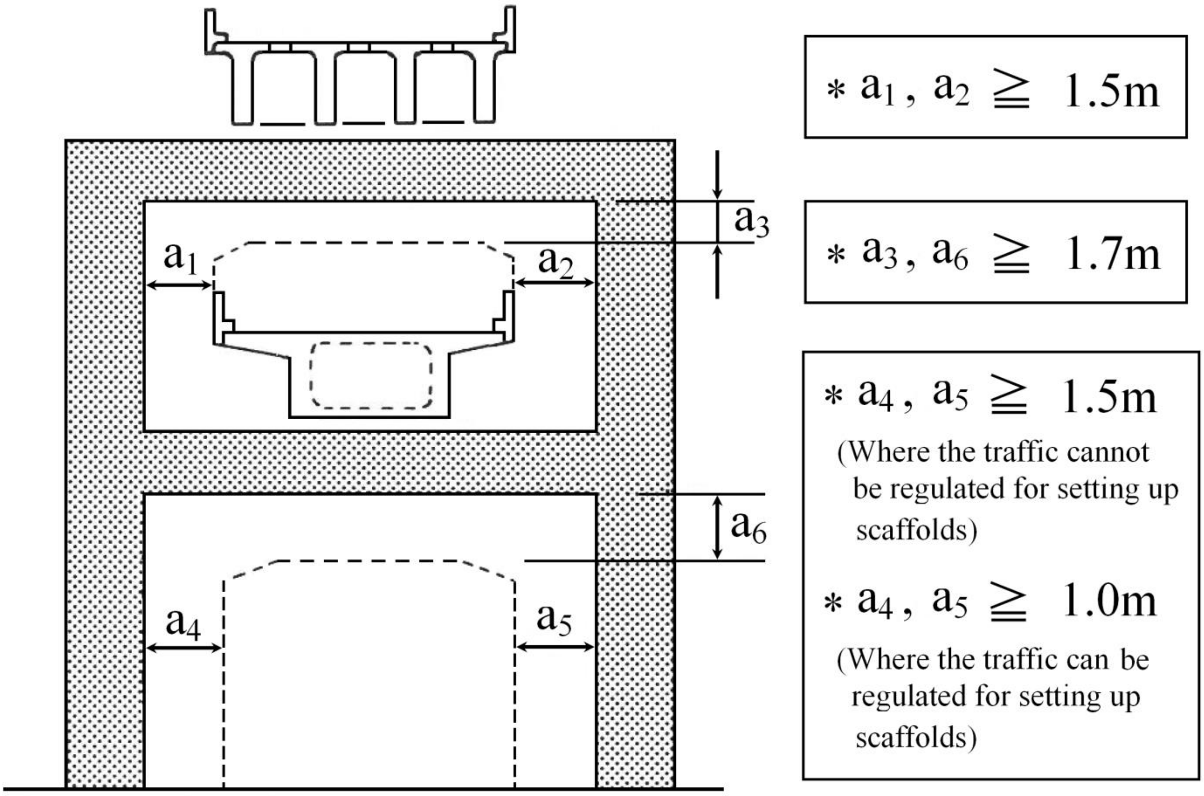
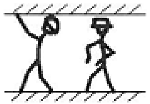
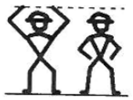
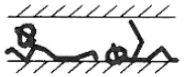
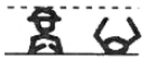
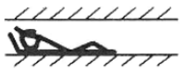
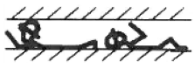


Fig. 4.1.2 Minimum Dimensions for Maintenance Space of Layered Structure

Table 4.1.2 Working Positions and Worker's Fatigue

		Working Position			Required Space (Standard size) : m			Fatigue (Reference)	Resting Position		
		Position	Sketch								
			Side view	Front view	Height	Width	Length	standard	Short	Medium	Long
1	**Standing**	**Free to Work without restriction**			1.8	0.8	1.0	1.0	Free		
2	**Hunching**	**Unable to work unless slightly hunched**			1.5	0.8	1.0	1.5	Squatting		sitting
3	**Squatting**	**Unable to work unless squatting**			1.2	0.8	1.0	1.2	Squatting		sitting
4	**Kneeling or sitting**	**Unable to work unless kneeling or sitting**			1.0	1.0	1.0	1.1	Sitting on chair	Stretching legs	
5	**Lying**	**Unable to work unless lying face down or face up and stretching or flexing lower limbs**			Prone position > 0.6 Supine position > 0.6	0.8	1.6	2.0	Stretching body on floor		Supine position
6		**Unable to work unless lying sideways and stretching or flexing lower limbs**			0.7	0.8	1.8	2.5	Supine position		
7		**Working in most difficult position lying face down, with arms and abdomen on the floor, or lying face up**			0.4	0.8	1.8	2.5	Supine position		

NOTES: 1. In the resting position column, short, medium, and long refer to short rest, medium rest, and long rest, respectively

2. Rest means taking a rest at the same place, as differentiated from a coffee break or the like

4.2 Concrete Material

4.2,1 Composition of Concrete

Concrete is the mixture of cement, water, fine aggregate, coarse aggregate, and admixture **(Fig. 4.2.1).** Coarse aggregate has the largest share in cubical volume followed by fine aggregate, water, cement, and admixture in order.

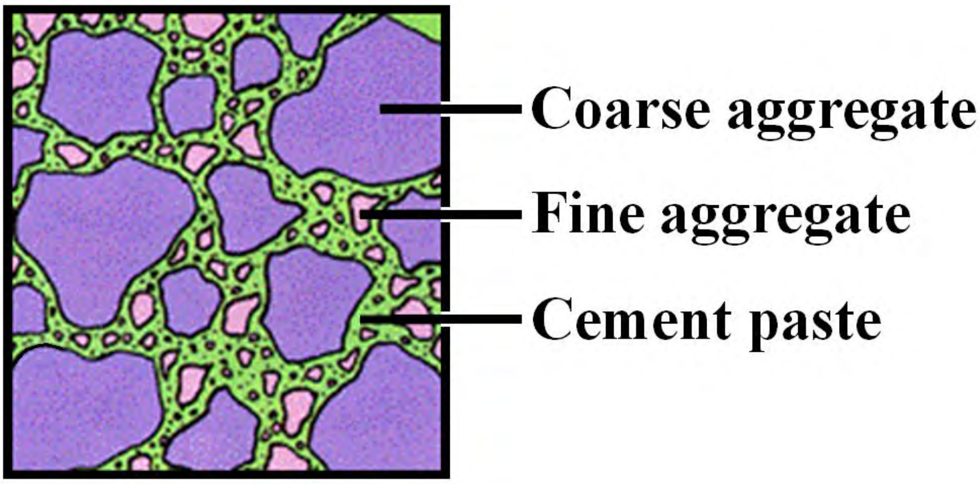


Fig. 4.2.1 Composition of Concrete

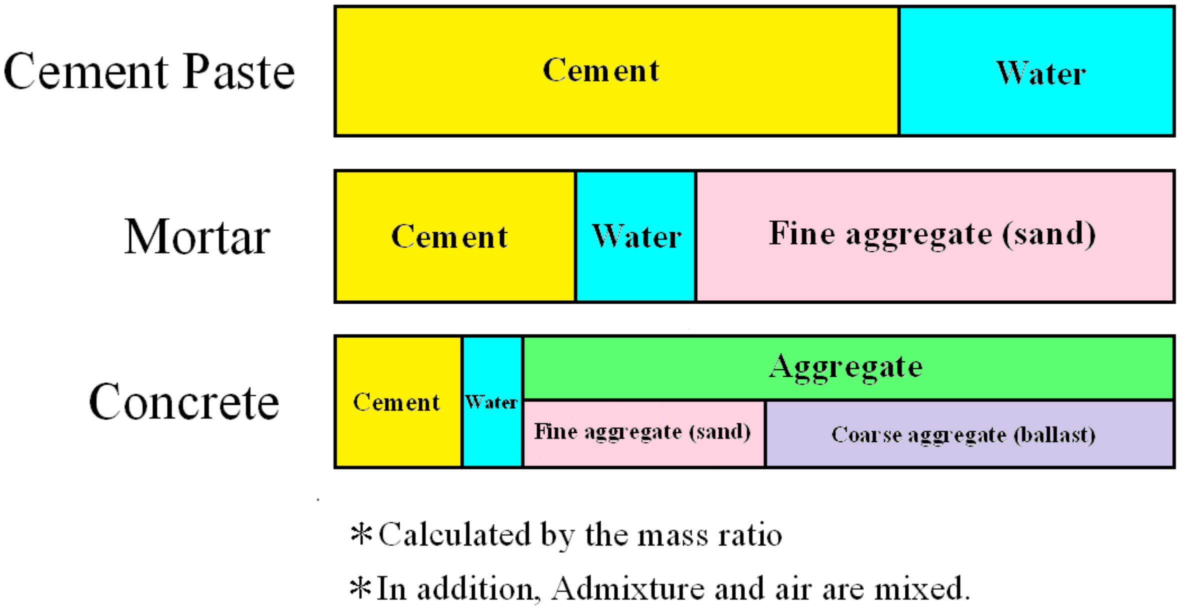


Fig.4.2.2 Component comparison in different mixture states

4.2.2 Aggregate

Sand or gravel component of concrete material is generally called aggregate. Aggregate is classified into coarse and fine ones by particle dimension. Coarse aggregate is the gravel mass whose 85% of weight volume can remain on 5mm wire sieve (equivalent of gravel over 5mm in dimension). Fine aggregate is the sand mass all of which goes through 10mm wire sieve and whose 85% of weight volume go through the 5mm one.

Since total cubical volume of aggregate consists of about 70% of concrete, its quality largely influences on the overall concrete performance.

(a)Coarse aggregate

(b)Fine aggregate

Photo 4.2.1 Aggregate

4.2.3 Cement

Cement is the concrete component with gray colored and powdery state and hardened by hydrate and polymerized effects when mixed with water or liquid material.

Cement is roughly classified into three types: portland cement, blended cement and special cement. Generally, portland cement is used for regular concrete.

4.3 Damages due to construction failures

Any concrete structure requires specified strength, durability, water-tightness and external appearance according to its intended purpose. When it is constructed, careful execution is critical to meet the required qualities.

However, since concrete is a complex mixture of cement, aggregates and water, it is very vulnerable of bleeding failures with poor execution of mixing, transport and casting. Also, concrete's smaller tensional strength may induce initial cracks due to construction misconducts.

As these failures and cracks during the construction stage may cause many problems on strength, durability, water-tightness and external appearance of finished products, careful and proper quality management is essential at this stage. Common failures and their countermeasures are shown in the following (**Fig. 4.3.1**).

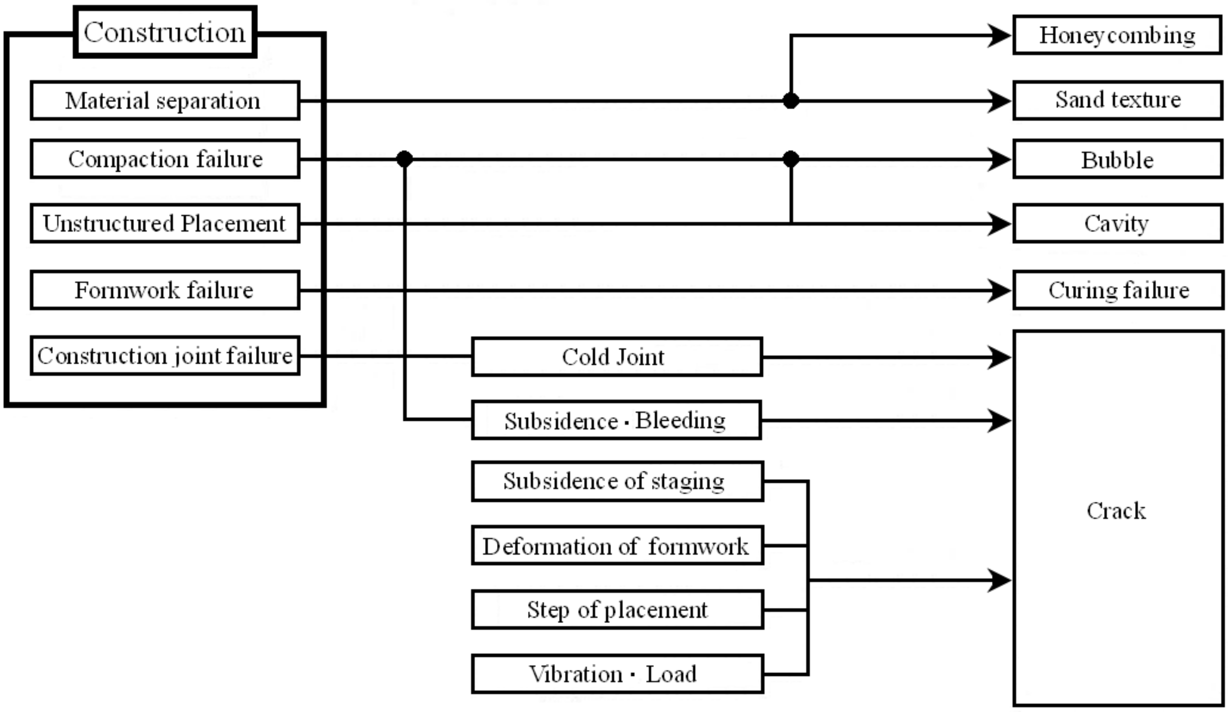


Fig. 4.3.1 Typical construction failures and their causes

4.3.1 Honeycombing and Cavity

Since fresh concrete is a state where materials with different specific weight such as cement and aggregates are distributed in the water, uneven mixture and the consequent bleeding failure may happen with poor mixing and casting. Here, bleeding is a phenomenon where a part of water component is concentrated on the surface with sedimentation of aggregate and cement particle.

When bleeding occurs and coarse aggregates concentrate disproportionately without enough mortar infusion, section with many small voids may appear. This failure is usually called honeycombing. Also, when there is a poor concrete workability with crowded reinforcements, large void or cavity is prone with insufficient compaction.

Honeycombing and cavity cause not only poor external appearance but also significant deterioration on durability and water-tightness. When there is a partial areal loss, structural strength may also be decreased.

Photo 4.3.1 Honeycombing

(1) Causes of honeycombing and cavity

Honeycombing and cavity are likely to appear when casting improper workability concrete for a required dimension.

1) Concrete mix design

When aggregate proportion against cement is higher than regular mixture, cement component does not reach to the entire area and honeycombing may occur

2) Insufficient concrete compaction

When concrete is casted in a section where vibrator cannot reach or reinforcements are placed densely with smaller gap, concrete cannot come through entirely and honeycombing or cavity is likely to appear.

3) High concrete casting position

Structures like high wall and pier for which fresh concrete has to be casted from relatively higher position, it collides with formwork and reinforcements and bleeding is likely to occur.

(2) Preventive measures

The execution of right mix design based on standard specification is the key to avoid forming voids. Also concrete with proper workability should be chosen by considering the size and shape of cross-section and reinforcement arrangement, while concrete should be casted and compacted with a well-examined plan.

When formwork is high, casting hole in the intermediate height and supplementary casting devices such as vertical shoot, pump or concrete hopper should be provided.

If possible in the design stage, enough lateral space between reinforcements should be secured so that vibrator can be inserted easily.

4.3.2 Bubble and Sand Texture

Although bubble and sand texture are not structural problems but they cannot be accepted when external appearance shall be taken into account.

(1) Causes of bubble and sand texture

When bleeding occurs and the water remains along the formwork panel, bubble holes appear on the concrete surface after dry-up. Sand texture is a phenomenon where the water washes away the cement component and fine aggregated stand out on the surface.

(2) Preventive measures

To avoid or reduce bubble or sand texture due to bleeding, good workability concrete should be used and the height of one casting unit should be less than 40-50cm with sufficient compaction.

Photo 4.3.2 Sand Texture

4.3.3 Cracking

Concrete cracking causes bad effects on structural strength, durability, water-tightness and external appearance. They occur by the four main types of cause as follows:

(1) Related to construction performance
(2) Related to concrete material behaviors
(3) Related to use conditions and ambient environment
(4) Related to structural and loading conditions

Table 4.3.1 shows the causes categorized in the abovementioned types. Most of the actual cracks occur with the combination of multiple causes.

Table 4.3.1 Causes categorized in concrete crack

Classifications			Causes
Execution	Concrete Mixture	Mixing Work	Uneven dispersion of Materials
			Prolonged mixing time
		Transport	Change of mixing design at pumping
		Casting	Inappropriate casting order
			Overquick casting
		Compaction	Inappropriate compaction
		Curing	Vibration/loading before setting
			Overquick drying at initial stage
			Freezing at curing
		Casting Joint	Inappropriate casting joint
	Reinforcement	Re-bar Placement	Random interval placemen
			Insufficient coverage depth
	Formwork	Formwork Panel	Swelling
			Water leakage
			Removal before concrete setting
		Supports	Support sagging
Material	Material Components	Cement	Abnormal setting
			Existence of hydration water
			Abnormal swelling
		Aggregates	Clay content in aggregates
			Use of low-quality aggregates
			Silica reaction
	Fresh Concrete		Chlorides in concrete
			Material sedimentation, bleeding
			Dry shrinkage of concrete
Use Condition Ambient Environment	Physical	Temperature, Humidity	Change of ambient condition
			Difference between structural sides
			Fire
			Surface heating
	Chemical	Chemical Reaction	Acid/chloride reactions
			Re-bar corrosion by concrete carbonation
			Re-bar corrosion by chlorides in concrete
Structural Loading	Loading Condition	Dead/Long-term Loads	Excessive loads beyond design
		Live/Short-term Loads	Excessive loads beyond design
	Structural Design		Insufficient dimension or reinforcement
	Supporting Condition		Uneven sedimentation

4.3.4 Cold Joint

When massive volume of concrete is casted, the casting is done incrementally. If one layer of concrete is casted after the previous layer becomes solidified, material discontinuity called "cold joint" sometimes appear in the boundary section between layers.

Cold joint not only becomes the main factor of deterioration on structural strength but also brings negative effects on external appearance, water-tightness and durability.

Photo 4.3.3 Cold Joint

(1) Causes of cold joint

The dominant causes of cold joint are concrete solidification time and casting interval between layers. The factors to dictate each duration are as follows:

1) Factors for concrete solidification time
  - Type of cement and admixture
  - Slump
  - Water-cement ratio
  - Temperature
  - Humidity
  - With or without re-vibration

2) Factors for casting interval between layers
  - Casting order
  - Casting time
  - Transport time
  - With or without stand-by time before casting

(2) Standard specification on casting interval

When more than two layers of concrete are casted, concrete of upper layer shall be casted before the one of the previous layer begins to be solidified. Also in order to avoid cold joint, allowable maximum casting intervals are set as in **Table 4.3.2**. Since works are conducted in daytime in Cambodia, target interval should be less 2 hours

These intervals are defined as the hours between the time when concrete is mixed and finished being casted in the lower layer and the time concrete is casted in the upper layer with a certain curing period.

Table 4.3.2 Allowable Maximum Casting Interval

Ambient Temperature	Allowable Maximum Casting Interval
Over 25 ℃	2.0 hours
Less than 25 ℃	2.5 hours

(3) Preventive measures

The best way to prevent the occurrence of cold joints is to make a well-examined casting plan before hand and execute casting accordingly. Also cold joint forming can be avoided by using admixture for setting retarding

4.4 Concrete Work

4.4.1 Requirements of Fresh Concrete materials

(1) The slump shall be 80mm.

This workability is generally determined by the ease with which fresh concrete can be deformed and resistance to the separation of materials. For general concrete, it may be established from the slump and maximum size of the coarse aggregate.

(2) The unit cement concrete shall be determined from the unit water content and water-cement ratio. For the minimum unit cement content, the values in **Table 4.3.1** shall generally be taken.

Fig. 4.3.1 Minimum unit cement content (kg/m^3)

Component Member type		Minimum unit cement content
Reinforced concrete member		230
Pre-stressed concrete member	Pre-tensioning method	350
	Post-tensioning method	300

The unit cement content shall be determined from the unit water content and water-cement ratio. Here, in the pre-tensioning method, the bond strength between the concrete and the PC tendon shall be adequately ensured. Therefore, the minimum unit cement content in the pre-tensioning method is stipulated to be larger than in the post-tensioning method.

Because there is a risk of a large water content having a detrimental effect on the structure such as cracking due to thermal stress and drying shrinkage, an examination shall be performed regarding the construction method and curing method when the unit cement content is high.

(3) The sand ratio shall be determined so that the unit water content is minimized within the limits of easy work execution.

(4) The maximum size of coarse aggregate shall be 40 mm or less, and not greater than 1/5 of the minimum dimensions of the member and not greater than 3/4 of the minimum clear distance of the reinforcement.

The maximum coarse aggregate size depends on the amount and arrangement of the steel; however, it is desirably taken at 20 or 25 mm.

4.4.2 Storage

The materials shall be stored so that their quality does not change.

It is desirable to store materials paying attention to the following matters to ensure their quality.

1) Storage of steel

Reinforcing bars and structural steel shall be supported at appropriate spacing and stored in storage facilities or, if stored outdoors, under appropriate cover instead of being placed directly on the ground surface.

2) Storage of cement

When cement that has been stored for a long period of time is, the cement shall be tested to ascertain its quality prior to the use.

When the temperature of cement is excessively high, the temperature of the cement shall be lowered prior to the use.

If bags of cement are stored for a relatively long period of time or during a high-humidity period, it is good practice to take weathering prevention measures such as using bags lined with a damp-proof membrane. If bags of cement are stacked while in storage, the cement in the lower bags might consolidate. A recommended limit to the number of layers of stacked bags of cement, therefore about 13.

Photo 4.4.1 Storage of concrete material

4.4.3 Concrete work

(1) General

In performing concrete work, a plan shall be established beforehand concerning the concrete transport method, transport route, site placed, placement method, placement procedure, amount of one placement, curing method, and construction joint treatment method so that the prescribed quality can be ensured.

(2) Transport

Concrete shall be transported and placed using an appropriate method so that no separation of materials occurs.

When a concrete pump is used, an appropriate type of concrete pump shall be chosen considering the concrete placement method. In placing a pipeline, it shall be ensured that the pipeline does not impart harmful vibrations or deformation to the reinforcement, formwork or support. The pipeline is desirably placed horizontally or upward. Since the pipeline to a pump moves around while the concrete is being pumped, it should not be placed directly on the reinforcement, formwork or the like but desirably placed on supports.

(3) Placement

1) Concrete placement shall not generally be performed in rain or strong wind.

2) Before concrete placement, the placing facilities and formwork shall be cleaned to prevent miscellaneous matter from penetrating the concrete. Parts that may absorb the moisture of the concrete shall be placed in wet conditions beforehand.

3) Time from Mixing to Finishing the Placement

As a standard, the time from the completion of mixing to the completion of placement should be 2 hours or less or l.5 hours or less when outdoor air temperature is 25 degree Celsius or lower or higher than 25 degree Celsius, respectively.

4) If concrete is placed in two or more layers, placement shall be carried out so that an overlying layer becomes integral with an underlying layer. The area of each concreting zone, concrete supply capacity, allowable placement interval, etc., shall be determined so that cold joints do not result. The term allowable placement interval is the time after completion of the placement and compaction of the underlying layer of concrete until the overlying layer of concrete is placed after a period of standing time. Standard allowable placement intervals are shown in **Table 4.3.2**.

(4) Compaction

1) In principle, internal vibrators should be used for compacting concrete. Form vibrators may be used for such structures as thin walls where the use of internal vibrators is difficult.

2) In conducting concrete compaction, it shall be ensured that concrete is spread around the reinforcement and to every corner of the formwork.

3) Scaffold installation and concreting methods shall be determined so that the compaction height does not exceed the planned value.

4) Concrete adjacent to the sheathing board shall be properly compacted around the sheathing board to ensure that the final concrete surface is as flat as possible.

5) During compaction using vibration, the internal vibrator shall be inserted about 10cm into the lower layer of concrete.

6) The spacing should not be greater than a diameter in the range in which vibration is effective, which is usually 50 cm or less for concrete with the average level of fluidity and viscosity.

7) The spacing of interval vibrators and the vibration time at each location shall be determined so that concrete can be adequately compacted. Internal vibrators shall be withdrawn gradually so that holes are not left in the concrete.

As a rule of thumb, vibration time is about 5 to 15 seconds. Pulling out vibrators slowly is very important in order to make sure that holes are not left in the concrete.

8) The time for re-vibration should be as late as possible to the extent that the compaction of concrete is possible and there is no adverse effect such as cracking on the concrete.

9) Internal vibrators must not be used for lateral movement, which may cause segregation.

Photo 4.4.2 Compaction

(5) Curing

Photo 4.4.3 Curing

1) Concrete shall be cured so that it is not subjected to the effects of drying, low temperature or rapid temperature changes after placement.

2) Concrete shall be cured so that it is not subjected to the effects of harmful vibrations, impact or the like while it being hardened.

3) The curing method shall generally be wet curing. When ordinary Portland cement is used, the concrete shall be cured for at least 5 days after placement, and if high-early-strength Portland cement is used, the concrete shall be cured for at least 3 days after placement. Seawater shall not be used for the curing water.

(6) Construction joint

1) The construction joint shall be formed at a position of small shear force and perpendicular to the direction of action of compressive forces on the member.

2) For the construction joint, consideration shall be given so that cracks due to thermal stresses and drying shrinkage do not occur.

At the construction joint, there is a risk of cracking by thermal stress due to heat of hydration, thermal stress due to the effects of ambient air temperature, drying shrinkage and other causes. Therefore, construction work shall be performed in a manner that minimizes the temperature difference between the new and existing concrete. Near the construction joint, it is necessary to place stirrups, transverse bars and other reinforcement densely compared to the other parts or to take other measures.

3) At the construction joint, the concrete surface shall be cleared of laitance, loose aggregate or the like and allowed to absorb water sufficiently before new concrete is placed.

The water remaining on the existing concrete surface shall be removed before placing new concrete.

4) As for structures exposed to salt environment such as sea side, it is advised the number of construction joints should be minimized and the vertical joint should be averted as far as possible.

5) When concrete is placed several times in multiple layers, integrity shall be ensured at the layer interfaces between the upper – and lower – layer concrete, and cracks or cold joints with an adverse effect on durability shall not occur.

When the lower concrete beings to harden, there is a risk of the formation of a cold joint when the upper concrete is placed without consideration. To prevent this, it is important to set and control placement intervals considering the effects of the type and quality of concrete, the elapsed time from the start of kneading to the completion of placement, concrete temperature, compaction method, and other factors.

4.4.4 Work and placement of reinforcement

(1) Reinforcement shall be assembled firmly using spacers made of concrete or mortar that is equivalent or superior in quality to the body concrete so as not to cause dislocation during concrete placement.

(2) Reinforcement shall be bended at normal temperature and the bending work shall be performed using a bending machine in a manner that causes no change in material property.

(3) At assembling reinforcement, loose rust or other matter that may impair the bond with concrete shall be removed.

Matter including loose rust, mud, oil, paint or others impairs the bond between concrete and reinforcement. Not only should they be removed in assembling the reinforcement but it should also be ensured that they do not adhere to the reinforcement during storage or working.

(4) When a lap joint is used, the prescribed length shall be lapped and firmly bound by annealed iron wire of 0.9 mm or more in diameter.

(5) Reinforcement jutting from the structure in an exposed state for future extension shall be protected from damage, corrosion and the like.

When reinforcement is exposed for a long time for future extension, it shall be coated with cement paste or shielded by a vinyl cover or otherwise treated to protect it from damage or the adverse effects of corrosion.

4.5 Concrete quality verification test

4.5.1 Slump test

Slump test is used to know the workability of fresh concrete and the easiest way to know the concrete properties. The concrete slump test is used for the measurement of a property of fresh concrete. The test is an empirical test that measures the workability of fresh concrete. More specifically, it measures consistency between batches. The test is popular due to the simplicity of apparatus used and simple procedure.

The big slump means high workability. But it is not so good for concrete durability. And bigger slump concrete is easy to produce materials separation, contains much water and produce materials separation easily and quality of the concrete after the ramming down is easy to become the often heterogeneity, and its dry shrinkage is also big.

So, it is important to minimize the slump water content within the limits of workability for casting.

Photo 4.5.1 Slump Test

Slump test method is as following (**Fig. 4.5.1**).

①The tester called slump cone is set. The steel slump cone is placed on a solid, impermeable, level base.

②Filling the slump cone with fresh concrete in 3 steps in three equal layers.

③Each steps, tamping 25 times by a stick. Each layer is rodded 25 times to ensure compaction.

④Finishing the top flat, and lifting the slump cone up vertically and slowly. And, slump is measured. The third layer is finished off level with the top of the cone. The cone is carefully lifted up, leaving a heap of concrete that settles or ‘slumps’ slightly. The difference in level between the height of the slump cone and that of the highest point of the subsided concrete is measured. This difference in height in mm is the slump of the concrete.

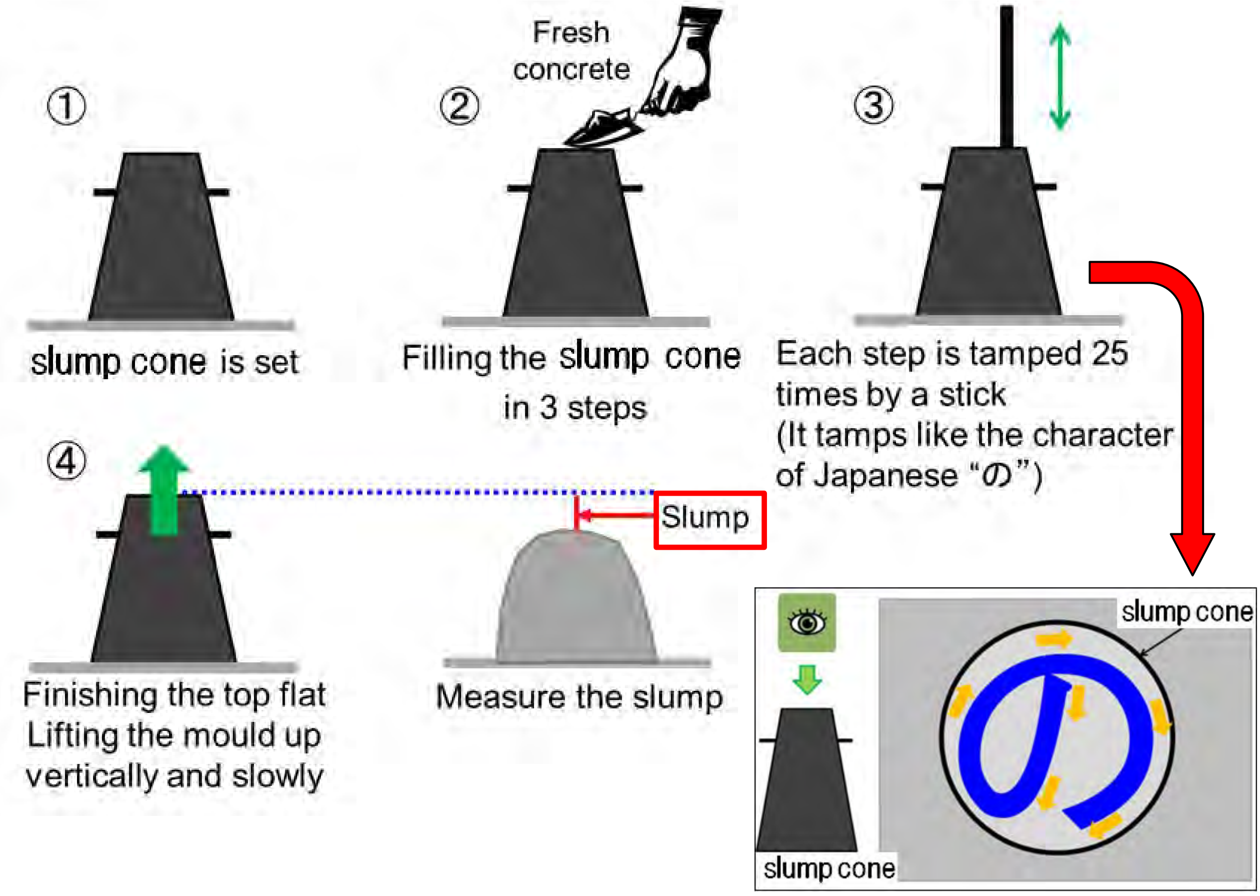


Fig. 4.5.1 Step of Slump Test

4.5.2 Air content test

Photo 4.5.2 Air content test

Air content test is to measure air content contained in concrete.
Test for Air Content of Freshly Mixed Concrete by the Pressure Method is based on Boyle's law, which states that the volume occupied by air is proportional to the applied pressure. The meter shown in the photograph, a separate air chamber is connected through a valve to the test bowl that is filled with concrete. With the valve closed, the separate chamber is pressurized to a predetermined operating pressure. When the valve is opened, the air expands into the test chamber, and the pressure drops in proportion to the air contained within the concrete sample. The pressure gauge is read in units of air content.
When concrete is mixed, minimal air is put into concrete. The more amount of air is large, workability of concrete is good. However, if air is put in too much, compressive strength is reduced.
So, suitable air content should be designed.

Air content test method is as following (**Fig. 4.5.2**).

① The tester is set on the level stock.
② The taster is filled with fresh concrete in 3 steps in three equal layers.
③ Each steps is tamped 25 times by a stick.
④ The side of tester is tapped with a hummer
⑤ The cover is set up, and the inside of tester is made into a vacuum.
⑥ Air content is measured.
⑦ Weight of this tester is measured.
⑧ Unit water content can be calculated by air content and specimen weight.

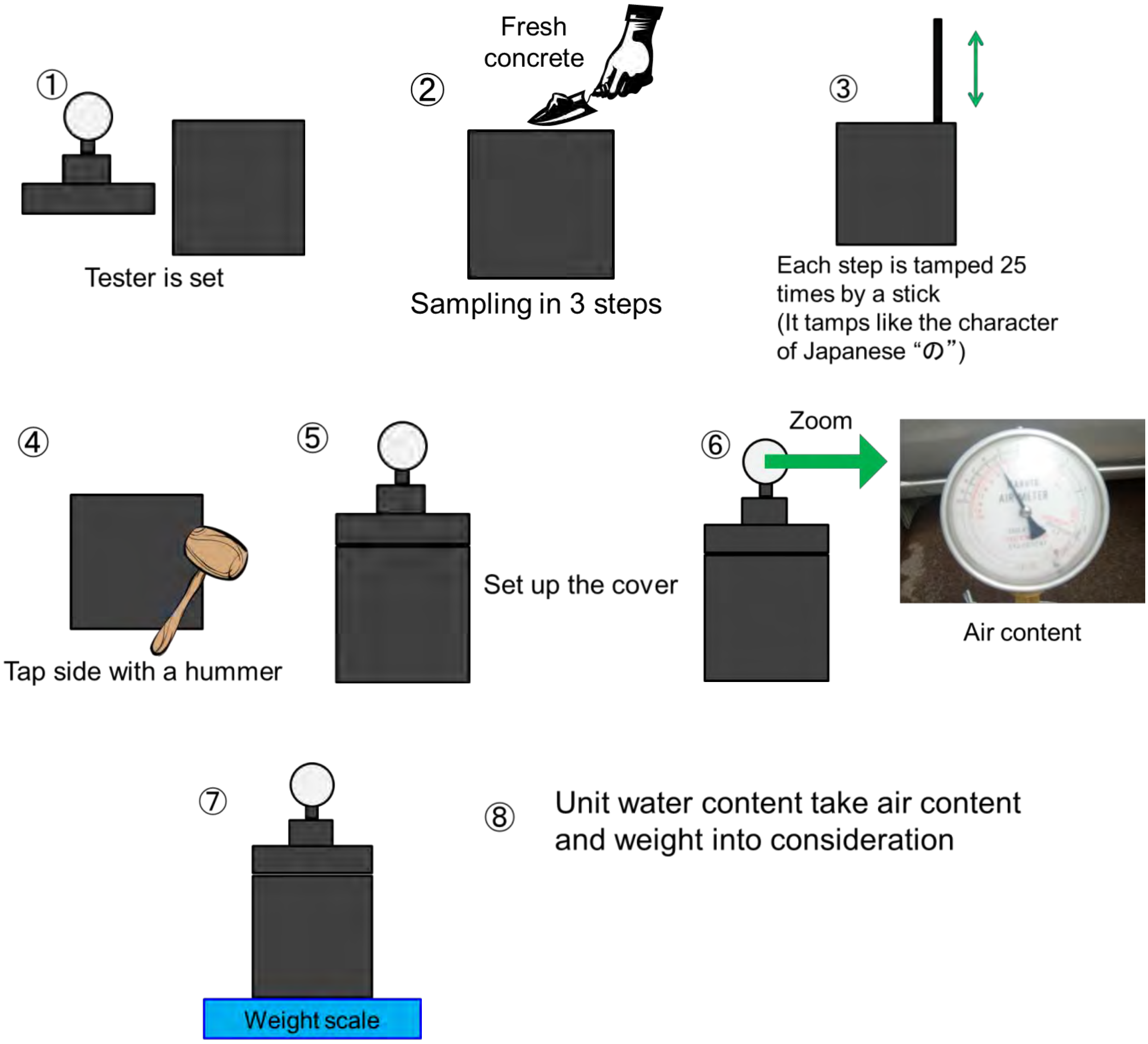


Fig. 4.5.2 Step of Air content test

4.5.3 Compressive strength test

This test measures the compressive strength of hardened concrete.

We confirm that cast-in-site concrete strength exceeds the design one. This test measures the compressive strength of hardened concrete to confirm whether the concrete has design strength or not.

We test three pieces and compressive strength is the average of them. Average compressive strength of three specimens is adopted as the result.

Photo 4.5.3 Compressive strength test machine

(1) Sampling method (**Photo 4.5.4**)

1) In case of sampling from agitator

To get homogeneous fresh concrete, sample should be taken equally after high speed stirring and excluding first 50 or 100 litter concrete.

2) In case of sampling from concrete pomp

Sample should be taken from three place of discharged concrete.

(a) From agitator **(b) From concrete pomp**

Photo 4.5.4 Sampling method

(2) Specimens making

*Three specimens should be made every $150m^3$ – $300m^3$ concrete casting.

*Specimens should be made as cylinder with diameter of more or 100mm and more or 3 times of maximum aggregates and height of more or 2 times of diameter. (for example φ100×200mm) (**Photo 4.5.5**)

*Filling the mold with fresh concrete in more or 2 equal layers and each layer is rodded 1 time every 10 times ensure compaction.

* Mold should be removed after 16 to 72 hours. Specimens should be kept away from impacts or vibration and protected from drying during molded time.

* After that specimens should be kept in the constant temperature water tank and compressive test will be carried out on 28th day.

Photo 4.5.5 Cylinder

4.5.4 Chloride Ion Content Test

When there is a certain amount of chloride ion in concrete, reinforcements are vulnerable for rusting. Also, the existence of sodium chloride in concrete may induce alkali-silica reaction. In order to avoid the chloride-related failures, the total amount of chloride ion content in concrete shall be less than 0.30kg/m3 in principle.

Test methods to measure the volume of chloride ion concrete includes test strip (Quan Tab Test), machine test, and dry analysis method using concrete powder drilled by depth from core samples. Recently Electron Probe Micro Analyzer (EPMA) can measure the chloride content precisely and quickly.

Photo 4.5.6 Chloride Ion Content Test