MANUAL 1 : Technical Manual on Inspection and Diagnosis of Bridge

CAMBRIDGE

Technical Cooperation Project for Capacity Development in Construction and Maintenance of Bridges in the Kingdom of Bhutan

Technical Manual on Inspection and Diagnosis of Bridge

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Department of Road
Ministry of Works & Human Settlement
Royal Government of Bhutan

Japan International Cooperation Agency

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1. Periodic inspection of bridge

1.1 Scope

The scope of this manual is limited to the periodic inspection of the bridges managed by DoR / MoWHS.

This manual prescribes general contents and its considerations with present knowledge of periodic inspection.

1.2 Purpose of periodic inspection

Periodic inspection shall be carried out in order to obtain the required information for securing safe and smooth traffic and execution of efficient operation and maintenance. Understanding of the damage status, determination of measures category and recording of the inspection results shall be conducted.

Figure 1.1 shows the standard procedure for operation and maintenance in periodic inspection.

Periodic inspection shall be carried out in order to obtain the basic data to develop plans for maintenance, repair and reinforcement by grasping of damage status and evaluating of damage degree.

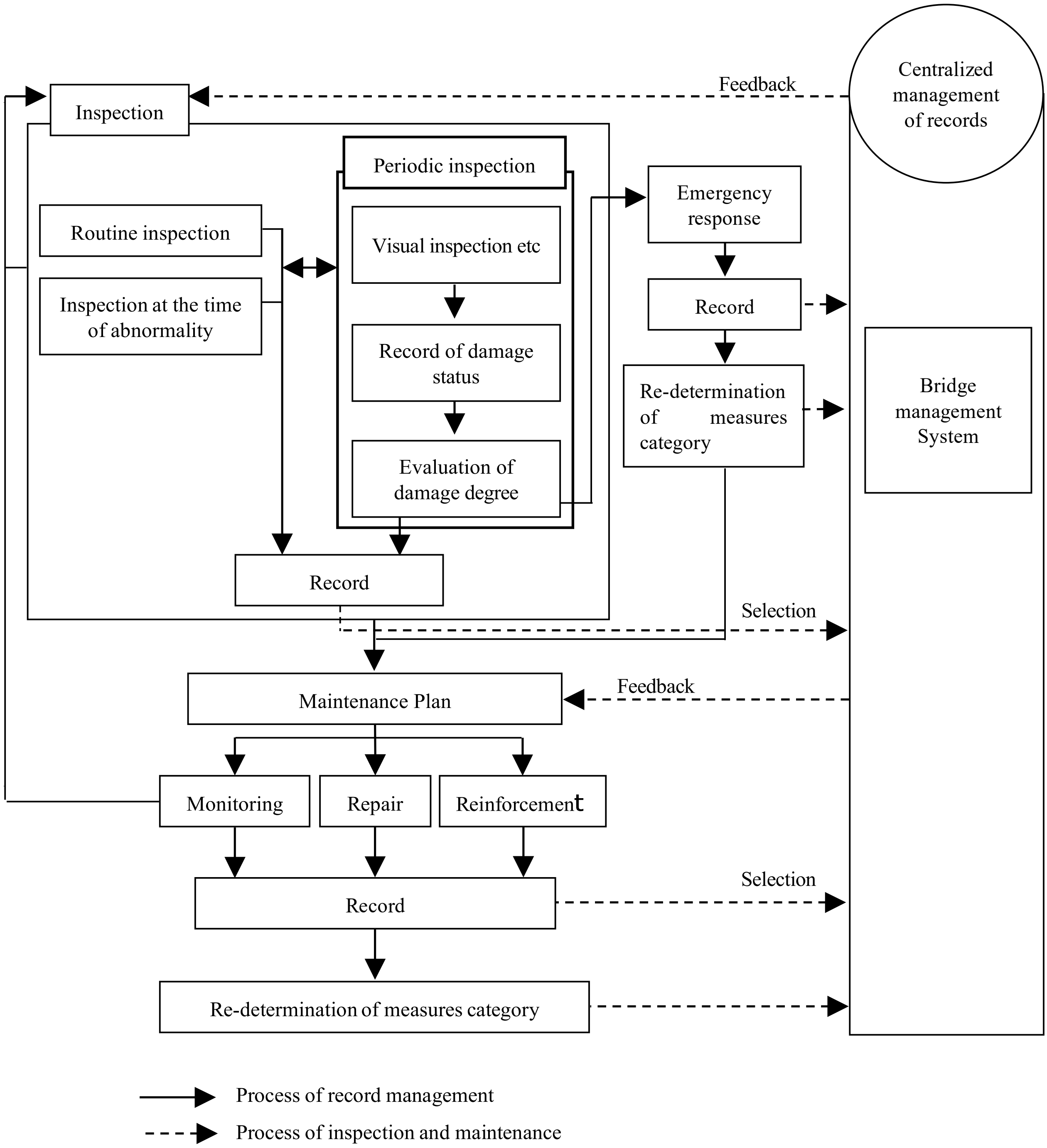


Figure1.1 Operation and maintenance flow in periodic inspection

1.3 Type of inspection

The types of inspections are categorized into three inspections as follows;

【Routine inspection】

Routine inspection is a visual inspection conducted during a regular patrol of roads for early damage detection.

【Periodic inspection】

Periodic inspection is a detailed visual inspection conducted on a regular basis for the bridge maintenance.

【Inspection at the time of abnormality (After monsoon season inspection)】

Inspection at the time of abnormality is conducted to ensure the bridge safe when a disaster such as heavy intensive rainfall occur or is likely to occur, or an abnormality is found on the bridge. Especially, it is necessary to be conducted immediately after monsoon season.

1.4 Frequency of inspection

【Routine inspection】

Routine inspection shall be conducted once a week by site engineer during their regular patrol.

【Periodic inspection】

Initial inspection shall be conducted by 2 years after in service.
Initial inspection is aimed to detect initial conditions of the bridges at the early stage. Defects which were not apparent at the completion of the bridge shall be detected by the initial inspection and the result shall be initial parameter for subsequent process of development of damages.
The following examples are some of the typical initial defects;

Examples: Peeling and swelling of coating, loosening of bolts

・The low construction quality may result change in the state of bridges.

Examples: The vibration of members by wind and damage due to it, occurrence of traffic vibration, crack of concrete in slab etc.

・Unexpected phenomenon or multiple factors may result change in the state.

Procedure of Periodic inspection is shown in Figure1.2. Basically, periodic inspection shall be conducted by close-eye inspection. However, depends upon the bridge situation, there are several cases that close-eye inspection is difficult. Only that case, distance-eye inspection shall be conducted instead of close-eye inspection. The frequency of inspection shall be shorter than close-eye inspection in that case.

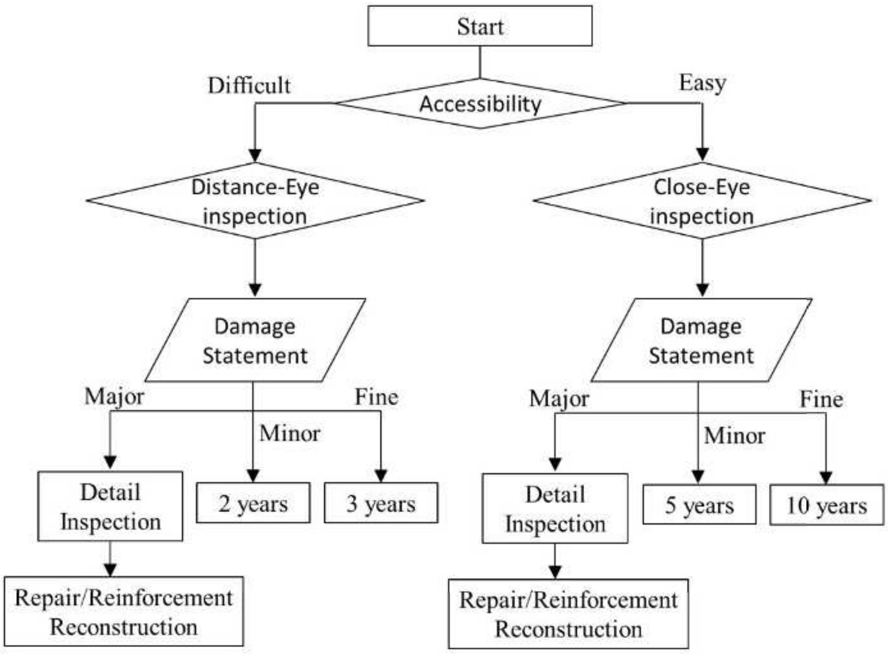


Figure1.2 Flow chart for periodic inspection

【Inspection at the time of abnormality (After monsoon season inspection)】

"After monsoon season inspection" shall be conducted every year immediately after monsoon season. In the "After monsoon season inspection", especially substructure and its surrounding area shall be cleaned before the inspection to check scouring situation clearly. Cleaning work shall include as follows;

<Superstructure>

- ✓ Removing sediment on bridge surface
- ✓ Removing clogging on drainage facility
- ✓ Removing sediment around bearing

<Substructure>

- ✓ Cutting plants substructure and around wing wall affected by river
- ✓ Brushing on substructure and around wing wall affected by river

Picture1.3 Cleaning situation (Left: before, Right: after)

1.5 Plan of inspection

1.5.1 Purpose of inspection plan

Prior to the inspection, inspection plan shall be prepared in order to conduct an adequate inspection. Inspection plan includes all plans relating to the inspection such as survey of existing data, items and methods, system and schedule for undertaking the inspection work.

1.5.2 Items and methods

Upon execution of periodic inspection, inspection plan shall be prepared in order to conduct an adequate periodic inspection corresponding to the bridge situation.

Table 1.1 shows the standard items of periodic inspection.

Table1.1 Standard items of inspection

<table>
<tr><th colspan="2" rowspan="2">Part / Member</th><th colspan="3">Subject items (type of damage)</th></tr>
<tr><th>Steel</th><th>Concrete</th><th>Others</th></tr>
<tr><td rowspan="6">Superstructure</td><td>Main girder</td><td rowspan="6">・Corrosion
・Deformation / Damage
・Looseness / Omission
・Fracture
・Deterioration of painting</td><td rowspan="6">・Crack
・Peeling / Exposure of rebar
・Water leakage / Free lime
・Crack on slab
・Deformation / Damage
・Honeycomb</td><td rowspan="6">・Deformation / Damage</td></tr>
<tr><td>Cross beam</td></tr>
<tr><td>Vertical girder</td></tr>
<tr><td>Deck slab</td></tr>
<tr><td>Cross frame</td></tr>
<tr><td>Lateral bracing</td></tr>
<tr><td rowspan="2">Substructure</td><td>Abutment</td><td rowspan="2">—</td><td rowspan="2">・Crack
・Peeling / Exposure of rebar
・Water leakage / Free lime
・Deformation / Damage
・Scouring
・Honeycomb</td><td rowspan="2">・Deformation / Damage
・Scouring</td></tr>
<tr><td>Pier</td></tr>
<tr><td rowspan="2">Deck Surface</td><td>Wheel guard</td><td>・Corrosion
・Deformation / Damage</td><td>・Crack
・Peeling / Exposure of rebar
・Water leakage / Free lime
・Deformation / Damage</td><td>・Deformation / Damage</td></tr>
<tr><td>Pavement</td><td>—</td><td>—</td><td>・Uneven road surface
・Sediment deposition</td></tr>
<tr><td>Bearing
Railing
Expansion joint
Drainage facility</td><td>—</td><td>・Corrosion
・Noise
・Deformation / Damage</td><td>・Deformation / Damage
・Sediment deposition</td><td>・Sediment clogging
・Uneven road surface</td></tr>
</table>

Periodic inspection shall be conducted in an appropriate manner depending on items.

Table 1.2 shows the standard methods of periodic inspection.

Table1.2 Standard methods of inspection

Material	Type of damage	Standard method of inspection
Steel	Corrosion	Visual inspection, Photograph
	Looseness / omission	Visual inspection, Photograph
Concrete	Crack	Visual inspection, Crack gauge, Photograph
	Peeling / Exposure of rebar	Visual inspection, Photograph
	Water leakage / Free lime	Visual inspection, Photograph
	Crack on slab	Visual inspection, Crack gauge, Photograph
Others	Uneven road surface	Visual inspection, Convex rule, Photograph
	Sediment clogging	Visual inspection, Photograph
Common	Deformation / damage	Visual inspection, Convex rule, Photograph
	Scouring	Visual inspection, Pole, Photograph

1.6 Detection of damage status

1.6.1 Detection of damage status

Inspection sheet shall be used on the site. If any damage is found during the inspection, the damage status shall be examined for each type of damage according to the inspection sheet. The damage degree shall be recorded by following ways;

- ✓ The damage degree shall be evaluated by “Damage evaluation criterion” on the Inspection sheet.
- ✓ The damage status which cannot be indicated in inspection sheet shall be recorded in damage figure as sketch.

[Examples of record by sketch]

- ✓ Status of the crack in concrete member
- ✓ Location and area of the deformation such as peeling in concrete member
- ✓ Location and status of the crack in steel member
- ✓ Location and status of the deformation in steel member
- ✓ Location and status of other defects, such as water leakage

1.6.2 Evaluation of damage degree

The damage degree shall be evaluated based on appendix-2 “evaluation criteria of damage”.

Those records shall be compiled as the most basic data that indicates the bridge status and be used to consider maintenance plans. Therefore, the evaluation of damage degree shall be conducted accurately to the extent possible.

1.7 Determination of measures category

In periodic inspection, measures category for each member on the structure or each part and each damage type shall be determined by table 1.3 (determination category) referring to appendix-3 “Guideline for determination of measures category” on understanding damage status of the bridge.

Table1.3 Determination category of measures category

Determination category	Contents of determination
A	Damage is not observed, or repair is not required since damage is slight.
B	Repair is required according to the situation.
C	Repairs are required immediately.
E1	Emergency response is required from the view of safety of the bridge structure.
E2	Emergency response is required.
M	Maintenance work is required.

The basic concepts of determination of measures category prescribed in this manual are as follows;

【Category A】

In the range seen in the periodic inspection, damage is not observed, or repair is not required since damage is slight.

【Category B】

Damage that requires repair, but emergency repair is not required since the cause and scale of damage is clearly understood. It is confirmed that the safety is not compromised significantly before the next periodic inspection.

【Category C】

It is confirmed that the repairs are required before the next periodic inspection since the damage has progressed considerably and significant decreased in the function of the member and safety is in stake.

【Category E1】

It is confirmed that the emergency measures are required since the safety of bridge structure has been severely impaired.

【Category E2】

It is determined that emergency measures are required since bicycle, pedestrian traffic failure and fear of damage to third parties are concerned.

【Category M】

Damage is observed, and immediate measures are required in the daily maintenance work in order to keep functionality of the member in good condition.

In the case of determination with C or E1, it is necessary to determine repair or replacement.

1.8 Record of periodic inspection results

Inspection results for damage in the periodic inspection shall be recorded and compiled appropriately.

2. Basic information of the bridge

2.1 Scope

Collecting the basic information of the bridge shall assist to centralize the records relating to bridge maintenance managed by DoR / MoWHS.

2.2 Purpose of collecting basic information

The purpose of collecting basic information is to maintain the bridges appropriately and efficiently. Therefore results of data collection shall be clearly recorded as inventory.

2.3 Composition of bridge inventory

Basic information of the bridge shall be collected. Its information shall be visually and quantitatively clarify the location, scale and traffic volume, etc. Inventory sheet attached in Appindix-2 shall be used for data collection. The composition of the bridge inventory is as follows;

(1) General Data

General data such as a name, date of data collection and bridge number allocated by each RO shall be recorded.

(2) Geographic Data

Name of road, regional office and sub-regional office in charge and location such as coordinate and distance from main town shall be recorded.

(3) Bridge Data

Basic information about the bridge shall be recorded. Items to be collected are;

- ✓ Structure type
- ✓ Number of span and length
- ✓ Bridge length
- ✓ Bridge width (Total and effective width)
- ✓ Height (Abutment and Pier)
- ✓ Type of Deck, Pavement, Wheel guard, Abutment and Pier
- ✓ Loading capacity
- ✓ Construction year (Completion year)
- ✓ Repair record
- ✓ Traffic volume

(4) Photograph

Photograph shall be taken to identify the bridge type and surrounding conditions.

2.4 Establish timeframe of the bridge inventory

Establish and update timeframe of the bridge inventory of a bridge inventory shall follow in Table 2.1.

Table2.1 Establish timeframe of the bridge inventory

	Establish timeframe	Modification	Update
1. General Data	Immediately	If bridge number is changed.	As required
2. Geographic Data	Immediately	When the bridge is hand over from responsible regional office to another regional office, etc.	As required
3. Bridge Data	Immediately for existing bridge Immediately after completion for new bridge	Immediately If there is a change such as height of abutment and pier and traffic volume.	As required Once every five years is desirable
4. Photograph	Immediately for existing bridge Immediately after completion for new bridge	Immediately If surrounding situation of bridge is changed.	As required Once every five years is desirable

Appendix-1 Periodic Inspection Record

1. Bridge Inventory Sheet

Bridge Ledger

Data Collector		Update of Record	／　　／2019
Bridge Name		Bridge Number	

Section	Title	Information	Remarks
Geographic Data	Highway Name/Road Name		
	Stretch Name		
	Dzongkhag		
	Division/Agency		
	Location(Ch. from starting point)		
	Coordinate (latitude)		
	(longitude)		
	Alternate route(Bypass near bridge)		
	Rainfall		
Bridge Data	Bridge Classification		
	Bridge Type		
	Number of Span		
	Span Length [m] (1)		
	(2)		
	(3)		
	(4)		
	Bridge Length[m]		
	Effective Width[m]		
	Total Width[m]		
	Abutment Height(L/B)[m]		
	Abutment Height(R/B)[m]		
	Pier Height[m] (1)		
	(2)		
	Deck Type		
	Wearing Course Type		
	Railing Type		
	Abutment Type		
	Pier Type		
	Loading Capacity		
	Compleation Year		
	Repair Record		
	Total Traffic volume(msa)		

Comments

Update of Record	／　　／2019
Data Collector	
Bridge Name	
Bridge Number	

Photograph			
No.1	From the right	No.2	From the left
No.3	From the right downstream	No.4	From the left downstream
No.5	From the right upstream	No.6	From the left upstream
No.7	From the center to downstream	No.8	From the center to upstream

2. Periodic Inspection Sheet

Inspention Sheet 1

Inspector		Update of Record	/　/20
Bridge Name		Bridge Number	

1.Overall Condition of Bridge

Structure	Damage	Contents	Damage evaluation criterion(a~e)	Evaluation
Whole Bridge	Deflection	Deflection/Sagging	a:Not found b:- c:Minor d:- e:Severe	
	Settlement/ Movement/Inclination	Settlement, movement, inclination of foundation or bearing, etc	a:Not found b:- c:Minor d:- e:Severe	
	Scouring	Scouring of pier or foundation	a:Not found b:- c:Minor d:- e:Severe	
	Sediment Deposition	Dirt/litter deposited on Deck, Girder (Steel) or Abutment	a:Not found b:- c:- d:- e:Found	
	Others	Graffiti, bird damage, fire damage, etc.	Only record	

2.Condition of Damage(Super Structure)

Structure	Member	Material	Damage	Damage evaluation criterion (a~e)	Evaluation
Super Structure	Deck Slab	Concrete	Crack	Appendix	
			Peeling/Rebar exposure	a:Not found b:- c:Peeling d:Rebar exposure (small) e:Rebar exposure (large)	
			Water leakage/Free lime	a:Not found b:- c:Water leakage d:Free lime e:Free lime+Rust fluid	
			Partial loss of concrete	a:Not found b:- c:- d:- e:Found	
			Honeycomb	a:Not found b:- c:Extensively d:Rebar exposure (small) e:Rebar exposure (large)	
		Steel	Corrosion	Appendix	
			Crack	a:Not found b:- c:Less than 3mm (length) d:- e:3mm or more (length)	
			Looseness/Omission	a:Not found b:- c:Less than 5% d:- e:5% or more	
			Fracture	a:Not found b:- c:- d:- e:Found	
			Deterioration of Painting	a:Not found b:- c:Partially d:Peelling e:Peelling and Rust	
	Main Girder	Concrete	Crack	Appendix	
			Peeling/Rebar exposure	a:Not found b:- c:Peeling d:Rebar exposure (small) e:Rebar exposure (large)	
			Water leakage/Free lime	a:Not found b:- c:Water leakage d:Free lime e:Free lime+Rust fluid	
			Honeycomb	a:Not found b:- c:Extensively d:Rebar exposure (small) e:Rebar exposure (large)	
		Steel	Corrosion	Appendix	
			Crack	a:Not found b:- c:Less than 3mm (length) d:- e:3mm or more (length)	
			Looseness/Omission	a:Not found b:- c:Less than 5% d:- e:5% or more	
			Fracture	a:Not found b:- c:- d:- e:Found	
			Deterioration of Painting	a:Not found b:- c:Partially d:Peelling e:Peelling and Rust	

Inspention Sheet 2

Inspector	0	Update of Record	／　／20
Bridge Name	0	Bridge Number	0

3.Condition of Damage(Sub Structure)

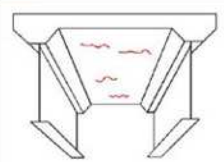
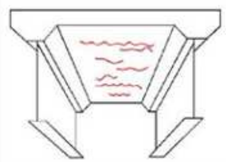
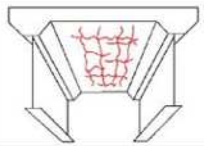
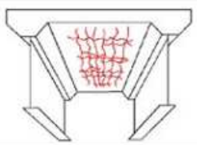
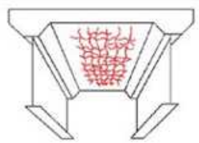
Structure	Member	Material	Damage	Damage evaluation criterion (a～e)	Evaluation
Sub Structure	Body	Concrete	Crack	Appendix	
			Peeling/Rebar exposure	a:Not found b:- c:Peeling d:Rebar exposure (small) e:Rebar exposure (large)	
			Water leakage/Free lime	a:Not found b:- c:Water leakage d:Free lime e:Free lime+Rust fluid	
			Honeycomb	a:Not found b:- c:Extensively d:Rebar exposure (small) e:Rebar exposure (large)	
		Masonry	Damage/Deformation	a:Not found b:- c:Partial Damage d:- e:Deformation	

4.Presence of Damage

Structure	Member	Damage	Contents	Damage evaluation criterion(a～e)	Evaluation
Bearing	Bearing	Defect	Severe corrosion, defect / hardening / missing parts	a:Not found b:- c:Minor d:- e:Severe	
		Noise	Extraordinary noise during passing vehicle	a:Not found b:- c:Minor d:- e:Severe	
	Base Mortar (Bearing Sheet)	Sediment Deposition	Dirt/litter deposited on/around base mortar	a:Not found b:- c:- d:- e:Found	
		Deformation/ Loss	Crack of mortar, partial defect	a:Not found b:- c:Minor d:- e:Severe	
Ancillary Facilities	Railing	Deformation/ Damage	Deformation or broken part	a:Not found b:- c:Less than 50% d:- e:50% or more	
			Risk for bridge users	a:Not found b:- c:Minor d:- e:Severe	
Deck Surface	Wearing Course	Abnormity	Hole, big pothole, crack	a:Not found b:- c:Cracks d:- e:Pot Holes	
		Unevenness	Risk for bridge users	a:Not found b:- c:Less than 2cm d:- e:More than 2cm	
		Sediment Deposition	Dirt/litter deposited on pavement	a:Not found b:- c:- d:- e:Found	
	Expansion joint	Abnormity	Broken	a:Not found b:- c:Minor d:- e:Separating or Squeezing	
		Unevenness	Level difference	a:Not found b:- c:less than 2cm d:- e:2cm or more	
Drainage Facilities		Clogging	Clogging with soil and overlay	a:Not found b:- c:- d:- e:Found	
		Water Leakage	Broken or drained water afftected to girder or other member	a:Not found b:- c:Minor d:- e:Severe	

Appendix

【Crack on slab】

	Crack phenomenon	
a	【Crack spacing & crack characteristic】 Crack has occurred only on one direction and more than 1.0m as minimum crack spacing. 【Crack width】 Less than 0.05mm of maximum	
b	【Crack spacing & crack characteristic】 Crack has mainly occurred on one direction and crack spacing of between 1.0m～0.5m, but not square-block type. 【Crack width】	
c	【Crack spacing & crack characteristic】 Crack has occurred on about 0.5m before square-block type. 【Crack width】 Mainly less than 0.2mm, but partly	
d	【Crack spacing & crack characteristic】 Crack has occurred on 0.5m～0.2m and also square-block type. 【Crack width】 Over 0.2mm and partly peeling off	
e	【Crack spacing & crack characteristic】 Crack has occurred on less than 0.2m and mainly square-block type. 【Crack width】 More than 0.2mm and continuously	

【Corrosion on steel】

	Corrosion phenomenon
a	Nothing
b	Corrosion has ocuurred on steel surface, but impossible to see reduction of its thickness. Furtheremore very minor area of corrosion damage.
c	Corrosion has ocuurred on steel surface, but impossible to see reduction of its thickness. And rust has occurred entirely on focusing parts or some spred area.
d	Corrosion has ocuurred on steel surface, also possible to see slightly reduction of its thickness. And rust has occurred entirely on focusing parts or many spred area.
e	Corrosion has apparently expanded on steel surface, also possible to see definitely reduction of its thickness. And rust has occurred entirely with many spred area.

【Crack on concrete structure】

	Crack phenomenon
a	Nothing
b	-
c	Small crack width (less than 0.2mm in case of RC structure)
d	Midium crack width (more than 0.2mm to less than 1.0mm in case of RC structure)
e	Large crack width (more than 1.0mm in case of RC structure)

3. Type of typical damage

Material	Type of damage
Steel	Corrosion
	Looseness / omission
Concrete	Crack
	Peeling / Exposure of rebar
	Water leakage / Free lime
	Crack in slab
Others	Uneven road surface
	Sediment clogging
Common	Deformation / damage
	Scouring

4. Evaluation of damage degree

Good	——	Mild	——	Severe
a	b	c	d	e

5. Determination of measures category

Determination category	Contents of determination
A	Damage is not observed or repair is not required since damage is slight.
B	Repair is required according to the situation.
C	Repairs are required immediately.
E1	Emergency response is required from the view of safety of the bridge structure.
E2	Emergency response is required.
M	Maintenance work is required.

6. Total Condition

Total rating of Bridges are classified into 5 categories in consideration of factors affecting collapsing of bridges and ultimate load carrying capacity.

Determination category	Contents of determination
A (Very good)	The structure is not damaged.
B (Good)	The structure is damaged but not dangerous for users.
C (Fair)	The structure is damaged and getting dangerous for users in near future.
D (Poor)	The structure is severely damaged and dangerous for users.
E (Bad)	The structure is completely destroyed and unusable.

7. Elision Mark for the Regional Office of DoR

Location of the Office	Elision Mark
Thimphu	Th
Lobeysa	Lo
Phuntsholing	Pl
Sarpang	Sa
Trongsa	Tr
Tingtibi	Ti
Lingmethang	Li
Trashigang	Tg
Samdrup Jongkhar	Sj

Appendix-2 Evaluation Criteria of Damage

1. Corrosion

It refers to the state that rust has occurred intensively, or reduction in cross section or corrosion has occurred due to rust proceeds extremely in ordinary steel (protected against corrosion by plating or coating), and the state that abnormal rust has occurred without the formation of stable rust, or reduction in cross section is remarkable due to the extreme progress of rust in weathering steel.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

The category shall be determined by combining of large and small scale judged from their general condition to each following factor about damage.

1.1 Category of evaluation of the damage degree

Category	General condition	
	The depth of damage	The area of damage
a	No damage	
b	Small	Small
c	Small	Large
d	Large	Small
e	Large	Large

1.2 General condition of each factor

(1) The depth of damage

Category	General condition
Large	Significant expansion has occurred in the steel surface or apparent decrease in thickness is visible.
Small	Rust is superficial, and significant reduction in thickness is not visible.

(2) The area of damage

Category	General condition
Large	A gap has occurred in focused part all over, or there are more than one of occurrence of spread damage in focused part.
Small	The area of damage is small and local.

1.3 Case of evaluation of the damage degree

Category : b	Category : c
	
Category : d	Category : e
	

2. Crack

It refers to the state that cracks have occurred on the surface of the concrete member. About the crack occurred on the slab; refer to “5.Crack in slab”.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

The category shall be determined by combining of large and small scale judged from their general condition to each following factor about damage.

2.1 Category of evaluation of the damage degree

Category	Damage degree focused on the maximum crack width	Damage degree focused on the minimum crack spacing
a	No damage	
b	Small	Small
c	Small	Large
	Middle	Small
d	Middle	Large
	Large	Small
e	Large	Large

2.2 General condition of each factor

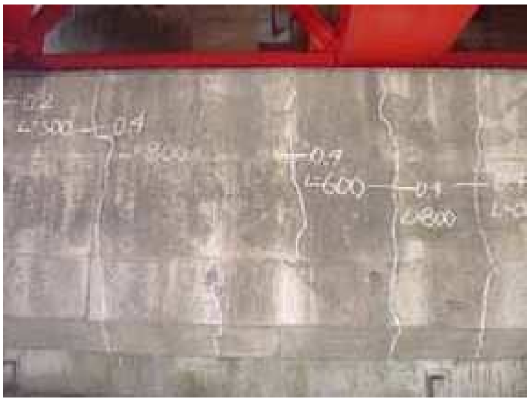
(1) Damage degree focused on the maximum crack width

Category	General condition
Large	Crack width is large. (1.0 mm or more)
Medium	Crack width is medium. (over 0.2 mm less than 1.0 mm)
Small	Crack width is small. (less than 0.2 mm)

(2) Damage degree focused on the minimum crack spacing

Category	General condition
Large	Crack spacing is small. (approximately less than 0.5 m)
Small	Crack spacing is large. (approximately 0.5 m or more)

2.3 Case of evaluation of the damage degree

Category : c	Category : d
	
Category : e	Category :
	

3. Peeling/ Rebar exposure

It refers to the state that concrete surface has been peeled off. Rebar exposure refers to the case that the rebar in the peeling part is exposed.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	Only peeling has occurred
d	Although rebar is exposed, but the corrosion of rebar is slight.
e	Rebar is exposed, and the rebar has corroded significantly.

3.1 Case of evaluation of the damage degree

Category : c	Category : d
	
Category : e	
	

4. Water leakage / Free lime

It is refers to the state that leakage or exudation of water or lime has occurred from the concrete joint or crack.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	Water leakage or free lime has occurred, but rust fluid is hardly seen.
d	—
e	Water leakage or free lime from crack has occurred significantly, or significant contamination of mud or rust fluid in water leakage is observed.

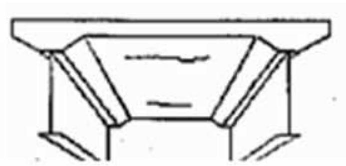
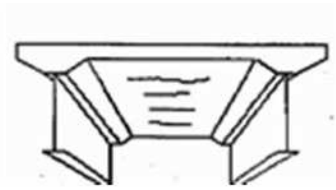
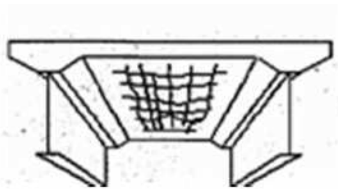
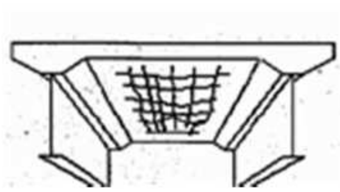
4.1 Case of evaluation of the damage degree

Category : c	Category : e
	

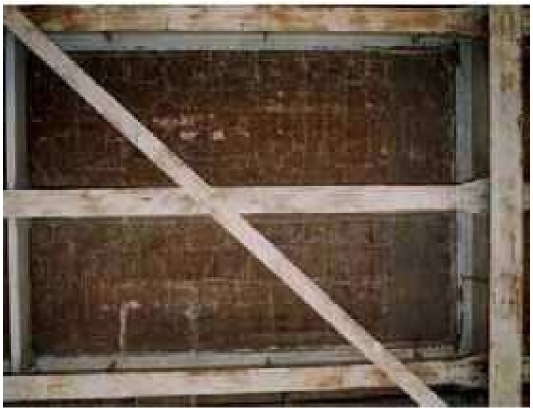
5. Crack on slab (Partial loss of concrete)

It is cracks occurred in slab, and refers to the state that crack has occurred in one or two direction on the lower surface of slab.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	Damage degree focused on the maximum crack width	Damage degree focused on the minimum crack spacing
a	Cracks are seen mostly in only one direction. The minimum crack spacing is approximately 1.0 m or more. The maximum crack width is less than 0.05 mm.	
b	The crack spacing is 1.0-0.5 m. Crack is mainly in one direction and not a lattice pattern. The crack width is mainly less than 0.1 mm and some are 0.1 mm or more.	
c	The crack spacing is approximately 0.5 m. Crack is just before becoming lattice pattern. The crack width is mainly less than 0.2 mm and some are 0.2 mm or more.	
d	The crack spacing is 0.5-0.2 m. Cracks occur in a lattice pattern. The cracks wider than 0.2 mm are quite noticeable and partial falling of corner is also seen.	
e	The crack spacing is less than 0.2 m. Cracks occur in a lattice pattern. The cracks wider than 0.2 mm are noticeable and continuous fallings of corner are also seen.	

5.1 Case of evaluation of the damage degree

Category : b	Category : c
	
Category : d	Category : e
	

6. Uneven road surface

It refers to the irregularities in the horizontal axis and the differences in level occur on the road surface that result the increase of the impact force.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	The irregularities in the horizontal axis have occurred, but the difference in level is small. (less than 20 mm)
d	—
e	The irregularities in the horizontal axis have occurred, and the difference in level is large. (20 mm or more)

6.1 Case of evaluation of the damage degree

Category : c	Category : e
	

7. Sediment clogging

It refers to the state that the sediment clogged in catch basin or drainage pipe, or the sediment is deposited around bearing.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	—
d	—
e	There is the sediment clogging in catch basin and around bearing.

7.1 Case of evaluation of the damage degree

Category : e	Category :
	

8. Deformation/damage

It refers to the state that the local deformation of the member has occurred or parts of member lacked regardless of the cause such as collision of the vehicle, scratch during construction and influence of the earthquake.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	The member is deformed locally.Parts of member lacked.
d	—
e	The member is significantly deformed locally. Parts of member lacked significantly.

8.1 Case of evaluation of the damage degree

Category : c	Category : e
	

9. Scouring

It is refers to the state that the foundation body is carved by running water and lacked.

[Evaluation of the damage degree]

The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	The foundation of substructure or wing wall is scoured by running water.
d	—
e	The foundation of substructure is significantly scoured by running water.

9.1 Case of evaluation of the damage degree

Category : c	Category : e
	

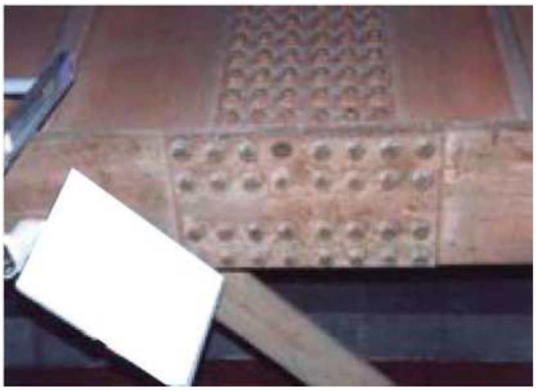
10. Looseness/omission

It is refers to the state that looseness of the bolt occurs or nuts and bolts is missing. Include those that bolts are broken.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	―
c	The looseness or omission of bolts has occurred, but the number is small. (less than 5% of number per group)
d	―
e	The looseness or omission of bolts has occurred, and the number is large.(more than 5% of number per group)

10.1 Case of evaluation of the damage degree

Category : c	Category : e
	

11. Honeycomb

It is refers to the state of honeycomb by initial defect.

[Evaluation of the damage degree]

The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	Honeycomb is slightly seen.
c	Honeycomb is slightly seen and aggregates are partly peeling off.
d	Honeycomb is extensively seen and aggregates are easily peeling off
e	Honeycomb is extensively seen and aggregates are easily peeling off besides rebar is exposed and rusted.

11.1 Case of evaluation of the damage degree

Category : b	Category : c
	
Category : d	Category : e
	

Appendix-3 Guideline for determination of measures category

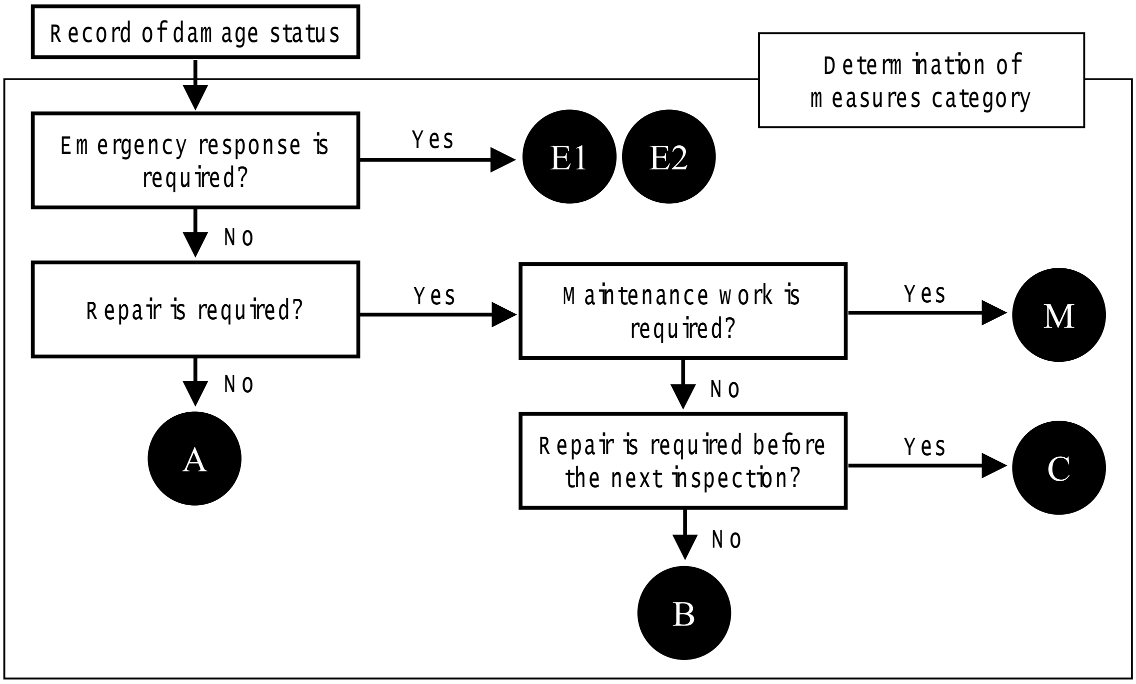
1. Basic of determination of measures category

1.1 General

The determination of damage status shall be conducted by comprehensive evaluation of various factors such as the progress of damage of member and environmental condition.

1.2 Flow of determination of measures category

The basic flow of determination of measures category is as follows;



1.3 Observation

It describes the view of the surveyor on damage status.

2. Determination of measures category

2.1 Corrosion

[Category E1: Emergency response is required from the view of safety of the bridge structure]

The significant reduced cross-sectional area has occurred in the main members, emergency response may be reasonable in the situation that the structural safety has been compromised significantly due to the loss of load bearing capacity of member.

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

There is no overall damage, but the corrosion caused by small scratches can be seen partially. Maintenance work may be reasonable in the situation that damage is small in a scale and in a convenient location for measures.

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
General steel member	➢ Water leakage from cracks in slab ➢ Non-installation of waterproof layer ➢ Water leakage from the installation part of drainage equipment ➢ Water leakage from the damaged part of the expansion joint	➢ Excess stress due to reduced cross sectional area ➢ Development to the crack due to concentration of stress

2.2 Crack

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Whole concrete member	➢ Lack of designed strength ➢ Freezing and thawing ➢ Lack of compaction ➢ Poor curing ➢ Temperature stress ➢ Drying shrinkage ➢ Poor quality of concrete ➢ Cold joint ➢ Uneven settlement	➢ Progress of crack and decrease in load bearing ability due to excess stress ➢ Corrosion of rebar due to crack ➢ Occurrence of water leakage/free lime

2.3 Peeling / Exposure of rebar

[Category E1: Emergency response is required from the view of safety of the bridge structure]

Emergency response may be reasonable in the situation that the third-party damage is a concern because the risk is very high resulting in peeling off.

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

There is no overall damage, but peeling can be seen partially. Maintenance work may be reasonable in the situation that damage is small in a scale and in a convenient location for measures.

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Whole concrete member	➢ Lack of covering, poor finishing of construction joint ➢ Freezing and thawing ➢ Lack of compaction ➢ Concentration of local stress ➢ Collision or contact ➢ Volume expansion due to corrosion of steel	➢ Decrease in load bearing ability due to reduced cross-sectional area ➢ Decrease in load bearing ability due to corrosion of steel

2.4 Water leakage / Free lime

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Whole concrete member	➢ Progress of water leakage ➢ Progress of crack ➢ Lack of compaction ➢ Poor finishing of construction joint ➢ Poor method of placing	➢ Corrosion of steel due to crack ➢ Concrete degradation

2.5 Crack in slab

[Category E1: Emergency response is required from the view of safety of the bridge structure]

The significant cracks can be seen. Emergency response may be reasonable in the situation that structural safety has been compromised significantly due to reduction of stiffness of the entire superstructure.

[Category E2: Emergency response is required]

Cracks just on the verge of falling in slab have occurred. Emergency response may be reasonable in the situation that the third-party damage due to peeling fall is a concern.

[Category M: Maintenance work is required]

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Concrete slab	➢ Lack of designed strength ➢ Drying shrinkage ➢ Lack of distribution reinforcement ➢ Uneven settlement of support girder	➢ Progress of water leakage and free lime

2.6 Uneven road surface

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

Emergency response may be reasonable in the situation that the obstruction to traffic of bicycles due to significant unevenness on the road is a concern.

[Category M: Maintenance work is required]

Maintenance work such as partial overlay of the pavement may be reasonable in the situation that the unevenness on the road is small and damage is partial, and its area is small.

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Expansion device	➢ Subsidence of bearing, uplift due to damage of bolt set	➢ Effect of impact force to the main structure, traffic obstacles

2.7 Sediment clogging

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

The sediment clogging has occurred only in catch basin. Maintenance work may be reasonable in the situation that its scale is small.

[Category B, C: Repairs are required]

In case that the maintenance work cannot deal for a scale because the sediment clogging has occurred over the entire length of drainage pipe.

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Drainage facilities, bearing	➢ Sediment clogging	➢ Corrosion of main structure ➢ Degradation of slab

2.8 Deformation / damage

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

Emergency response may be reasonable in the situation that the obstruction to the third party such as pedestrians and vehicles due to significant deformation of the bridge railing is a concern.

[Category M: Maintenance work is required]

Maintenance work may be reasonable in the situation that the small deformation has occurred locally on the bridge railing.

[Category B, C: Repairs are required]

In case that the maintenance work cannot deal for a scale because the damage due to collision of the vehicle has occurred to the overhanging slab.

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Whole member	➢ Lack of covering ➢ Concentration of local stress ➢ Collision or contact	➢ Secondary disaster ➢ Decrease in load bearing ability due to reduced cross-sectional area

2.9 Scour

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Foundation	➢ Change in the running water due to driftwood	➢ Progress of scour may cause the slope in the substructure

2.10 Looseness/omission

[Category E1: Emergency response is required from the view of safety of the bridge structure]

Emergency response may be reasonable in the situation that damaging the structure stability for bonding strength shortage due to a number of bolts is missing at the junction.

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

Maintenance work may be reasonable in the situation that scale of damage is small such as looseness occurs in the ordinary bolt of parapet and attachment.

[Category B, C: Repairs are required]

[Reference on describing the observations]

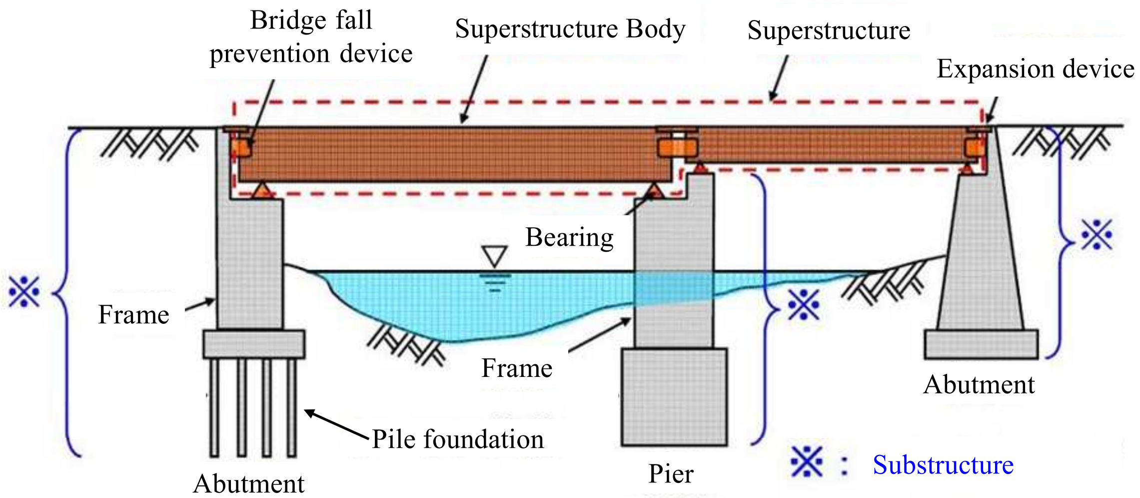
Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Main girder Cross beam Sway frame Lateral	➢ Omission of bolts at splice	➢ Breakage due to delayed fracture may occur.

Appendix-4 Basics of bridge

1. Basic structure of bridge

1.1 Name of the bridge structure

- Bridge
  - Superstructure
    - Body
    - Appendages・・・・・Bearing, Expansion device etc.
  - Substructure
    - Frame・・・・・・・・・・Abutment, Pier
    - Foundation・・・・・・Pile foundation etc.



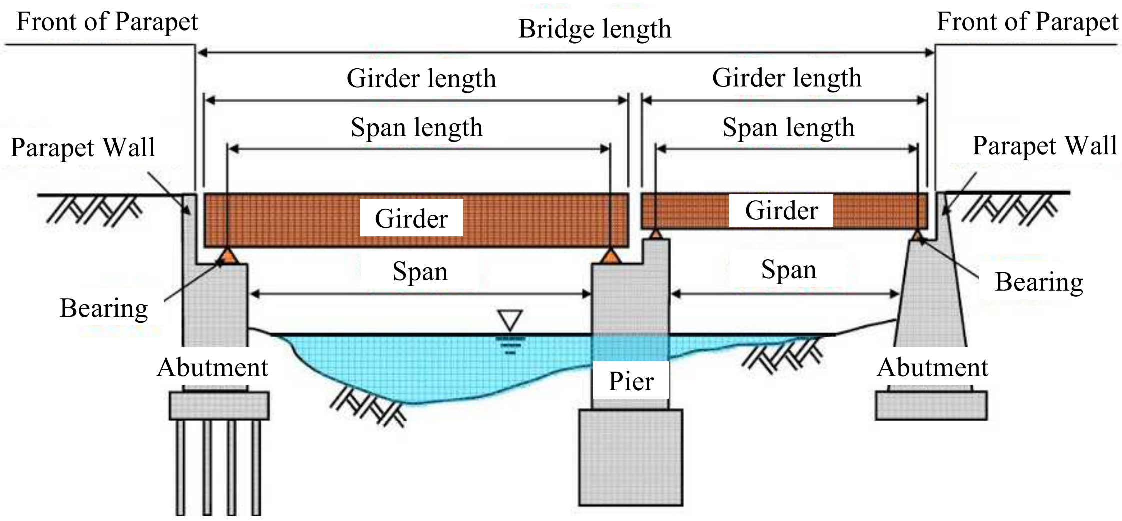
1.2 Length of the bridge

Bridge length・・・・・length between the front parapet of the bridge at both ends

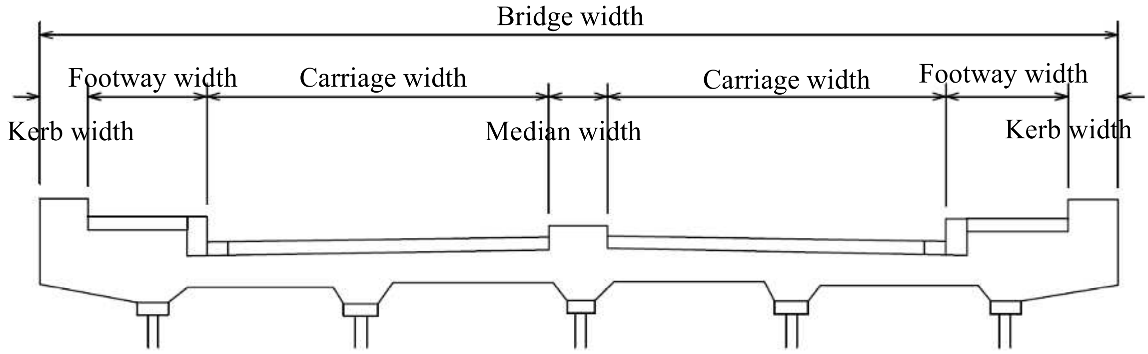
Girder length・・・・・length of main girder

Span length・・・・・length between bearings

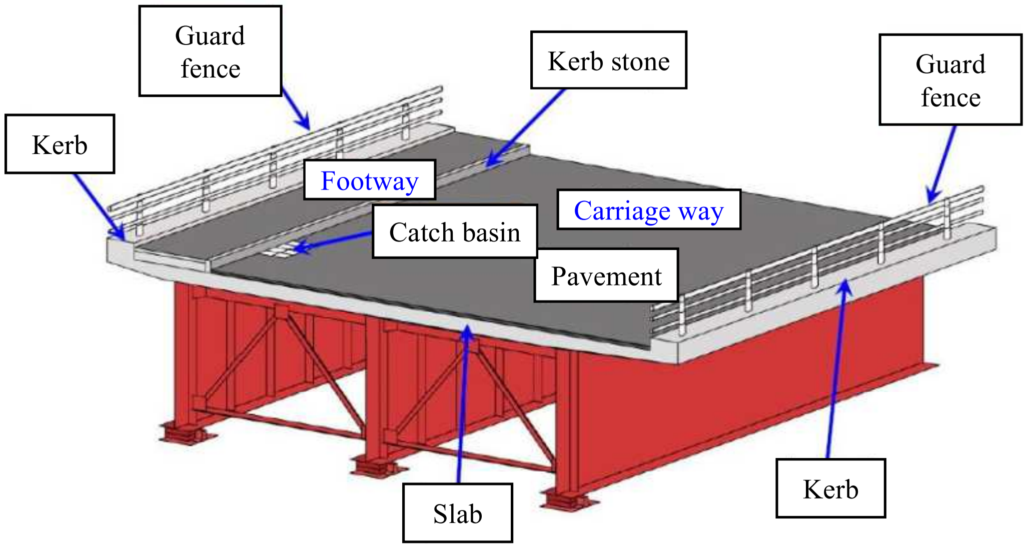
Span・・・・・length between abutments (piers) of substructure



1.3 Width of the bridge

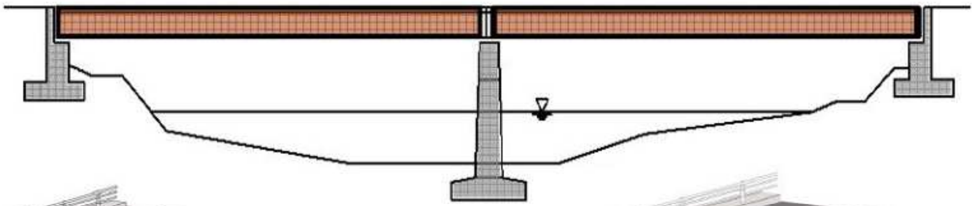


1.4 Bridge surface



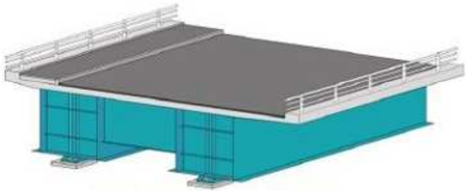
2. Bridge type

2.1 Girder bridge

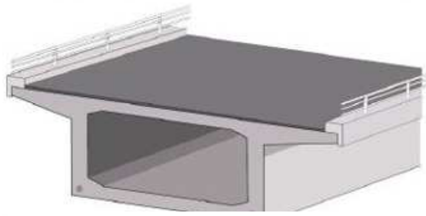


I-Girder Bridge（Steel Bridge）

T-Girder Bridge（Concrete Bridge）



Box Girder Bridge（Steel Bridge）



Box Girder Bridge（Concrete Bridge）

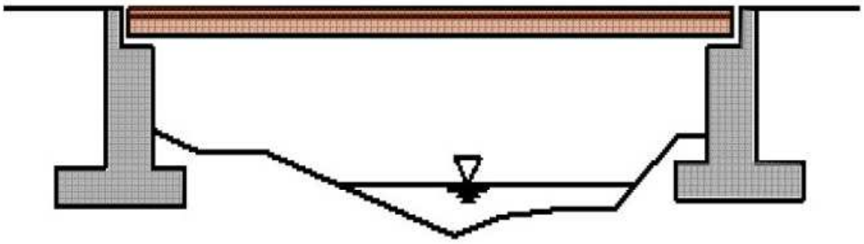
【Under the girder】

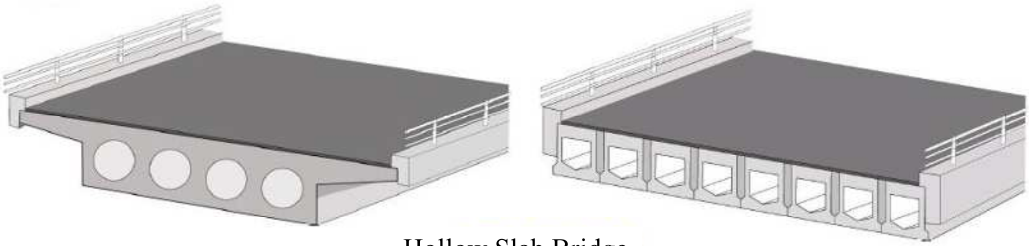
I-Girder Bridge

T-Girder Bridge

Box-Girder Bridge

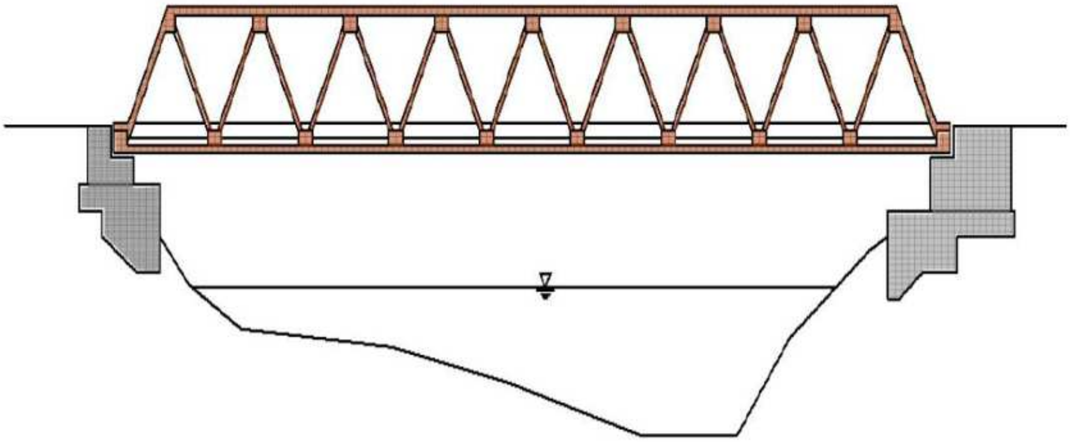
2.2 Slab bridge * (No girder)





Hollow Slab Bridge

2.3 Truss bridge

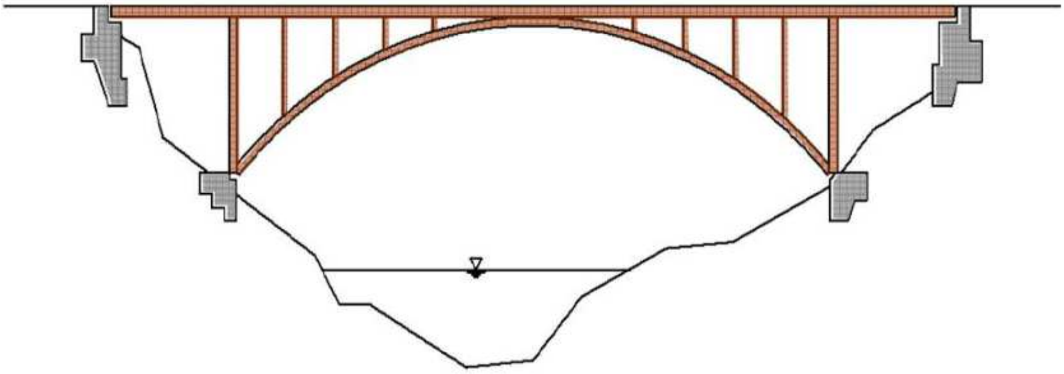


【Bridges in Bhutan】

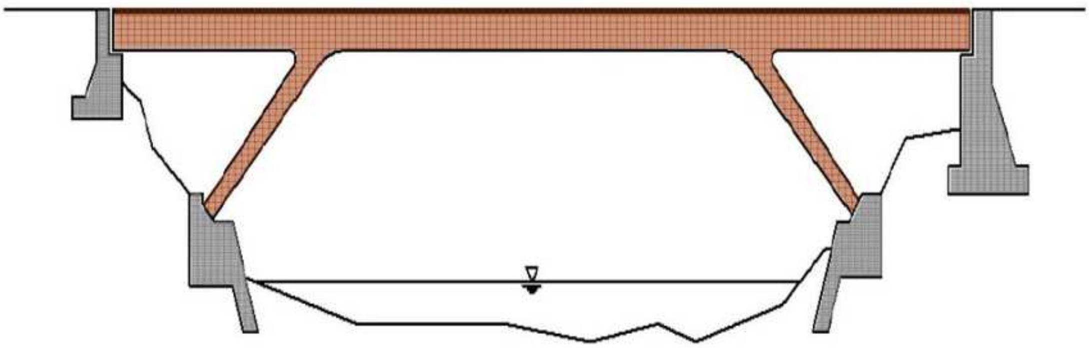
Slab Bridge
(NgashayZam in Wangdue)

Steel Truss Bridge
(Isuna in Paro)

2.4 Arch bridge



2.5 Rigid frame bridge



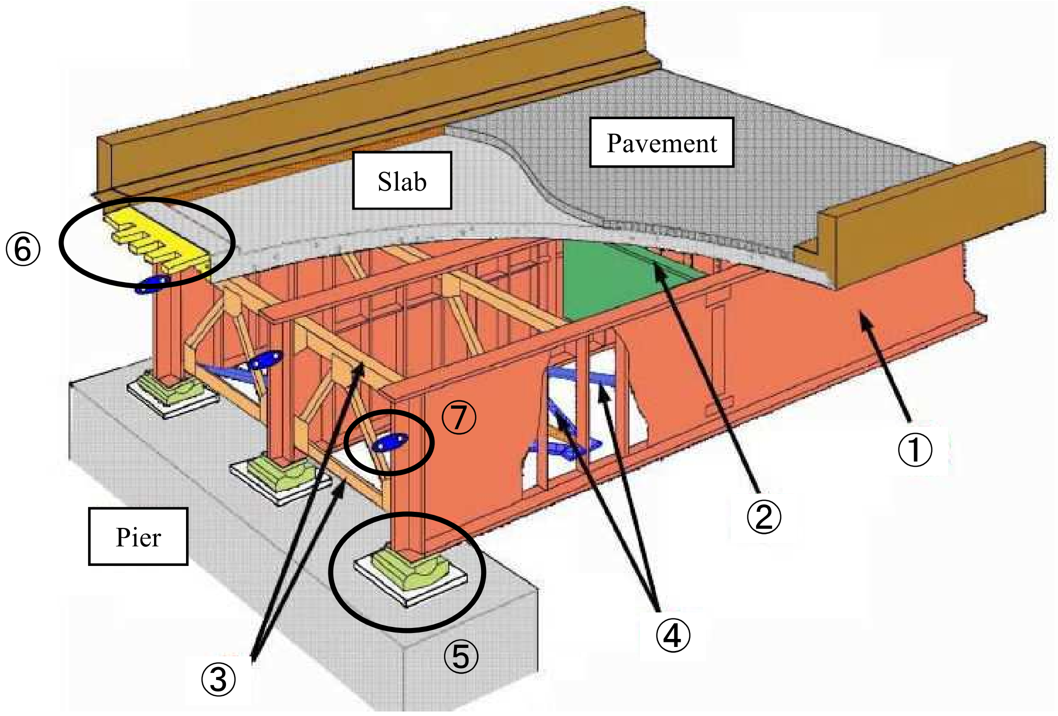
【Bridges in Bhutan and Japan】

Steel Langer Arch Bridge
（Wakleytar in Wangdue）

Rigid Frame Bridge

3. Names and Functions of the structural member

3.1 Superstructure



① Main girder

It is passed between the piers and abutments which support the loads such as passing vehicles on the slab and transmitted the loads to the piers and abutments.

② Cross beam

It is a member that connects the main girders that support the loads.

③ Cross frame

It is a member that connects main girders vertically in order to resist the lateral loads such as earthquakes and wind loads. (It is not in concrete bridge)

④ Lateral bracing

It is a member that connects main girders horizontally in order to resist the lateral loads such as earthquakes and wind loads. (It is not in concrete bridge)

⑤ Bearing

Which support the superstructure and transmits the load from the superstructure to the substructure (abutment or pier).

⑥ Expansion device

It is a device to absorb the expansion and contraction of the girder due to the influence of temperature or the like.

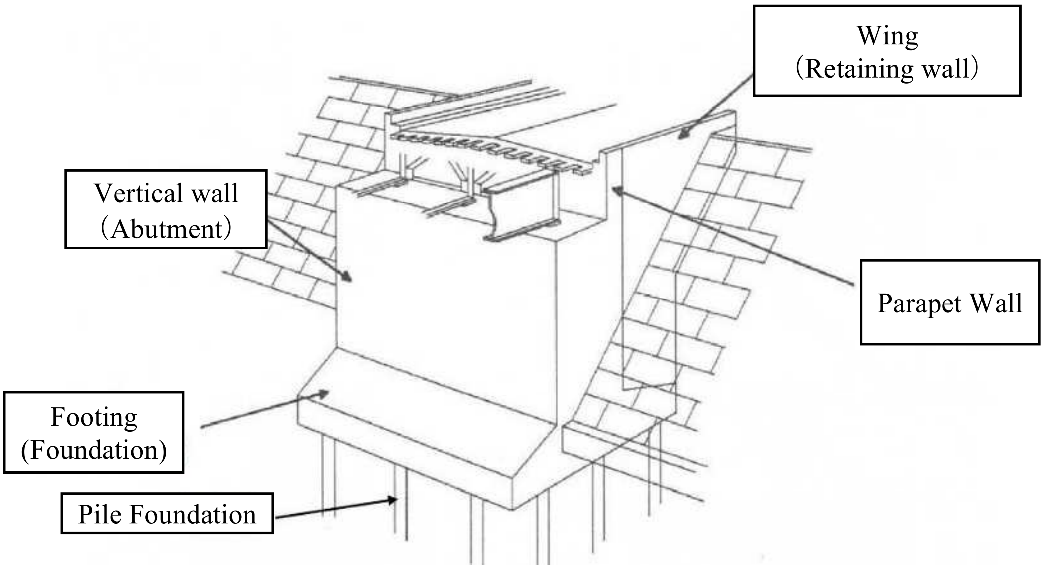
⑦ Bridge fall prevention device

It is a device that is installed in order to prevent the superstructure to fall from substructure (abutment or pier) by superstructure is moved due to earthquakes.

3.2 Substructure

3.2.1 Abutment

It is located at both ends of the bridge, connects the bridge and roads, which supports the sediment on the back and the load from the superstructure.

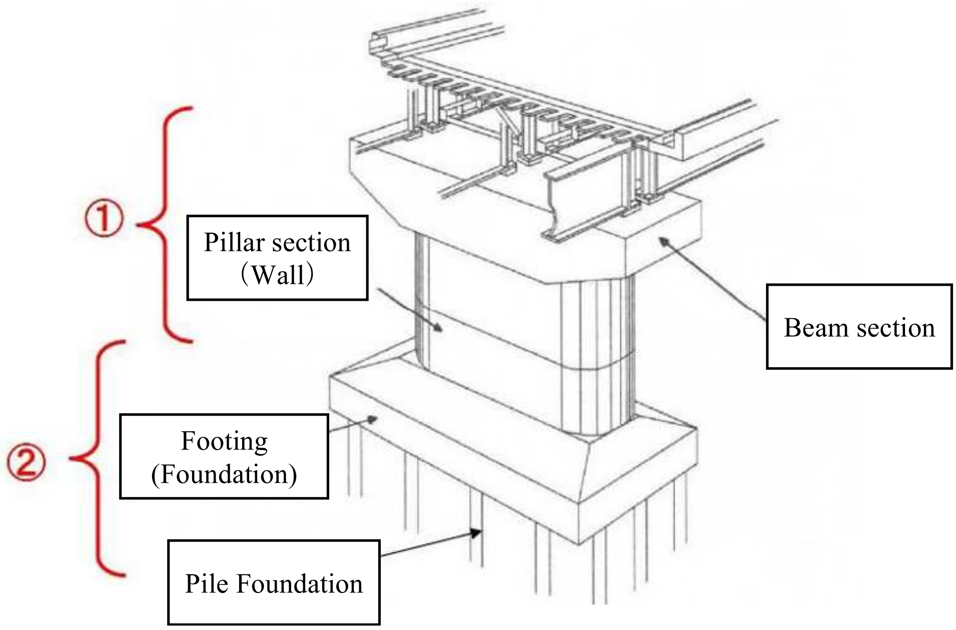


3.2.2 Pier

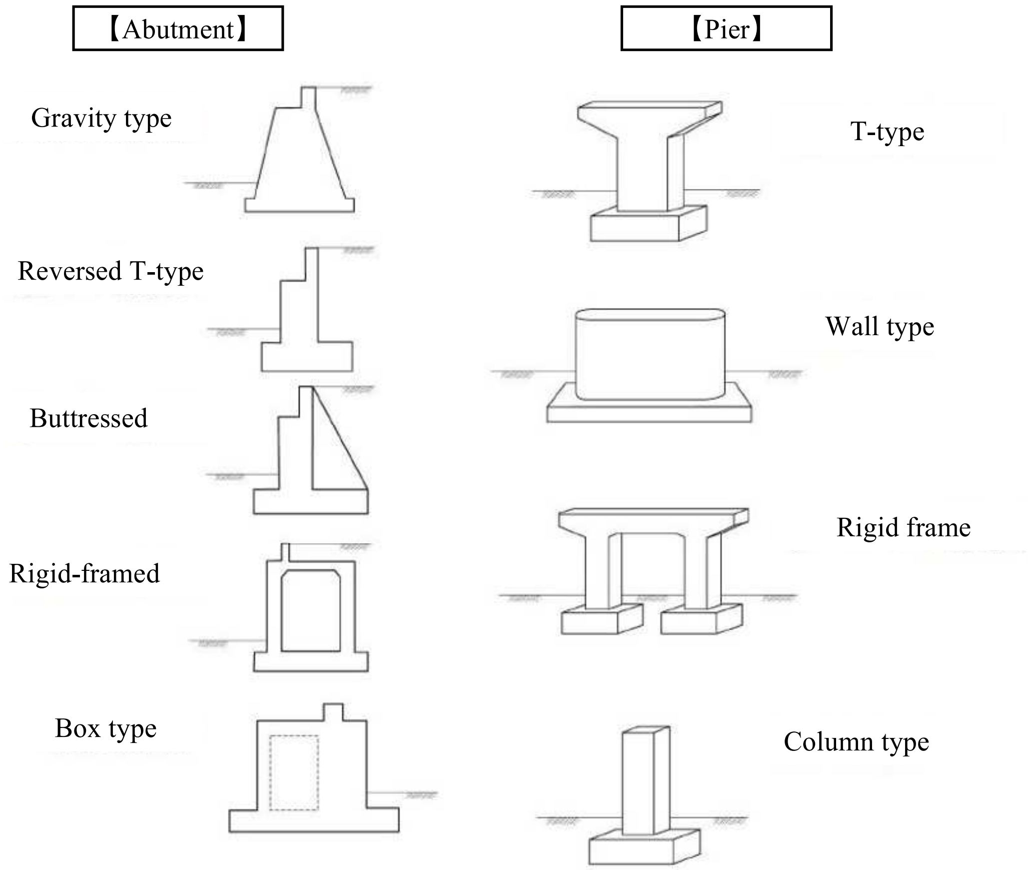
It is located at middle of the bridge, supports the load from the superstructure.

3.2.3 Foundation

It is located under abutment and pier, transmits the load to the ground.



3.2.4 Substructure Type



Appendix-5 Bridge List

1. Bridge List

1.1 Thimphu

Bridges under Regional Office, DoR, Thimphu

Name of Bridge	Bridge No.	Road	Section	Sub Division	Dzongkhag
Khasadrapchu Zam	Th-1	Khasadrapchu-Bjemina SNH	Thimphu (Sub-1)	Thimphu (Sub-2)	Thimphu
Simtokha Fly over Bridge	Th-2	Simtokha-Dochula Highway			
Dhop Shari Bridge	Th-3	Jangsa – Rimpung Dzong	Paro	Paro (Sub-3)	Paro
Hungrel Bridge	Th-4	Jangsa – Hungrel Gewog Office			
Jangsa Bridge	Th-5	Jangsa_Rimpung Road			
NIE Bridge	Th-6	Town to Bondey Road			
Taktsang Bridge	Th-7	Drukgyel junction to Taktsang Road			
Tshendona Bridge	Th-8	Town to Lamgong Gewog office			
Balamna Bridge	Th-9	Haa-Samtse SNH	Haa	Haa (Sub-4)	Haa
Haa Chu Bridge	Th-10	Yangthang,Talung,Tshenkhar Road.			

1.2 Lobeysa

Bridges under Regional Office, DoR, Lobesa

Name of Bridge	Bridge No.	Load	Section	Sub Division	Dzongkhag
Zameychu Zam	Lo-1	Punakha-Gasa SNH	Gasa	Damji	Gasa
Gayza Zam	Lo-2	Punakha-Gasa SNH			
Gathana Zam	Lo-3	Punakha-Gasa SNH			
Yemina Zam	Lo-4	Punakha-Gasa SNH			
Kukuna Zam	Lo-5	Punakha-Gasa SNH			
Tingtha Zam	Lo-6	Punakha-Gasa SNH			
Rableythang Zam	Lo-7	Punakha-Gasa SNH	Tsodelmo		
Tshorim Zam	Lo-8	Punakha-Gasa SNH			
Rimchu Zam	Lo-9	Punakha-Gasa SNH			
Serigang Zam	Lo-10	Punakha-Gasa SNH			
Teoporongchu Zam	Lo-11	Punakha-Gasa SNH			
Changyul Zampa	Lo-12	Dzongchung Road	Phochu	Lobeysa	Punakha
Khuru Kuenphen Zam	Lo-13	Bajo-Khuru SNH			
Samdingkha Zam	Lo-14	Chubu GC roads			
Wangdue Zam (arch bridg	Lo-15	Dochula- Wangdue PNH	Lobeysa		Wangdue
Ruebesa Zam	Lo-16	Rubesa Gewog center Road			
Rakey Zam	Lo-17	Samtengang Dz.Road	Rabuna		
Chabjiha Zam -I	Lo-18	Baylangdra Dz.Road			
Chabjiha Zam -II	Lo-19	Baylangdra Dz.Road			
Chuzomsa Zam	Lo-20	Wangdue-Chuserbu PNH			
Wachey Zam (New)	Lo-21	Wangdue-Chuserbu PNH			
Nobding shongZam	Lo-22	Jangchubcholing-Tashidingkha Dzongkhag Road	Nobding	Nobding	
Ridha shong Zam	Lo-23	Jangchubcholing-Tashidingkha Dzongkhag Road			
Ridha shong Zam II	Lo-24	Jangchubcholing-Tashidingkha Dzongkhag Road			
Shamoshong Zam	Lo-25	Jangchubcholing-Tashidingkha Dzongkhag Road			
Dangchu Zam	Lo-26	Jangchubcholing-Tashidingkha Dzongkhag Road			
Nikachu Zam	Lo-27	Wangdue-Chuserbu PNH	Rukubji		
Longmey Zam	Lo-28	Wangdue-Chuserbu PNH			
Phenchimerizam	Lo-29	Wangdi-Trongsa Highway			
Phojikha Zam	Lo-30	Gangtay Phobjikha GC road			
Gemzina Zam	Lo-31	Wangdi-Trongsa Highway	Nobding		
Wachey Zam	Lo-32	Wangdue-Chuserbu PNH			
Hesothangkha Zam	Lo-33	Wangdue-Tsirang PNH	Petekarp	Pinsa	
Lawakha Zam	Lo-34	Wangdue-Tsirang PNH			
Basochu Zam	Lo-35	Wangdue-Tsirang PNH			
Rurichu Zam	Lo-36	Wangdue-Tsirang PNH			
Baychu Zam	Lo-37	Wangdue-Tsirang PNH			
Kamichu Zam	Lo-38	Wangdue-Tsirang PNH	kamichu		
Nyarachu Zam	Lo-39	Wangdue-Tsirang PNH			
Dickchu Zam	Lo-40	Athang GC Road			

1.3 Phuntsholing

Bridges under Regional Office, DoR, Phuentsholing

Name of Bridge	Bridge No.	Load	Section	Sub Division	Dzongkhag
Damdum Bailey bridge	Pl-1	Samtse-Sipsu SNH(0-49)km	Samtse	Samtse	Samtse
Budhuney Bailey bridge -1	Pl-2	Samtse-Sipsu SNH(0-49)km			
Budhuney Bailey bridge -2	Pl-3	Samtse-Sipsu SNH(0-49)km			
Dram zam	Pl-4	Samtse-Sipsu SNH(0-49)km			
Kuenphen Zam	Pl-5	Samtse-Sipsu SNH(0-49)km			
Chungpathang Bridge	Pl-6	Samtse-Sipsu SNH(0-49)km			
KuchiDiana Bridge	Pl-7	Samtse-Sipsu SNH(0-49)km			
Lengthey Bridge	Pl-8	Samtse-Sipsu SNH(0-49)km			
Gathia Bridge	Pl-9	Samtse-Sipsu SNH(0-49)km			
Jitti A	Pl-10	Samtse-Sipsu SNH(0-49)km			
Jitti B	Pl-11	Samtse-Sipsu SNH(0-49)km			
Jitti C	Pl-12	Samtse-Sipsu SNH(0-49)km			
Jitti D	Pl-13	Samtse-Sipsu SNH(0-49)km			
Tashicholing Bridge	Pl-14	Samtse-Sipsu SNH(0-49)km			
Biru	Pl-15	Samtse-Sipsu SNH(0-49)km	Sipsu		
Pakpey Bridge	Pl-16	Samtse-Sipsu SNH(0-49)km			
Bindu Bridge	Pl-17	Samtse-Sipsu SNH(0-49)km			
Bhalujhora bridge	Pl-18	Rinchending-Pasakha PNH	Rinchending	Darla	Chukha
Padazekha Steel bridge	Pl-19	Rinchending-Pasakha PNH			
Shingkhola Zam	Pl-20	Pasakha-Manitar PNH			
Ademchhu Zam	Pl-21	Ganglakha-Dungna GC Road	Dungna		
Tomichu Zam	Pl-22	Ganglakha-Dungna GC Road			
Mailumchu Zam	Pl-23	Ganglakha-Dungna GC Road			
Wangchu Bailey bridge	Pl-24	Gedu-Jungley Dzongkhag Road	Mirchim		
Hobjelum Bailey bridge	Pl-25	Gedu-Jungley Dzongkhag Road			
Satholumpa steel bridge(1)	Pl-26	Geduchu Dzongkhag Road			
Raidak bridge	Pl-27	Manitar-Raidak PNH	Darla		
Outsholumpa Bridge(1)	Pl-28	Geduchu Dzongkhag Road	Mirchim		
Outsholumpa Bridge(2)	Pl-29	Geduchu Dzongkhag Road			
Satholumpa steel Bridge(2)	Pl-30	Geduchu Dzongkhag Road			
Geduchu Steel bridge	Pl-31	Geduchu Dzongkhag Road			
Kalikhola bridge	Pl-32	Raidak-Lhamoizingkha PNH	Darla		

1.4 Sarpang

Bridges under Regional Office, DoR, Sarpang

Name of Bridge	Bridge No.	Load	Section	Sub Division	Dzongkhag
Katley I	Sa-1	Gelephu-Trongsa PNH	Lungsaygang	Lungsaygang	Sarpang
Katley II	Sa-2	Gelephu-Trongsa PNH			
Katley III	Sa-3	Gelephu-Trongsa PNH			
Samkhara Zam	Sa-4	Gelephu-Trongsa PNH			
Beteni Zam	Sa-5	Gelephu-Trongsa PNH			
Passang Zam	Sa-6	Gelephu-Trongsa PNH	Pelrithang		
Geleg Zam	Sa-7	Gelephu-Trongsa PNH			
Barsong Zam	Sa-8	Gewog Connectivity Road			
Paithachu Bridge	Sa-9	Gelephu-Sarpang PNH (2.95km to 30km)	Bhur	Sarpang	
Goikolche Bridge	Sa-10	Gelephu-Sarpang PNH (2.95km to 30km)			
Kopche Bridge	Sa-11	Gelephu-Sarpang PNH (2.95km to 30km)			
Dolkhola Bridge	Sa-12	Gelephu-Sarpang PNH (2.95km to 30km)			
Panditchu Bridge	Sa-13	Gelephu-Sarpang PNH (2.95km to 30km)			
Leukhola Bridge	Sa-14	Gelephu-Sarpang PNH (2.95km to 30km)			
Lampathey Bridge	Sa-15	Gelephu-Sarpang PNH (2.95km to 30km)			
Jigmeling	Sa-16	Gelephu-Sarpang PNH (2.95km to 30km)			
Jigmeling 2	Sa-17	Gelephu-Sarpang PNH (2.95km to 30km)			
Chokorling Bridge	Sa-18	Gelephu-Sarpang PNH (2.95km to 30km)			
Kami Khola Bridge	Sa-19	Sarpang-Darachu PNH (30-67km)	Ranibagan		
Butabari 1 Zam	Sa-20	Sarpang-Darachu PNH (30-67km)			
Butabari 2 Zam	Sa-21	Sarpang-Darachu PNH (30-67km)			
Kharey Zam 1	Sa-22	Sarpang-Darachu PNH (30-67km)			
Kharey Zam 2	Sa-23	Sarpang-Darachu PNH (30-67km)			
Shompangkha Bridge	Sa-24	Sarpang-Darachu PNH (30-67km)			
Loring Bridge	Sa-25	Sarpang-Darachu PNH (30-67km)			
Budhichu Zam	Sa-26	Sunkosh-Dagana SNH	Youngsibi	Tshendagang	Dagana
Dagachu Zam .	Sa-27	Sunkosh-Dagana SNH			
Ampichu Zam	Sa-28	Sunkosh-Dagana SNH	Tshendagang		
Panachu Zam	Sa-29	Sunkosh-Dagana SNH			
Samarchu Zam	Sa-30	Dorona GC Road			
Nimtolachu Zam	Sa-31	Dorona GC Road			
Goshichu Zam	Sa-32	Sunkosh-Dagana SNH	Khagochen		
Bidulung Zam	Sa-33	Sunkosh-Dagana SNH			
Baleygangchu Zam	Sa-34	Sunkosh-Dagana SNH			
Zharingaychu Zam	Sa-35	Sunkosh-Dagana SNH			
Lemichu Zam	Sa-36	Sunkosh-Dagana SNH			
Tangrachu Zam	Sa-37	Sunkosh-Dagana SNH			
Darachu Zam	Sa-38	Sunkosh-Dagana SNH			
Chanchey Bailey Bridge	Sa-39	Semjong GCC Road	Damphu	Tsirang	Tsriang
Rateykhola Bailey Bridge	Sa-40	Tsirangtoeh GCC Road			
Burichhu Bailey Bridge	Sa-41	Sergithang GCC Road	Waklaytar		
Lhari Zam	Sa-42	Sergithang GCC Road			
Sunkosh Bridge	Sa-43	Dagana-Sunkosh SNH			
Changchey Bridge	Sa-44	Wakleytar-Changchey PNH			
Burichu Bridge	Sa-45	Wakleytar-Changchey PNH			
Mechichu Bridge	Sa-46	Wakleytar-Changchey PNH			
Wakleytar Bridge	Sa-47	Wakleytar-Changchey PNH			

1.5 Trongsa

Bridges under Regional Office, DoR, Trongsa

Name of Bridge	Bridge No.	Road	Section	Sub Division	Dzongkhag
Tyelegangchu Bridge	Tr-1	Trongsa - Gelegphu PNH	Trongsa	Trongsa	Trongsa
Chamdhegang Bailey Bridge	Tr-2	Bjeezam to Bemji GC Road			
Chela RCC Bridge	Tr-3	Bjeezam to Bemji GC Road			
Kaba Daba Bailey Bridge	Tr-4	Bjeezam to Bemji GC Road			
Bjee zam	Tr-5	Trongsa to Thimphu			
Yesheygangchu Bridge	Tr-6	Trongsa - Gelegphu PNH			
Chuserbu Zam	Tr-7	Chuserbu - Trongsa PNH	Tshangkha		
Chendebji Zam	Tr-8	Chuserbu - Trongsa PNH			
Nyala Zam	Tr-9	Chuserbu - Trongsa PNH			
Nagina Zam	Tr-10	Chuserbu - Trongsa PNH			
Tashiling Zam	Tr-11	Chuserbu - Trongsa PNH			
Gazamche	Tr-12	Serpang -Tang PNH	Ura	Ura	Bumthang
Leri Zam	Tr-13	Serpang -Tang PNH			
Gaktong Zam	Tr-14	Nangar-Ura PNH			
Chamkhar Zam	Tr-15	Nangar-Ura PNH	Jakar	Jakar	
Tangchhu Zam	Tr-16	Jakar-Ura PNH			
Babzur RCC Bridge	Tr-17	Tang GC Road PNH			
Pangshing Bailey Bridge	Tr-18	Tang GC Road PNH			
Tazambi Bridge	Tr-19	Tang Dzongkhag Road			
Bongzam	Tr-20	y/la-Jakar			
Gaytsha	Tr-21	y/la-Jakar			
Domkhar	Tr-22	y/la-Jakar			
Hurjee	Tr-23	y/la-Jakar			
Rubee	Tr-24	y/la-Jakar			
Yamthrak	Tr-25	y/la-Jakar			
Rabteen	Tr-26	y/la-Jakar			
Reotala	Tr-27	Wangdigang- Nabji GC Road	Khosela	Khosela	Trongsa
Wangdigang Zam	Tr-28	Wangdigang- Nabji GC Road			
Kartigang Zam	Tr-29	Gelephu-Trongsa PNH			
Dangdung Zam	Tr-30	Gelephu-Trongsa PNH			

1.6 Tingtibi

Bridges under Regional Office, DoR, Tingtibi

Name of Bridge	Bridge No.	Load	Section	Sub Division	Dzongkhag
Ringdigang Zam	Ti-1	Gomphu-Panbang Highway	Pantang	Panbang	Zhemgang
Tikiring Zam	Ti-2				
Pantang Zam	Ti-3				
Morongang Zam	Ti-4				
Gramlanggang Zam	Ti-5				
Darangang Zam	Ti-6				
Jirangang Zam	Ti-7				
Panbang Zam	Ti-8		Panbang		
Tshasapani Bridge	Ti-9	Mathangguri-Panbang-Galabe Feeder road			
Nangchu Bridge	Ti-10				
Marangdutt Bridge	Ti-11	Bjoka GC road			
Chakchawa Bridge	Ti-12				
Mangdi Zam	Ti-13	Gelephu-Trongsa Highway	Mangdichu	Mangdichu	
Wangdigangchu Zam	Ti-14				
Wangdigang Zam	Ti-15		Zhemgang		
Chablechu bridge	Ti-16		Tama		
Golipong bridge	Ti-17				
Kikhar Bailey bridge	Ti-18	Dhakphel-Buli feeder road	Buli		
Bomdelling bailey bridge	Ti-19				
Andhigangchu Zam	Ti-20	Tingtibi-Praling Highway	Goling		
Yebigangchu Zam	Ti-21				
Chendigangchu Zam	Ti-22				
Chamkharchu Bailey Bridge	Ti-23	Nimshong-Therang GC road	Nimshong	Nimshong	

1.7 Lingmethang

Bridges under Regional Office, DoR, Lingmetang

Name of Bridge	Bridge No.	Road	Section	Sub Division	Dzongkhag
Gangola Bridge	Li-1	Gangola-Lhuntse SNH	Chali	Autsho	Mongar
Horong Bridge	Li-2	Gangola-Lhuntse SNH			
Dorjilung Bridg	Li-3	Gangola-Lhuntse SNH			
Rewanchu Bridge	Li-4	Gangola-Lhuntse SNH			
Phawanchu Bridge	Li-5	Gangola-Lhuntse SNH	Autsho-I		
Karma Shangshong Bridge	Li-6	Gangola-Lhuntse SNH			
Rongmanchu Bridge	Li-7	Gangola-Lhuntse SNH			
Tangmachu Bridge	Li-8	Gangola-Lhuntse SNH			
Chhumedang Bridge	Li-9	Lhuntse-Dungkar GC Road	Lhuntshe		
Kelung Bridge	Li-10	Lhuntse-Dungkar GC Road			
Lingabi Bridge	Li-11	Lhuntse-Dungkar GC Road			
Chudeygangchu Bridge	Li-12	Lhuntse-Dungkar GC Road			
Khoma Zam	Li-13	Khoma GC Road			
Gorgan Bridge	Li-14	Shingkhar-Gorgan Road	Autsho-II		
Silbi Bridge	Li-15	Shingkhar-Gorgan Road			
Zhongmey Zam	Li-16	Silbi-Gorsum Road			
Jaray Bridge	Li-17	Autsho-Jaray Road			
Kerong Zam	Li-18	Nganglam-Gyelposhing Highway	Nganglam	Nganglam	Pemagatshel
Kurung Zam	Li-19	Nganglam-Gyelposhing Highway			
Khakhari Zam	Li-20	Nganglam-Gyelposhing Highway			
Shumari Zam	Li-21	Nganglam-Gyelposhing Highway			
Sokporong Zam	Li-22	Nganglam-Gyelposhing Highway			
Brongri Zam	Li-23	Nganglam-Gyelposhing Highway			
Wangchuk Zam	Li-24	Daksa GC Road			
Gyelposhing Zam	Li-25	Gyelposhing-Nganglam Highway	Gyelposhing Side	Gyelposhing	Pemagatshel
Yongri Zam	Li-26	Gyelposhing-Nganglam Highway			
Zimzorong Zam	Li-27	Gyelposhing-Nganglam Highway			
Sangpoyhai Zam	Li-28	Gyelposhing-Nganglam Highway			
Desuma Zam	Li-29	Gyelposhing-Nganglam Highway			
Kuri Zam	Li-30	Yadi-Serpang PNH	Lingmethang	Lingmethang	Mongar
Powerhouse Zam	Li-31	Gyelposhing-Nganglam Highway			
Zimzorong Zam	Li-32	Zimzorong-kengkhar GC road			
Brizingdang Zam	Li-33	Yadi-Sershong GC Road	Ningala		
Kaphu Zam	Li-34	Kaphu-Balam GC road			
Marungdang Zam	Li-35	Kaphu-Balam GC road			
Yauri Bridge	Li-36	Kaphu-Balam GC road			
Morichu zam (Manchugang)	Li-37	Silambi GC Road	Silam Road	Silambi	Mongar
Drogsar Bridge	Li-38	Silambi GC Road			
Namling Zam	Li-39	Yadi-Serpang PNH	Sengor		
Tsamang Bridge	Li-40	Yadi-Serpang PNH	Selshithang		

1.8 Trashigang

Bridges under Regional Office, DoR, Trashigang

Name of Bridge	Bridge No.	Road	Section	Sub Division	Dzongkhag
Johari bdge	Tg-1	Yadi-Chaskhar GC	Chaskhar	RoTong SD	Mongar
Jabrakhey bdge	Tg-2				
Gudhari Bailey Bridge	Tg-3				
Tshaling RCC	Tg-4	Doksum-Trashiyangtse SNH	Tyangtse	Duksum SD	Trashiyangtse
Tsherzam Bridge	Tg-5				
Buyang RCC	Tg-6				
Chumdu bridge	Tg-7				
Wangrimo Bridge	Tg-8		Ramjar		
Duksum bridge	Tg-9		Chazam-Duksum		
Gomkora RCC	Tg-10	Chazam-Duksum SNH			
Tsergom bridge	Tg-11				
Jamkhardhang RCC	Tg-12				
Reju bridge	Tg-13	Barthsam GC	Bartsham	Rangjung SD	Trashigang
Thungdari bridge	Tg-14	Tgang-Rangjung Dz Road	Rangjung		
Rangjung Bridge	Tg-15				
Chongdhiri Bridge	Tg-16	Radhi-Phongmey GC	Merak		
Gamrichu bridge	Tg-17	Bidung GC	Bartsham		
Yamkhardrang bridge	Tg-18	Sakteng GC	Sakteng		
Minjiri Bridge	Tg-19				
Thongrong Bridge	Tg-20				
Kubrangchu Bridge	Tg-21				
Sertherongchu Bridge	Tg-22				
Dhak Bridge	Tg-23				
Sona Drang Bridge	Tg-24				
Sherporongchu Bridge	Tg-25	Kharungla-Kangpar GC	Tsangpo	Tsangpo SD	Trashigang
Zachhu Bridge	Tg-26				
Nyera Ama Bridge	Tg-27				
Phekpari Bridge	Tg-28	Thrimshing GC			

1.9 Samdrup Jongkhar

Bridges under Regional Office, DoR, Samdrupjongkhar

Name of Bridge	Bridge No.	Road	Section	Sub Division	Dzongkhag
Rechanglu	Sj-1	Martshala GC road	Pemathang	Dewathang	SamdrupJongkhar
Warongkhola	Sj-2	Samrang SNH			
Kathubdrang 1	Sj-3	Samrang SNH			
Kathubdrang 2	Sj-4	Samrang SNH			
Kathubdrang 3	Sj-5	Samrang SNH			
Neuli	Sj-6	Samrang SNH			
Samrang	Sj-7	Samrang SNH			
Tshangchib	Sj-8	Narphung-Gomdar GC road	Narphung		
Sanguri	Sj-9	Dewathang-Samdrupchoeling SNH	Dewathang		
Martang	Sj-10	Dewathang-Samdrupchoeling SNH			
Demola	Sj-11	Dewathang-Samdrupchoeling SNH			
Tshangchuthama 1	Sj-12	Dewathang-Samdrupchoeling SNH			
Tshangchuthama 2	Sj-13	Dewathang-Samdrupchoeling SNH			
Tshalari	Sj-14	Kherigonpa-Yelchen (Nanong) GC road	Kherigonpa	Pemagatshel	Pemagatshel
Denchi	Sj-15	Yurung GC road	Yurung		
Nagpheldrang	Sj-16	Khar-Khotakpa-Tsebar-Yurung DR			
Marung	Sj-17	Khar-Khotakpa-Tsebar-Yurung DR			
Yuri	Sj-18	Tsebar-Mikure-Durungree SNH			
Chumo Dhur	Sj-19	LauriGC road	Minjeywoong	Jomotshangkha	SamdrupJongkhar
Chukarpo	Sj-20	Langchenphu GC road	Jomotshangkha		
Linzin	Sj-21	Linzin - TshengkhariPNH	Nganglam	Nganglam	Pemagatshel
Nganglam	Sj-22	Linzin - TshengkhariPNH			
Menchu	Sj-23	Linzin - TshengkhariPNH			
Dhop	Sj-24	Linzin - TshengkhariPNH			
Dezama	Sj-25	Chhoekhorling GC road			
Kurungdrang	Sj-26	Decheling GC road	Mekuri		

Appendix-6 Sample of Bridges

1. Sample of Steel Bridge

Photograph			
No.1	From the right	No.2	From the left
			
No.3	From the right downstream	No.4	From the left downstream
			
No.5	From the right upstream	No.6	From the left upstream
			
No.7	From the center to downstream	No.8	From the center to upstream
			

2. Sample of Concrete Bridge

Photograph			
No.1	From the right	No.2	From the left
			
No.3	From the right downstream	No.4	From the left downstream
			
No.5	From the right upstream	No.6	From the left upstream
			
No.7	From the center to downstream	No.8	From the center to upstream
			

3. Sample of Bailey Bridge

Photograph			
No.1	From the right	No.2	From the left
			
No.3	From the right downstream	No.4	From the left downstream
			
No.5	From the right upstream	No.6	From the left upstream
			
No.7	From the center to downstream	No.8	From the center to upstream
			

1. Periodic inspection of bridge

1.1 Scope

The scope of this manual is limited to the periodic inspection of the bridges managed by DoR / MoWHS.

This manual prescribes general contents and its considerations with present knowledge of periodic inspection.

1.2 Purpose of periodic inspection

Periodic inspection shall be carried out in order to obtain the required information for securing safe and smooth traffic and execution of efficient operation and maintenance. Understanding of the damage status, determination of measures category and recording of the inspection results shall be conducted.

Figure 1.1 shows the standard procedure for operation and maintenance in periodic inspection.

Periodic inspection shall be carried out in order to obtain the basic data to develop plans for maintenance, repair and reinforcement by grasping of damage status and evaluating of damage degree.

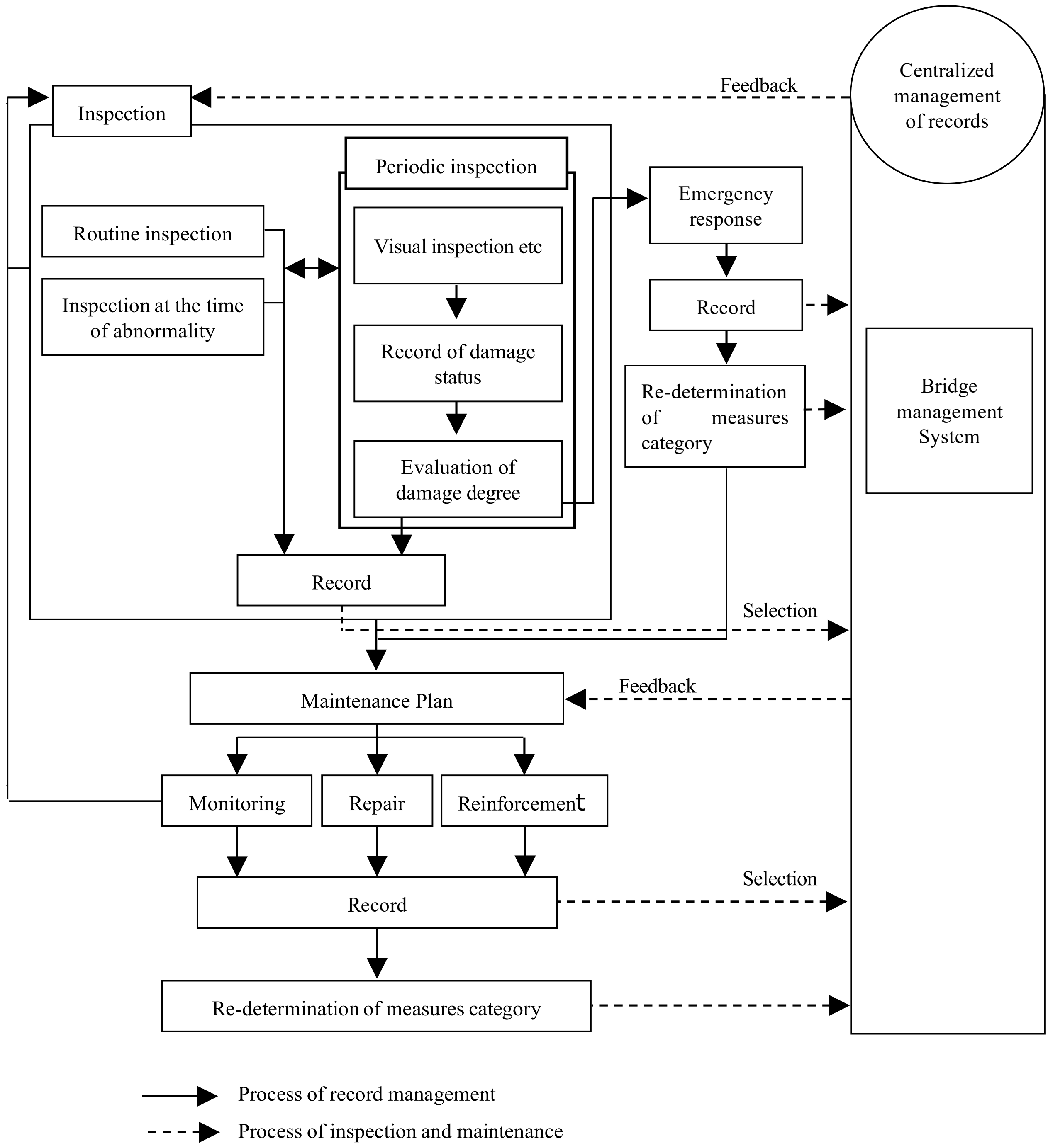


Figure1.1 Operation and maintenance flow in periodic inspection

1.3 Type of inspection

The types of inspections are categorized into three inspections as follows;

【Routine inspection】

Routine inspection is a visual inspection conducted during a regular patrol of roads for early damage detection.

【Periodic inspection】

Periodic inspection is a detailed visual inspection conducted on a regular basis for the bridge maintenance.

【Inspection at the time of abnormality (After monsoon season inspection)】

Inspection at the time of abnormality is conducted to ensure the bridge safe when a disaster such as heavy intensive rainfall occur or is likely to occur, or an abnormality is found on the bridge. Especially, it is necessary to be conducted immediately after monsoon season.

1.4 Frequency of inspection

【Routine inspection】

Routine inspection shall be conducted once a week by site engineer during their regular patrol.

【Periodic inspection】

Initial inspection shall be conducted by 2 years after in service.

Initial inspection is aimed to detect initial conditions of the bridges at the early stage. Defects which were not apparent at the completion of the bridge shall be detected by the initial inspection and the result shall be initial parameter for subsequent process of development of damages.

The following examples are some of the typical initial defects;

Examples: Peeling and swelling of coating, loosening of bolts

・The low construction quality may result change in the state of bridges.

Examples: The vibration of members by wind and damage due to it, occurrence of traffic vibration, crack of concrete in slab etc.

・Unexpected phenomenon or multiple factors may result change in the state.

Procedure of Periodic inspection is shown in Figure1.2. Basically, periodic inspection shall be conducted by close-eye inspection. However, depends upon the bridge situation, there are several cases that close-eye inspection is difficult. Only that case, distance-eye inspection shall be conducted instead of close-eye inspection. The frequency of inspection shall be shorter than close-eye inspection in that case.

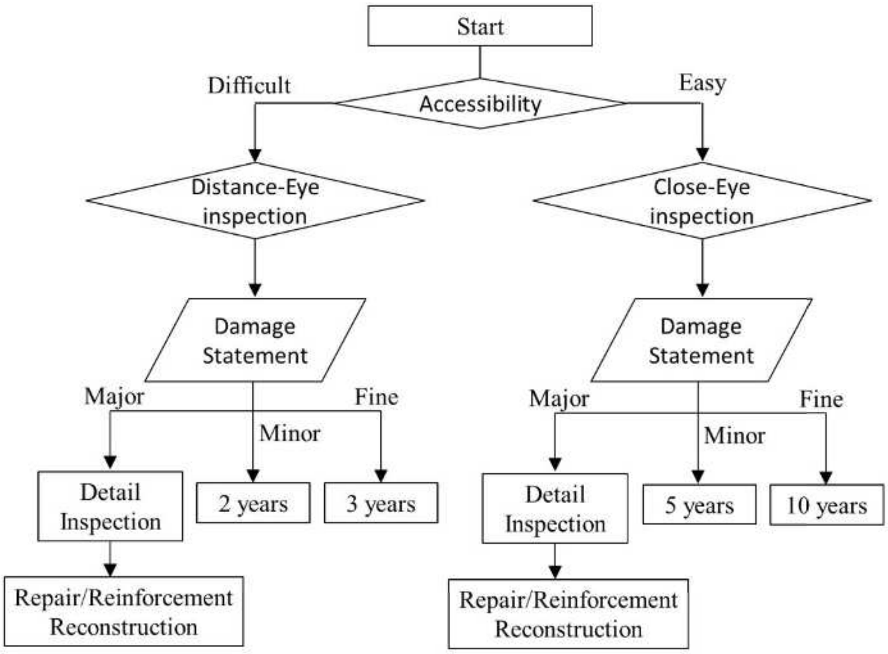


Figure1.2 Flow chart for periodic inspection

【Inspection at the time of abnormality (After monsoon season inspection)】

"After monsoon season inspection" shall be conducted every year immediately after monsoon season. In the "After monsoon season inspection", especially substructure and its surrounding area shall be cleaned before the inspection to check scouring situation clearly. Cleaning work shall include as follows;

<Superstructure>

- ✓ Removing sediment on bridge surface
- ✓ Removing clogging on drainage facility
- ✓ Removing sediment around bearing

<Substructure>

- ✓ Cutting plants substructure and around wing wall affected by river
- ✓ Brushing on substructure and around wing wall affected by river

Picture1.3 Cleaning situation (Left: before, Right: after)

1.5 Plan of inspection

1.5.1 Purpose of inspection plan

Prior to the inspection, inspection plan shall be prepared in order to conduct an adequate inspection. Inspection plan includes all plans relating to the inspection such as survey of existing data, items and methods, system and schedule for undertaking the inspection work.

1.5.2 Items and methods

Upon execution of periodic inspection, inspection plan shall be prepared in order to conduct an adequate periodic inspection corresponding to the bridge situation.

Table 1.1 shows the standard items of periodic inspection.

Table1.1 Standard items of inspection

Part / Member		Subject items (type of damage)		
		Steel	Concrete	Others
Superstructure	Main girder Cross beam Vertical girder Deck slab Cross frame Lateral bracing	・Corrosion ・Deformation / Damage ・Looseness / Omission ・Fracture ・Deterioration of painting	・Crack ・Peeling / Exposure of rebar ・Water leakage / Free lime ・Crack on slab ・Deformation / Damage ・Honeycomb	・Deformation / Damage
Substructure	Abutment Pier	—	・Crack ・Peeling / Exposure of rebar ・Water leakage / Free lime ・Deformation / Damage ・Scouring ・Honeycomb	・Deformation / Damage ・Scouring
Deck Surface	Wheel guard	・Corrosion ・Deformation / Damage	・Crack ・Peeling / Exposure of rebar ・Water leakage / Free lime ・Deformation / Damage	・Deformation / Damage
	Pavement	—	—	・Uneven road surface ・Sediment deposition
Bearing Railing Expansion joint Drainage facility	—	・Corrosion ・Noise ・Deformation / Damage	・Deformation / Damage ・Sediment deposition	・Sediment clogging ・Uneven road surface

Periodic inspection shall be conducted in an appropriate manner depending on items.

Table 1.2 shows the standard methods of periodic inspection.

Table1.2 Standard methods of inspection

Material	Type of damage	Standard method of inspection
Steel	Corrosion	Visual inspection, Photograph
	Looseness / omission	Visual inspection, Photograph
Concrete	Crack	Visual inspection, Crack gauge, Photograph
	Peeling / Exposure of rebar	Visual inspection, Photograph
	Water leakage / Free lime	Visual inspection, Photograph
	Crack on slab	Visual inspection, Crack gauge, Photograph
Others	Uneven road surface	Visual inspection, Convex rule, Photograph
	Sediment clogging	Visual inspection, Photograph
Common	Deformation / damage	Visual inspection, Convex rule, Photograph
	Scouring	Visual inspection, Pole, Photograph

1.6 Detection of damage status

1.6.1 Detection of damage status

Inspection sheet shall be used on the site. If any damage is found during the inspection, the damage status shall be examined for each type of damage according to the inspection sheet. The damage degree shall be recorded by following ways;

- ✓ The damage degree shall be evaluated by “Damage evaluation criterion” on the Inspection sheet.
- ✓ The damage status which cannot be indicated in inspection sheet shall be recorded in damage figure as sketch.

[Examples of record by sketch]

- ✓ Status of the crack in concrete member
- ✓ Location and area of the deformation such as peeling in concrete member
- ✓ Location and status of the crack in steel member
- ✓ Location and status of the deformation in steel member
- ✓ Location and status of other defects, such as water leakage

1.6.2 Evaluation of damage degree

The damage degree shall be evaluated based on appendix-2 “evaluation criteria of damage”.

Those records shall be compiled as the most basic data that indicates the bridge status and be used to consider maintenance plans. Therefore, the evaluation of damage degree shall be conducted accurately to the extent possible.

1.7 Determination of measures category

In periodic inspection, measures category for each member on the structure or each part and each damage type shall be determined by table 1.3 (determination category) referring to appendix-3 "Guideline for determination of measures category" on understanding damage status of the bridge.

Table1.3 Determination category of measures category

Determination category	Contents of determination
A	Damage is not observed, or repair is not required since damage is slight.
B	Repair is required according to the situation.
C	Repairs are required immediately.
E1	Emergency response is required from the view of safety of the bridge structure.
E2	Emergency response is required.
M	Maintenance work is required.

The basic concepts of determination of measures category prescribed in this manual are as follows;

【Category A】

In the range seen in the periodic inspection, damage is not observed, or repair is not required since damage is slight.

【Category B】

Damage that requires repair, but emergency repair is not required since the cause and scale of damage is clearly understood. It is confirmed that the safety is not compromised significantly before the next periodic inspection.

【Category C】

It is confirmed that the repairs are required before the next periodic inspection since the damage has progressed considerably and significant decreased in the function of the member and safety is in stake.

【Category E1】

It is confirmed that the emergency measures are required since the safety of bridge structure has been severely impaired.

【Category E2】

It is determined that emergency measures are required since bicycle, pedestrian traffic failure and fear of damage to third parties are concerned.

【Category M】

Damage is observed, and immediate measures are required in the daily maintenance work in order to keep functionality of the member in good condition.

In the case of determination with C or E1, it is necessary to determine repair or replacement.

1.8 Record of periodic inspection results

Inspection results for damage in the periodic inspection shall be recorded and compiled appropriately.

2. Basic information of the bridge

2.1 Scope

Collecting the basic information of the bridge shall assist to centralize the records relating to bridge maintenance managed by DoR / MoWHS.

2.2 Purpose of collecting basic information

The purpose of collecting basic information is to maintain the bridges appropriately and efficiently. Therefore results of data collection shall be clearly recorded as inventory.

2.3 Composition of bridge inventory

Basic information of the bridge shall be collected. Its information shall be visually and quantitatively clarify the location, scale and traffic volume, etc. Inventory sheet attached in Appindix-2 shall be used for data collection. The composition of the bridge inventory is as follows;

(1) General Data

General data such as a name, date of data collection and bridge number allocated by each RO shall be recorded.

(2) Geographic Data

Name of road, regional office and sub-regional office in charge and location such as coordinate and distance from main town shall be recorded.

(3) Bridge Data

Basic information about the bridge shall be recorded. Items to be collected are;

- ✓ Structure type
- ✓ Number of span and length
- ✓ Bridge length
- ✓ Bridge width (Total and effective width)
- ✓ Height (Abutment and Pier)
- ✓ Type of Deck, Pavement, Wheel guard, Abutment and Pier
- ✓ Loading capacity
- ✓ Construction year (Completion year)
- ✓ Repair record
- ✓ Traffic volume

(4) Photograph

Photograph shall be taken to identify the bridge type and surrounding conditions.

2.4 Establish timeframe of the bridge inventory

Establish and update timeframe of the bridge inventory of a bridge inventory shall follow in Table 2.1.

Table2.1 Establish timeframe of the bridge inventory

	Establish timeframe	Modification	Update
1. General Data	Immediately	If bridge number is changed.	As required
2. Geographic Data	Immediately	When the bridge is hand over from responsible regional office to another regional office, etc.	As required
3. Bridge Data	Immediately for existing bridge Immediately after completion for new bridge	Immediately If there is a change such as height of abutment and pier and traffic volume.	As required Once every five years is desirable
4. Photograph	Immediately for existing bridge Immediately after completion for new bridge	Immediately If surrounding situation of bridge is changed.	As required Once every five years is desirable

Appendix-1 Periodic Inspection Record

1. Bridge Inventory Sheet

Bridge Ledger

Data Collector		Update of Record	／　　／2019
Bridge Name		Bridge Number	

Section	Title	Information	Remarks
Geographic Data	Highway Name/Road Name		
	Stretch Name		
	Dzongkhag		
	Division/Agency		
	Location(Ch. from starting point)		
	Coordinate (latitude)		
	(longitude)		
	Alternate route(Bypass near bridge)		
	Rainfall		
Bridge Data	Bridge Classification		
	Bridge Type		
	Number of Span		
	Span Length [m] (1)		
	(2)		
	(3)		
	(4)		
	Bridge Length[m]		
	Effective Width[m]		
	Total Width[m]		
	Abutment Height(L/B)[m]		
	Abutment Height(R/B)[m]		
	Pier Height[m] (1)		
	(2)		
	Deck Type		
	Wearing Course Type		
	Railing Type		
	Abutment Type		
	Pier Type		
	Loading Capacity		
	Compleation Year		
	Repair Record		
	Total Traffic volume(msa)		

Comments

Update of Record	/ /2019
Data Collector	
Bridge Name	
Bridge Number	

Photograph			
No.1	From the right	No.2	From the left
No.3	From the right downstream	No.4	From the left downstream
No.5	From the right upstream	No.6	From the left upstream
No.7	From the center to downstream	No.8	From the center to upstream

2. Periodic Inspection Sheet

Inspention Sheet 1

Inspector		Update of Record	/ /20
Bridge Name		Bridge Number	

1.Overall Condition of Bridge

Structure	Damage	Contents	Damage evaluation criterion(a~e)	Evaluation
Whole Bridge	Deflection	Deflection/Sagging	a:Not found b:- c:Minor d:- e:Severe	
	Settlement/ Movement/Inclination	Settlement, movement, inclination of foundation or bearing, etc	a:Not found b:- c:Minor d:- e:Severe	
	Scouring	Scouring of pier or foundation	a:Not found b:- c:Minor d:- e:Severe	
	Sediment Deposition	Dirt/litter deposited on Deck, Girder (Steel) or Abutment	a:Not found b:- c:- d:- e:Found	
	Others	Graffiti, bird damage, fire damage, etc.	Only record	

2.Condition of Damage(Super Structure)

Structure	Member	Material	Damage	Damage evaluation criterion (a~e)	Evaluation
Super Structure	Deck Slab	Concrete	Crack	Appendix	
			Peeling/Rebar exposure	a:Not found b:- c:Peeling d:Rebar exposure (small) e:Rebar exposure (large)	
			Water leakage/Free lime	a:Not found b:- c:Water leakage d:Free lime e:Free lime+Rust fluid	
			Partial loss of concrete	a:Not found b:- c:- d:- e:Found	
			Honeycomb	a:Not found b:- c:Extensively d:Rebar exposure (small) e:Rebar exposure (large)	
		Steel	Corrosion	Appendix	
			Crack	a:Not found b:- c:Less than 3mm (length) d:- e:3mm or more (length)	
			Looseness/Omission	a:Not found b:- c:Less than 5% d:- e:5% or more	
			Fracture	a:Not found b:- c:- d:- e:Found	
			Deterioration of Painting	a:Not found b:- c:Partially d:Peelling e:Peelling and Rust	
	Main Girder	Concrete	Crack	Appendix	
			Peeling/Rebar exposure	a:Not found b:- c:Peeling d:Rebar exposure (small) e:Rebar exposure (large)	
			Water leakage/Free lime	a:Not found b:- c:Water leakage d:Free lime e:Free lime+Rust fluid	
			Honeycomb	a:Not found b:- c:Extensively d:Rebar exposure (small) e:Rebar exposure (large)	
		Steel	Corrosion	Appendix	
			Crack	a:Not found b:- c:Less than 3mm (length) d:- e:3mm or more (length)	
			Looseness/Omission	a:Not found b:- c:Less than 5% d:- e:5% or more	
			Fracture	a:Not found b:- c:- d:- e:Found	
			Deterioration of Painting	a:Not found b:- c:Partially d:Peelling e:Peelling and Rust	

Inspention Sheet 2

Inspector	0	Update of Record	／　／20
Bridge Name	0	Bridge Number	0

3.Condition of Damage(Sub Structure)

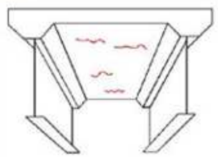
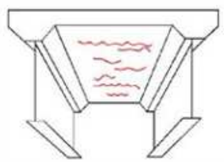
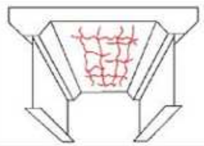
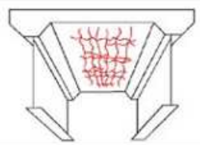
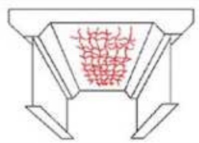
Structure	Member	Material	Damage	Damage evaluation criterion (a～e)	Evaluation
Sub Structure	Body	Concrete	Crack	Appendix	
			Peeling/Rebar exposure	a:Not found b:- c:Peeling d:Rebar exposure (small) e:Rebar exposure (large)	
			Water leakage/Free lime	a:Not found b:- c:Water leakage d:Free lime e:Free lime+Rust fluid	
			Honeycomb	a:Not found b:- c:Extensively d:Rebar exposure (small) e:Rebar exposure (large)	
		Masonry	Damage/Deformation	a:Not found b:- c:Partial Damage d:- e:Deformation	

4.Presence of Damage

Structure	Member	Damage	Contents	Damage evaluation criterion(a～e)	Evaluation
Bearing	Bearing	Defect	Severe corrosion, defect / hardening / missing parts	a:Not found b:- c:Minor d:- e:Severe	
		Noise	Extraordinary noise during passing vehicle	a:Not found b:- c:Minor d:- e:Severe	
	Base Mortar (Bearing Sheet)	Sediment Deposition	Dirt/litter deposited on/around base mortar	a:Not found b:- c:- d:- e:Found	
		Deformation/ Loss	Crack of mortar, partial defect	a:Not found b:- c:Minor d:- e:Severe	
Ancillary Facilities	Railing	Deformation/ Damage	Deformation or broken part	a:Not found b:- c:Less than 50% d:- e:50% or more	
			Risk for bridge users	a:Not found b:- c:Minor d:- e:Severe	
Deck Surface	Wearing Course	Abnormity	Hole, big pothole, crack	a:Not found b:- c:Cracks d:- e:Pot Holes	
		Unevenness	Risk for bridge users	a:Not found b:- c:Less than 2cm d:- e:More than 2cm	
		Sediment Deposition	Dirt/litter deposited on pavement	a:Not found b:- c:- d:- e:Found	
	Expansion joint	Abnormity	Broken	a:Not found b:- c:Minor d:- e:Separating or Squeezing	
		Unevenness	Level difference	a:Not found b:- c:less than 2cm d:- e:2cm or more	
Drainage Facilities		Clogging	Clogging with soil and overlay	a:Not found b:- c:- d:- e:Found	
		Water Leakage	Broken or drained water afftected to girder or other member	a:Not found b:- c:Minor d:- e:Severe	

Appendix

【Crack on slab】

	Crack phenomenon	
a	【Crack spacing & crack characteristic】 Crack has occurred only on one direction and more than 1.0m as minimum crack spacing. 【Crack width】 Less than 0.05mm of maximum	
b	【Crack spacing & crack characteristic】 Crack has mainly occurred on one direction and crack spacing of between 1.0m～0.5m, but not square-block type. 【Crack width】	
c	【Crack spacing & crack characteristic】 Crack has occurred on about 0.5m before square-block type. 【Crack width】 Mainly less than 0.2mm, but partly	
d	【Crack spacing & crack characteristic】 Crack has occurred on 0.5m～0.2m and also square-block type. 【Crack width】 Over 0.2mm and partly peeling off	
e	【Crack spacing & crack characteristic】 Crack has occurred on less than 0.2m and mainly square-block type. 【Crack width】 More than 0.2mm and continuously	

【Corrosion on steel】

	Corrosion phenomenon
a	Nothing
b	Corrosion has ocuurred on steel surface, but impossible to see reduction of its thickness. Furtheremore very minor area of corrosion damage.
c	Corrosion has ocuurred on steel surface, but impossible to see reduction of its thickness. And rust has occurred entirely on focusing parts or some spred area.
d	Corrosion has ocuurred on steel surface, also possible to see slightly reduction of its thickness. And rust has occurred entirely on focusing parts or many spred area.
e	Corrosion has apparently expanded on steel surface, also possible to see definitely reduction of its thickness. And rust has occurred entirely with many spred area.

【Crack on concrete structure】

	Crack phenomenon
a	Nothing
b	-
c	Small crack width (less than 0.2mm in case of RC structure)
d	Midium crack width (more than 0.2mm to less than 1.0mm in case of RC structure)
e	Large crack width (more than 1.0mm in case of RC structure)

3. Type of typical damage

Material	Type of damage
Steel	Corrosion
	Looseness / omission
Concrete	Crack
	Peeling / Exposure of rebar
	Water leakage / Free lime
	Crack in slab
Others	Uneven road surface
	Sediment clogging
Common	Deformation / damage
	Scouring

4. Evaluation of damage degree

Good	——	Mild	——	Severe
a	b	c	d	e

5. Determination of measures category

Determination category	Contents of determination
A	Damage is not observed or repair is not required since damage is slight.
B	Repair is required according to the situation.
C	Repairs are required immediately.
E1	Emergency response is required from the view of safety of the bridge structure.
E2	Emergency response is required.
M	Maintenance work is required.

6. Total Condition

Total rating of Bridges are classified into 5 categories in consideration of factors affecting collapsing of bridges and ultimate load carrying capacity.

Determination category	Contents of determination
A (Very good)	The structure is not damaged.
B (Good)	The structure is damaged but not dangerous for users.
C (Fair)	The structure is damaged and getting dangerous for users in near future.
D (Poor)	The structure is severely damaged and dangerous for users.
E (Bad)	The structure is completely destroyed and unusable.

7. Elision Mark for the Regional Office of DoR

Location of the Office	Elision Mark
Thimphu	Th
Lobeysa	Lo
Phuntsholing	Pl
Sarpang	Sa
Trongsa	Tr
Tingtibi	Ti
Lingmethang	Li
Trashigang	Tg
Samdrup Jongkhar	Sj

Appendix-2 Evaluation Criteria of Damage

1. Corrosion

It refers to the state that rust has occurred intensively, or reduction in cross section or corrosion has occurred due to rust proceeds extremely in ordinary steel (protected against corrosion by plating or coating), and the state that abnormal rust has occurred without the formation of stable rust, or reduction in cross section is remarkable due to the extreme progress of rust in weathering steel.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

The category shall be determined by combining of large and small scale judged from their general condition to each following factor about damage.

1.1 Category of evaluation of the damage degree

Category	General condition	
	The depth of damage	The area of damage
a	No damage	
b	Small	Small
c	Small	Large
d	Large	Small
e	Large	Large

1.2 General condition of each factor

(1) The depth of damage

Category	General condition
Large	Significant expansion has occurred in the steel surface or apparent decrease in thickness is visible.
Small	Rust is superficial, and significant reduction in thickness is not visible.

(2) The area of damage

Category	General condition
Large	A gap has occurred in focused part all over, or there are more than one of occurrence of spread damage in focused part.
Small	The area of damage is small and local.

1.3 Case of evaluation of the damage degree

Category : b	Category : c
	
Category : d	Category : e
	

2. Crack

It refers to the state that cracks have occurred on the surface of the concrete member. About the crack occurred on the slab; refer to “5.Crack in slab”.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

The category shall be determined by combining of large and small scale judged from their general condition to each following factor about damage.

2.1 Category of evaluation of the damage degree

Category	Damage degree focused on the maximum crack width	Damage degree focused on the minimum crack spacing
a	No damage	
b	Small	Small
c	Small	Large
	Middle	Small
d	Middle	Large
	Large	Small
e	Large	Large

2.2 General condition of each factor

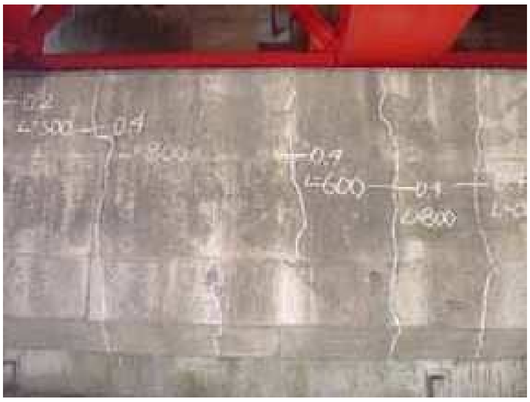
(1) Damage degree focused on the maximum crack width

Category	General condition
Large	Crack width is large. (1.0 mm or more)
Medium	Crack width is medium. (over 0.2 mm less than 1.0 mm)
Small	Crack width is small. (less than 0.2 mm)

(2) Damage degree focused on the minimum crack spacing

Category	General condition
Large	Crack spacing is small. (approximately less than 0.5 m)
Small	Crack spacing is large. (approximately 0.5 m or more)

2.3 Case of evaluation of the damage degree

Category : c	Category : d
	
Category : e	Category :
	

3. Peeling/ Rebar exposure

It refers to the state that concrete surface has been peeled off. Rebar exposure refers to the case that the rebar in the peeling part is exposed.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	Only peeling has occurred
d	Although rebar is exposed, but the corrosion of rebar is slight.
e	Rebar is exposed, and the rebar has corroded significantly.

3.1 Case of evaluation of the damage degree

Category : c	Category : d
	
Category : e	
	

4. Water leakage / Free lime

It is refers to the state that leakage or exudation of water or lime has occurred from the concrete joint or crack.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	Water leakage or free lime has occurred, but rust fluid is hardly seen.
d	—
e	Water leakage or free lime from crack has occurred significantly, or significant contamination of mud or rust fluid in water leakage is observed.

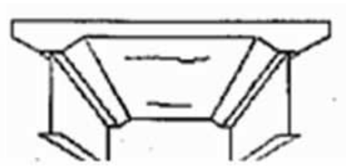
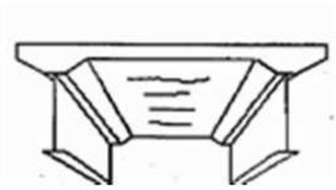
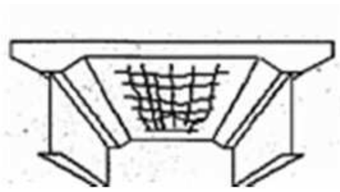
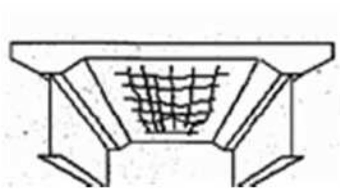
4.1 Case of evaluation of the damage degree

Category : c	Category : e
	

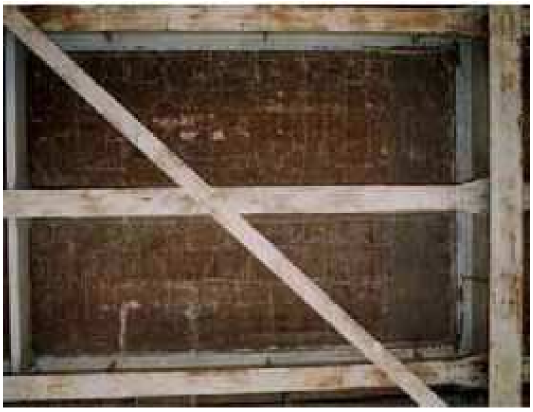
5. Crack on slab (Partial loss of concrete)

It is cracks occurred in slab, and refers to the state that crack has occurred in one or two direction on the lower surface of slab.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	Damage degree focused on the maximum crack width	Damage degree focused on the minimum crack spacing
a	Cracks are seen mostly in only one direction. The minimum crack spacing is approximately 1.0 m or more. The maximum crack width is less than 0.05 mm.	
b	The crack spacing is 1.0-0.5 m. Crack is mainly in one direction and not a lattice pattern. The crack width is mainly less than 0.1 mm and some are 0.1 mm or more.	
c	The crack spacing is approximately 0.5 m. Crack is just before becoming lattice pattern. The crack width is mainly less than 0.2 mm and some are 0.2 mm or more.	
d	The crack spacing is 0.5-0.2 m. Cracks occur in a lattice pattern. The cracks wider than 0.2 mm are quite noticeable and partial falling of corner is also seen.	
e	The crack spacing is less than 0.2 m. Cracks occur in a lattice pattern. The cracks wider than 0.2 mm are noticeable and continuous fallings of corner are also seen.	

5.1 Case of evaluation of the damage degree

Category : b	Category : c
	
Category : d	Category : e
	

6. Uneven road surface

It refers to the irregularities in the horizontal axis and the differences in level occur on the road surface that result the increase of the impact force.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	The irregularities in the horizontal axis have occurred, but the difference in level is small. (less than 20 mm)
d	—
e	The irregularities in the horizontal axis have occurred, and the difference in level is large. (20 mm or more)

6.1 Case of evaluation of the damage degree

Category : c	Category : e
	

7. Sediment clogging

It refers to the state that the sediment clogged in catch basin or drainage pipe, or the sediment is deposited around bearing.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	—
d	—
e	There is the sediment clogging in catch basin and around bearing.

7.1 Case of evaluation of the damage degree

Category : e	Category :
	

8. Deformation/damage

It refers to the state that the local deformation of the member has occurred or parts of member lacked regardless of the cause such as collision of the vehicle, scratch during construction and influence of the earthquake.

[Evaluation of the damage degree]
The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	The member is deformed locally.Parts of member lacked.
d	—
e	The member is significantly deformed locally. Parts of member lacked significantly.

8.1 Case of evaluation of the damage degree

Category : c	Category : e
	

9. Scouring

It is refers to the state that the foundation body is carved by running water and lacked.

[Evaluation of the damage degree]

The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	The foundation of substructure or wing wall is scoured by running water.
d	—
e	The foundation of substructure is significantly scoured by running water.

9.1 Case of evaluation of the damage degree

Category : c	Category : e
	

10. Looseness/omission

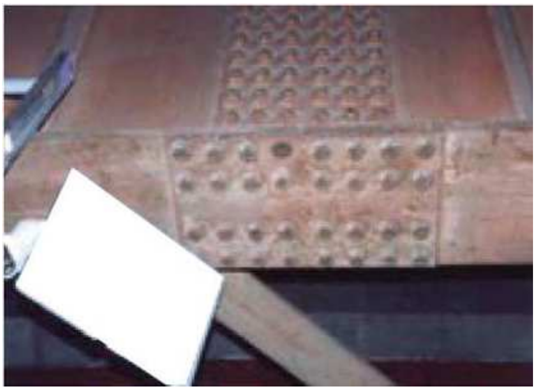
It is refers to the state that looseness of the bolt occurs or nuts and bolts is missing. Include those that bolts are broken.

[Evaluation of the damage degree]

The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	—
c	The looseness or omission of bolts has occurred, but the number is small. (less than 5% of number per group)
d	—
e	The looseness or omission of bolts has occurred, and the number is large.(more than 5% of number per group)

10.1 Case of evaluation of the damage degree

Category : c	Category : e
	

11. Honeycomb

It is refers to the state of honeycomb by initial defect.

[Evaluation of the damage degree]

The evaluation of the damage degree shall be categorized as follows;

Category	General condition
a	No damage
b	Honeycomb is slightly seen.
c	Honeycomb is slightly seen and aggregates are partly peeling off.
d	Honeycomb is extensively seen and aggregates are easily peeling off
e	Honeycomb is extensively seen and aggregates are easily peeling off besides rebar is exposed and rusted.

11.1 Case of evaluation of the damage degree

Category : b	Category : c
	
Category : d	Category : e
	

Appendix-3 Guideline for determination of measures category

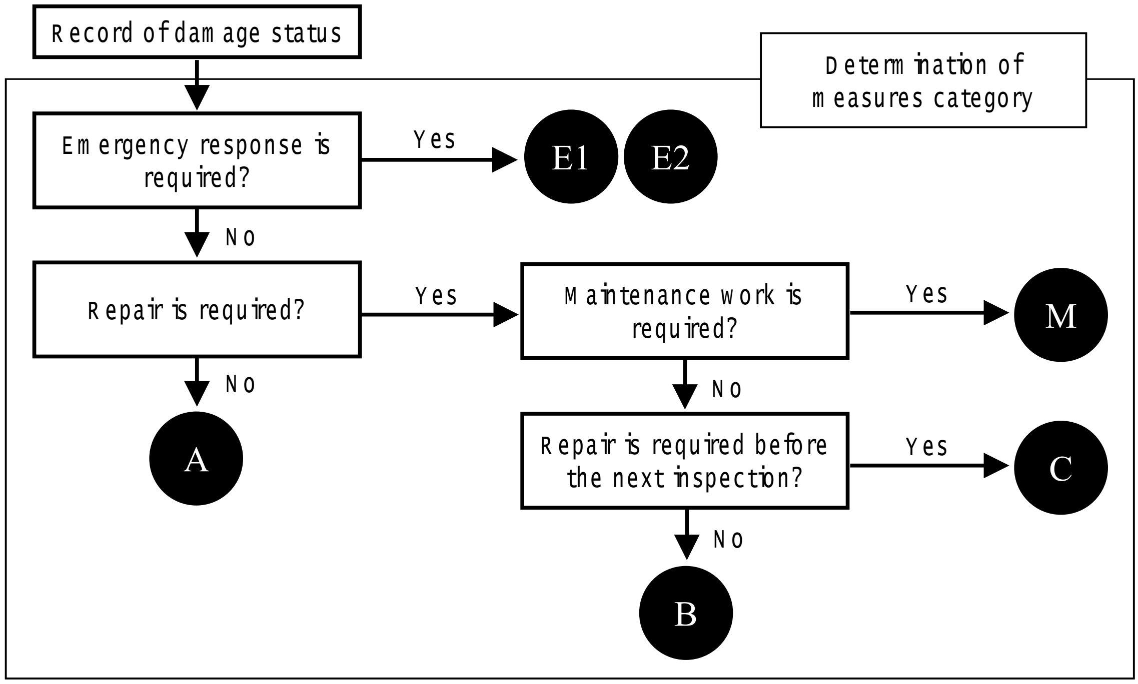
1. Basic of determination of measures category

1.1 General

The determination of damage status shall be conducted by comprehensive evaluation of various factors such as the progress of damage of member and environmental condition.

1.2 Flow of determination of measures category

The basic flow of determination of measures category is as follows;



1.3 Observation

It describes the view of the surveyor on damage status.

2. Determination of measures category

2.1 Corrosion

[Category E1: Emergency response is required from the view of safety of the bridge structure]

The significant reduced cross-sectional area has occurred in the main members, emergency response may be reasonable in the situation that the structural safety has been compromised significantly due to the loss of load bearing capacity of member.

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

There is no overall damage, but the corrosion caused by small scratches can be seen partially. Maintenance work may be reasonable in the situation that damage is small in a scale and in a convenient location for measures.

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
General steel member	➢ Water leakage from cracks in slab ➢ Non-installation of waterproof layer ➢ Water leakage from the installation part of drainage equipment ➢ Water leakage from the damaged part of the expansion joint	➢ Excess stress due to reduced cross sectional area ➢ Development to the crack due to concentration of stress

2.2 Crack

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Whole concrete member	➢ Lack of designed strength ➢ Freezing and thawing ➢ Lack of compaction ➢ Poor curing ➢ Temperature stress ➢ Drying shrinkage ➢ Poor quality of concrete ➢ Cold joint ➢ Uneven settlement	➢ Progress of crack and decrease in load bearing ability due to excess stress ➢ Corrosion of rebar due to crack ➢ Occurrence of water leakage/free lime

2.3 Peeling / Exposure of rebar

[Category E1: Emergency response is required from the view of safety of the bridge structure]

Emergency response may be reasonable in the situation that the third-party damage is a concern because the risk is very high resulting in peeling off.

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

There is no overall damage, but peeling can be seen partially. Maintenance work may be reasonable in the situation that damage is small in a scale and in a convenient location for measures.

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Whole concrete member	➢ Lack of covering, poor finishing of construction joint ➢ Freezing and thawing ➢ Lack of compaction ➢ Concentration of local stress ➢ Collision or contact ➢ Volume expansion due to corrosion of steel	➢ Decrease in load bearing ability due to reduced cross-sectional area ➢ Decrease in load bearing ability due to corrosion of steel

2.4 Water leakage / Free lime

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Whole concrete member	➢ Progress of water leakage ➢ Progress of crack ➢ Lack of compaction ➢ Poor finishing of construction joint ➢ Poor method of placing	➢ Corrosion of steel due to crack ➢ Concrete degradation

2.5 Crack in slab

[Category E1: Emergency response is required from the view of safety of the bridge structure]

The significant cracks can be seen. Emergency response may be reasonable in the situation that structural safety has been compromised significantly due to reduction of stiffness of the entire superstructure.

[Category E2: Emergency response is required]

Cracks just on the verge of falling in slab have occurred. Emergency response may be reasonable in the situation that the third-party damage due to peeling fall is a concern.

[Category M: Maintenance work is required]

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Concrete slab	➢ Lack of designed strength ➢ Drying shrinkage ➢ Lack of distribution reinforcement ➢ Uneven settlement of support girder	➢ Progress of water leakage and free lime

2.6 Uneven road surface

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

Emergency response may be reasonable in the situation that the obstruction to traffic of bicycles due to significant unevenness on the road is a concern.

[Category M: Maintenance work is required]

Maintenance work such as partial overlay of the pavement may be reasonable in the situation that the unevenness on the road is small and damage is partial, and its area is small.

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Expansion device	➢ Subsidence of bearing, uplift due to damage of bolt set	➢ Effect of impact force to the main structure, traffic obstacles

2.7 Sediment clogging

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

The sediment clogging has occurred only in catch basin. Maintenance work may be reasonable in the situation that its scale is small.

[Category B, C: Repairs are required]

In case that the maintenance work cannot deal for a scale because the sediment clogging has occurred over the entire length of drainage pipe.

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Drainage facilities, bearing	➢ Sediment clogging	➢ Corrosion of main structure ➢ Degradation of slab

2.8 Deformation / damage

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

Emergency response may be reasonable in the situation that the obstruction to the third party such as pedestrians and vehicles due to significant deformation of the bridge railing is a concern.

[Category M: Maintenance work is required]

Maintenance work may be reasonable in the situation that the small deformation has occurred locally on the bridge railing.

[Category B, C: Repairs are required]

In case that the maintenance work cannot deal for a scale because the damage due to collision of the vehicle has occurred to the overhanging slab.

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Whole member	➢ Lack of covering ➢ Concentration of local stress ➢ Collision or contact	➢ Secondary disaster ➢ Decrease in load bearing ability due to reduced cross-sectional area

2.9 Scour

[Category E1: Emergency response is required from the view of safety of the bridge structure]

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

[Category B, C: Repairs are required]

[Reference on describing the observations]

Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Foundation	➢ Change in the running water due to driftwood	➢ Progress of scour may cause the slope in the substructure

2.10 Looseness/omission

[Category E1: Emergency response is required from the view of safety of the bridge structure]

Emergency response may be reasonable in the situation that damaging the structure stability for bonding strength shortage due to a number of bolts is missing at the junction.

[Category E2: Emergency response is required]

[Category M: Maintenance work is required]

Maintenance work may be reasonable in the situation that scale of damage is small such as looseness occurs in the ordinary bolt of parapet and attachment.

[Category B, C: Repairs are required]

[Reference on describing the observations]

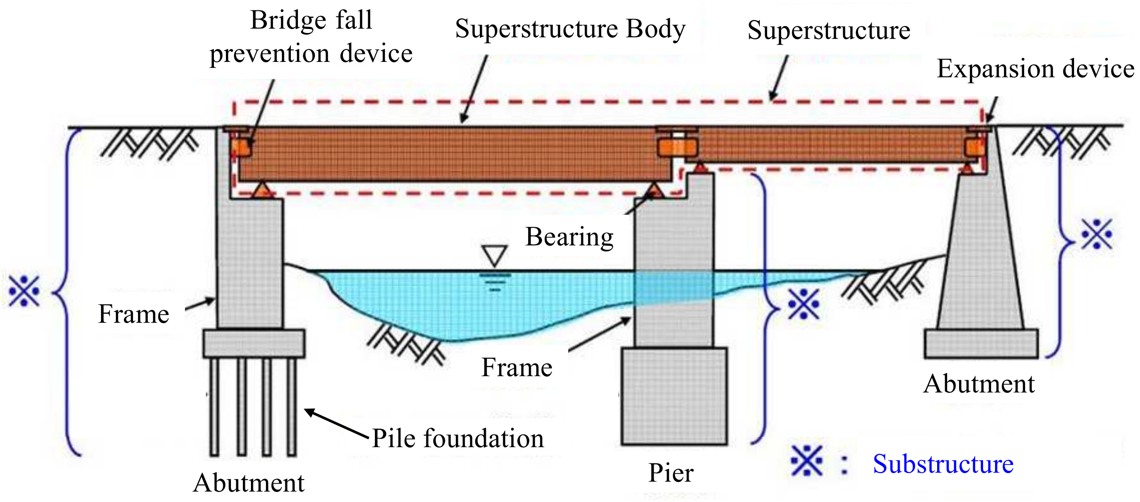
Place of damage	Typical example of cause of damage	Example of concerned effects on the structure
Main girder Cross beam Sway frame Lateral	➢ Omission of bolts at splice	➢ Breakage due to delayed fracture may occur.

Appendix-4 Basics of bridge

1. Basic structure of bridge

1.1 Name of the bridge structure

- Bridge
  - Superstructure
    - Body
    - Appendages・・・・・Bearing, Expansion device etc.
  - Substructure
    - Frame・・・・・・・・・・Abutment, Pier
    - Foundation・・・・・・Pile foundation etc.



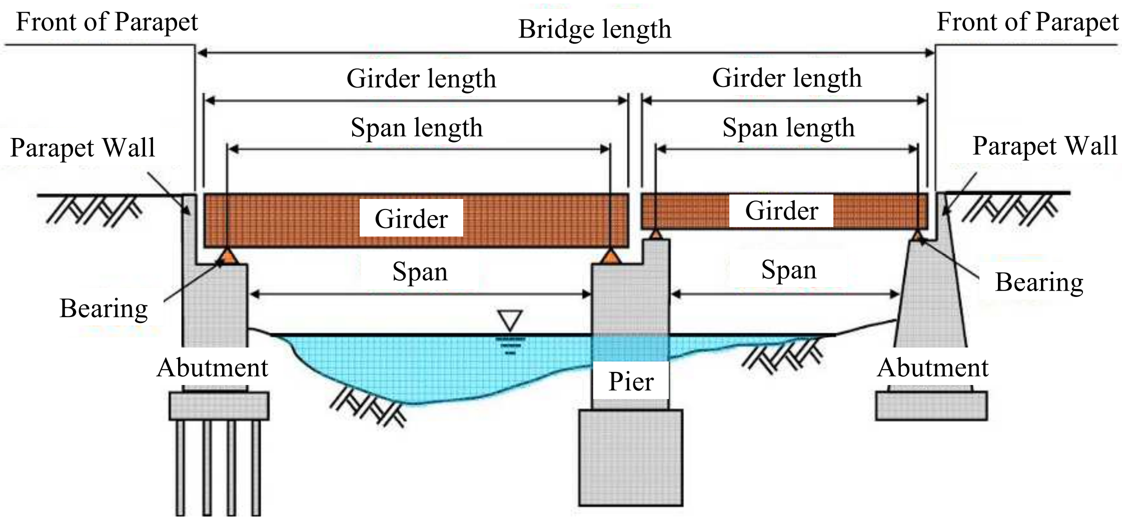
1.2 Length of the bridge

Bridge length・・・・・length between the front parapet of the bridge at both ends

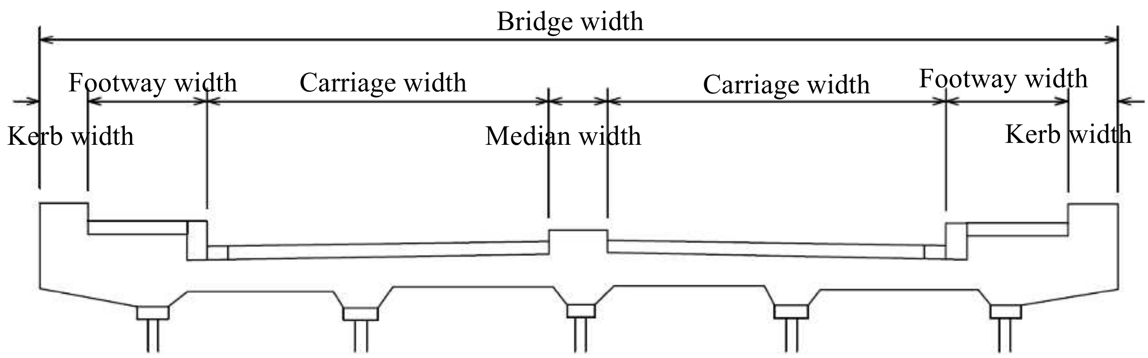
Girder length・・・・・length of main girder

Span length・・・・・length between bearings

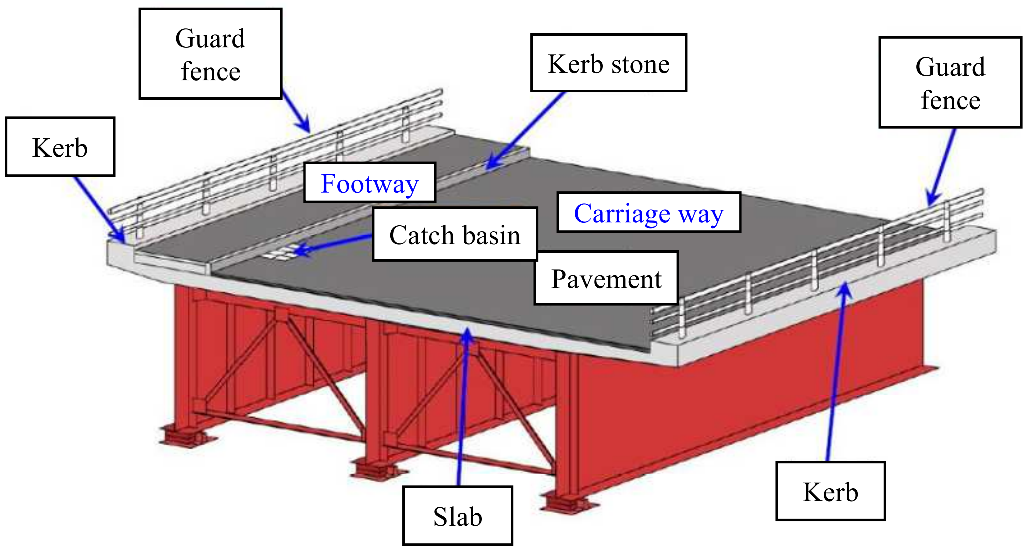
Span・・・・・length between abutments (piers) of substructure



1.3 Width of the bridge

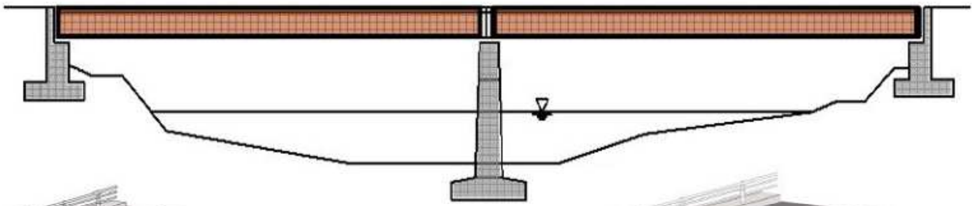


1.4 Bridge surface



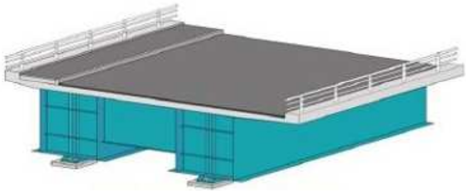
2. Bridge type

2.1 Girder bridge

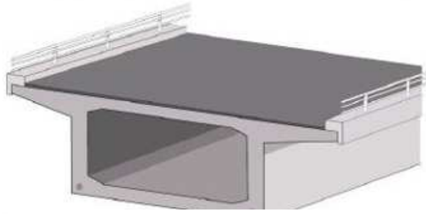


I-Girder Bridge（Steel Bridge）

T-Girder Bridge（Concrete Bridge）



Box Girder Bridge（Steel Bridge）



Box Girder Bridge（Concrete Bridge）

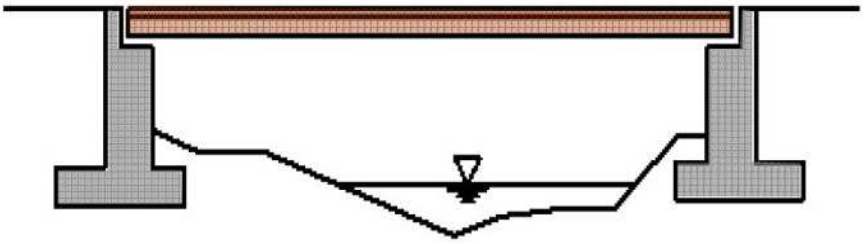
【Under the girder】

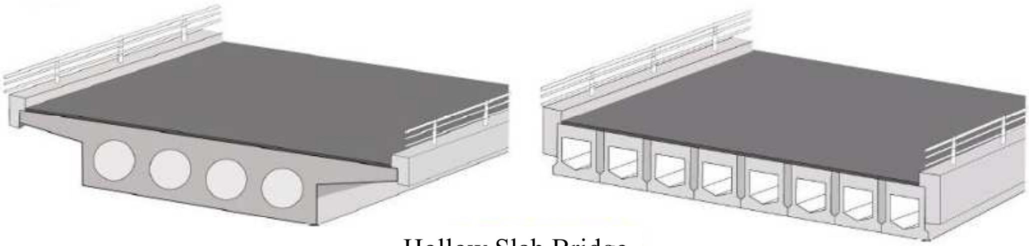
I-Girder Bridge

T-Girder Bridge

Box-Girder Bridge

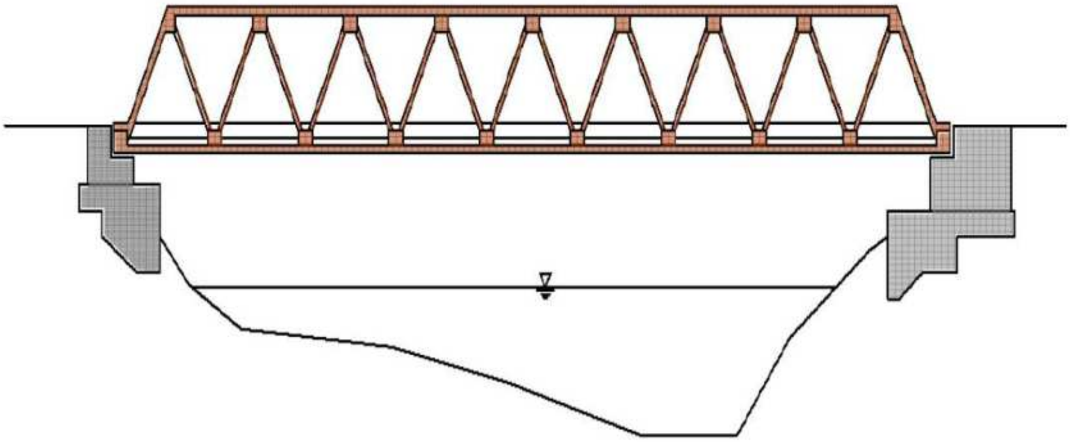
2.2 Slab bridge *（No girder）





Hollow Slab Bridge

2.3 Truss bridge

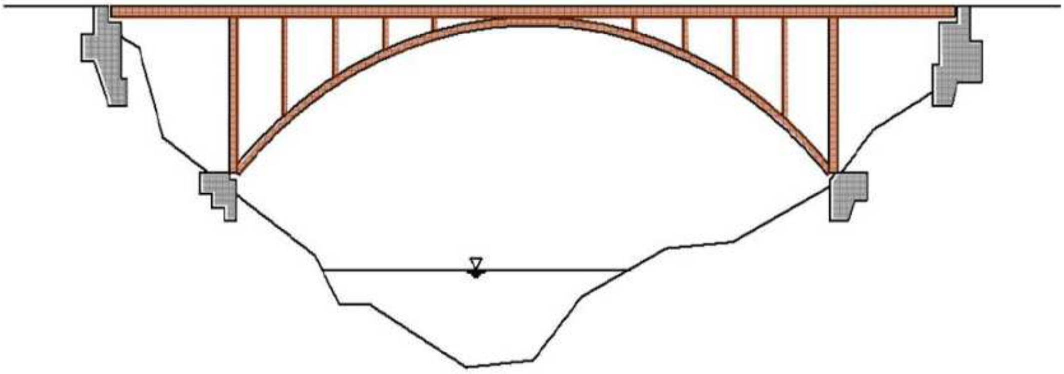


【Bridges in Bhutan】

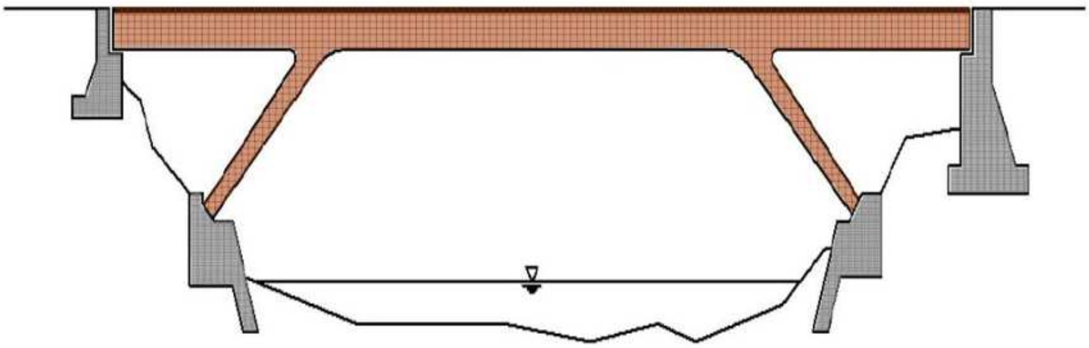
Slab Bridge
（NgashayZam in Wangdue）

Steel Truss Bridge
（Isuna in Paro）

2.4 Arch bridge



2.5 Rigid frame bridge



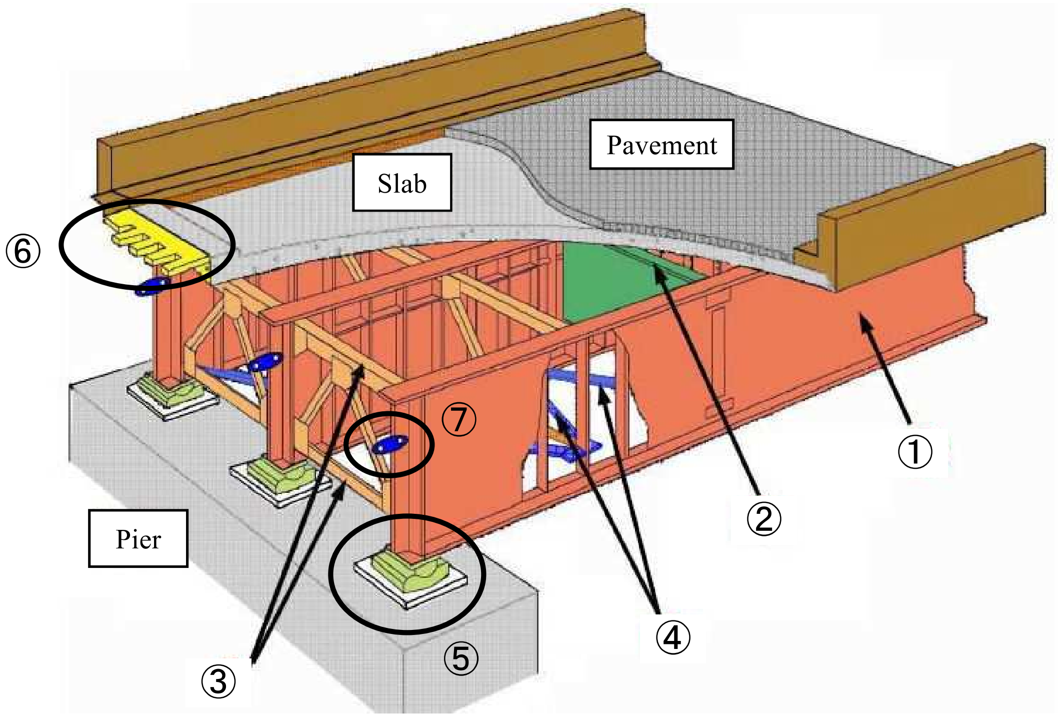
【Bridges in Bhutan and Japan】

Steel Langer Arch Bridge
（Wakleytar in Wangdue）

Rigid Frame Bridge

3. Names and Functions of the structural member

3.1 Superstructure



① Main girder

It is passed between the piers and abutments which support the loads such as passing vehicles on the slab and transmitted the loads to the piers and abutments.

② Cross beam

It is a member that connects the main girders that support the loads.

③ Cross frame

It is a member that connects main girders vertically in order to resist the lateral loads such as earthquakes and wind loads. (It is not in concrete bridge)

④ Lateral bracing

It is a member that connects main girders horizontally in order to resist the lateral loads such as earthquakes and wind loads. (It is not in concrete bridge)

⑤ Bearing

Which support the superstructure and transmits the load from the superstructure to the substructure (abutment or pier).

⑥ Expansion device

It is a device to absorb the expansion and contraction of the girder due to the influence of temperature or the like.

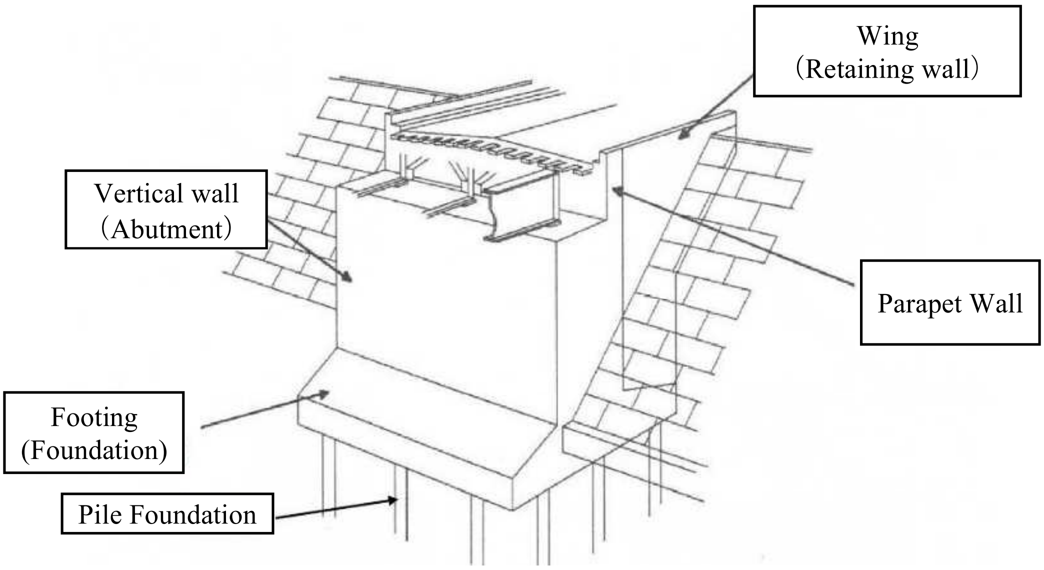
⑦ Bridge fall prevention device

It is a device that is installed in order to prevent the superstructure to fall from substructure (abutment or pier) by superstructure is moved due to earthquakes.

3.2 Substructure

3.2.1 Abutment

It is located at both ends of the bridge, connects the bridge and roads, which supports the sediment on the back and the load from the superstructure.

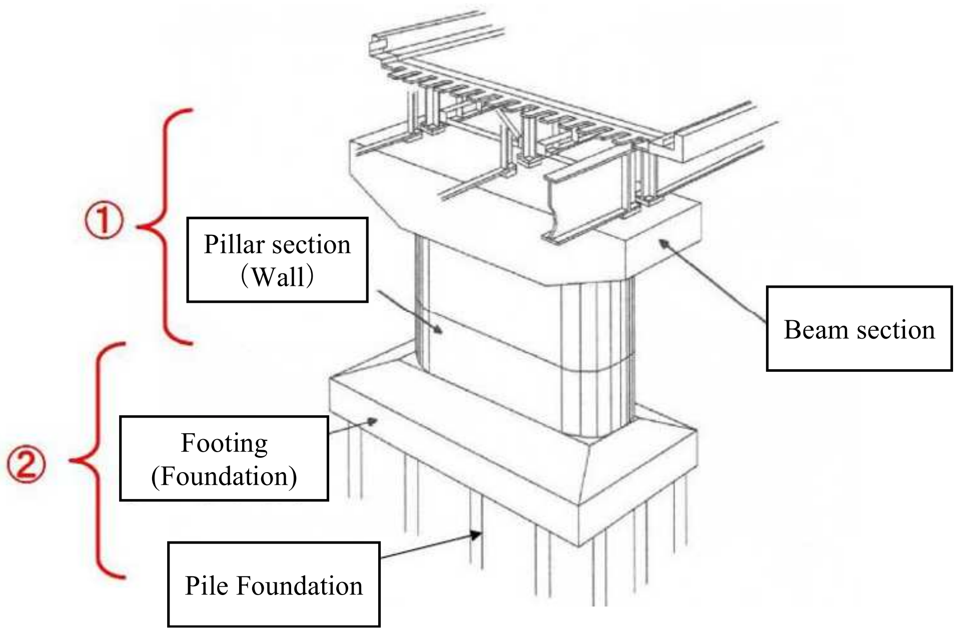


3.2.2 Pier

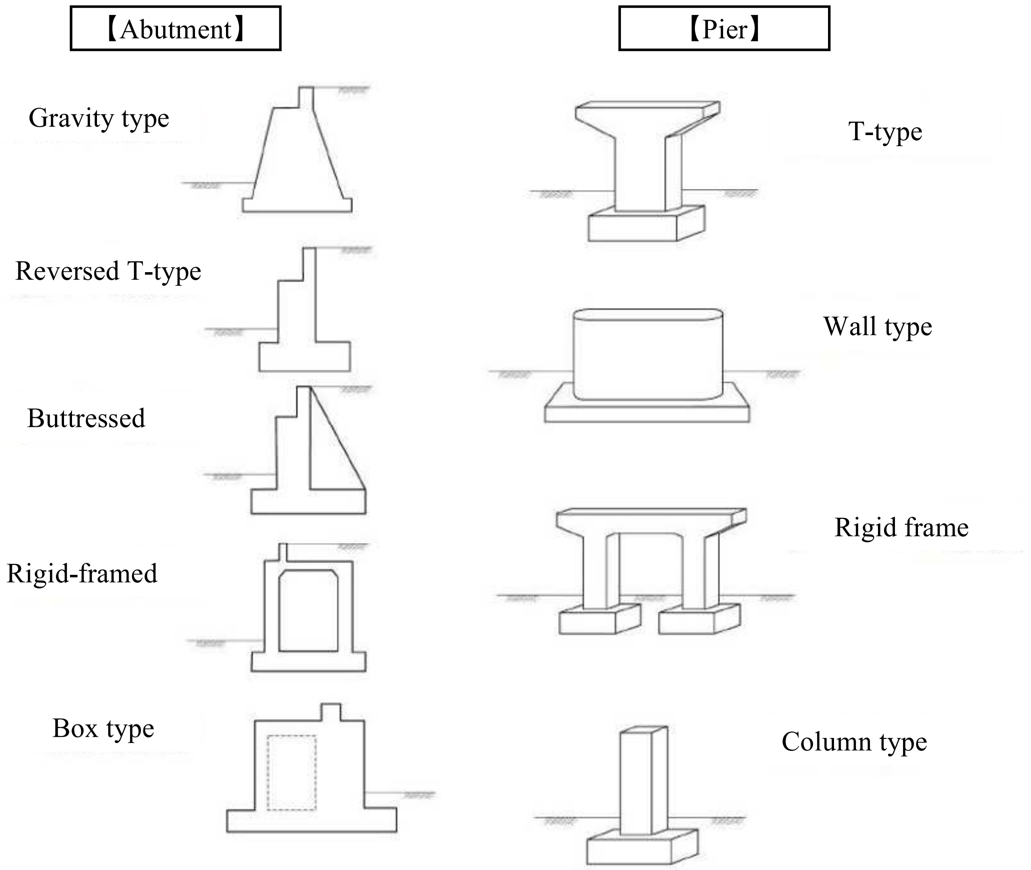
It is located at middle of the bridge, supports the load from the superstructure.

3.2.3 Foundation

It is located under abutment and pier, transmits the load to the ground.



3.2.4 Substructure Type



Appendix-5 Bridge List

1. Bridge List

1.1 Thimphu

Bridges under Regional Office, DoR, Thimphu

Name of Bridge	Bridge No.	Road	Section	Sub Division	Dzongkhag
Khasadrapchu Zam	Th-1	Khasadrapchu-Bjemina SNH	Thimphu (Sub-1)	Thimphu (Sub-2)	Thimphu
Simtokha Fly over Bridge	Th-2	Simtokha-Dochula Highway			
Dhop Shari Bridge	Th-3	Jangsa – Rimpung Dzong	Paro	Paro (Sub-3)	Paro
Hungrel Bridge	Th-4	Jangsa – Hungrel Gewog Office			
Jangsa Bridge	Th-5	Jangsa_Rimpung Road			
NIE Bridge	Th-6	Town to Bondey Road			
Taktsang Bridge	Th-7	Drukgyel junction to Taktsang Road			
Tshendona Bridge	Th-8	Town to Lamgong Gewog office			
Balamna Bridge	Th-9	Haa-Samtse SNH	Haa	Haa (Sub-4)	Haa
Haa Chu Bridge	Th-10	Yangthang,Talung,Tshenkhar Road.			

1.2 Lobeysa

Bridges under Regional Office, DoR, Lobesa

Name of Bridge	Bridge No.	Load	Section	Sub Division	Dzongkhag
Zameychu Zam	Lo-1	Punakha-Gasa SNH	Gasa	Damji	Gasa
Gayza Zam	Lo-2	Punakha-Gasa SNH			
Gathana Zam	Lo-3	Punakha-Gasa SNH			
Yemina Zam	Lo-4	Punakha-Gasa SNH			
Kukuna Zam	Lo-5	Punakha-Gasa SNH			
Tingtha Zam	Lo-6	Punakha-Gasa SNH			
Rableythang Zam	Lo-7	Punakha-Gasa SNH	Tsodelmo		
Tshorim Zam	Lo-8	Punakha-Gasa SNH			
Rimchu Zam	Lo-9	Punakha-Gasa SNH			
Serigang Zam	Lo-10	Punakha-Gasa SNH			
Teoporongchu Zam	Lo-11	Punakha-Gasa SNH			
Changyul Zampa	Lo-12	Dzongchung Road	Phochu	Lobeysa	Punakha
Khuru Kuenphen Zam	Lo-13	Bajo-Khuru SNH			
Samdingkha Zam	Lo-14	Chubu GC roads			
Wangdue Zam (arch bridg	Lo-15	Dochula- Wangdue PNH	Lobeysa		Wangdue
Ruebesa Zam	Lo-16	Rubesa Gewog center Road			
Rakey Zam	Lo-17	Samtengang Dz.Road	Rabuna		
Chabjiha Zam -I	Lo-18	Baylangdra Dz.Road			
Chabjiha Zam -II	Lo-19	Baylangdra Dz.Road			
Chuzomsa Zam	Lo-20	Wangdue-Chuserbu PNH			
Wachey Zam (New)	Lo-21	Wangdue-Chuserbu PNH			
Nobding shongZam	Lo-22	Jangchubcholing-Tashidingkha Dzongkhag Road	Nobding	Nobding	
Ridha shong Zam	Lo-23	Jangchubcholing-Tashidingkha Dzongkhag Road			
Ridha shong Zam II	Lo-24	Jangchubcholing-Tashidingkha Dzongkhag Road			
Shamoshong Zam	Lo-25	Jangchubcholing-Tashidingkha Dzongkhag Road			
Dangchu Zam	Lo-26	Jangchubcholing-Tashidingkha Dzongkhag Road			
Nikachu Zam	Lo-27	Wangdue-Chuserbu PNH	Rukubji		
Longmey Zam	Lo-28	Wangdue-Chuserbu PNH			
Phenchimerizam	Lo-29	Wangdi-Trongsa Highway			
Phojikha Zam	Lo-30	Gangtay Phobjikha GC road			
Gemzina Zam	Lo-31	Wangdi-Trongsa Highway	Nobding		
Wachey Zam	Lo-32	Wangdue-Chuserbu PNH			
Hesothangkha Zam	Lo-33	Wangdue-Tsirang PNH	Petekarp	Pinsa	
Lawakha Zam	Lo-34	Wangdue-Tsirang PNH			
Basochu Zam	Lo-35	Wangdue-Tsirang PNH			
Rurichu Zam	Lo-36	Wangdue-Tsirang PNH			
Baychu Zam	Lo-37	Wangdue-Tsirang PNH			
Kamichu Zam	Lo-38	Wangdue-Tsirang PNH	kamichu		
Nyarachu Zam	Lo-39	Wangdue-Tsirang PNH			
Dickchu Zam	Lo-40	Athang GC Road			

1.3 Phuntsholing

Bridges under Regional Office, DoR, Phuentsholing

Name of Bridge	Bridge No.	Load	Section	Sub Division	Dzongkhag
Damdum Bailey bridge	Pl-1	Samtse-Sipsu SNH (0-49)km	Samtse	Samtse	Samtse
Budhuney Bailey bridge -1	Pl-2	Samtse-Sipsu SNH (0-49)km			
Budhuney Bailey bridge -2	Pl-3	Samtse-Sipsu SNH (0-49)km			
Dram zam	Pl-4	Samtse-Sipsu SNH (0-49)km			
Kuenphen Zam	Pl-5	Samtse-Sipsu SNH (0-49)km			
Chungpathang Bridge	Pl-6	Samtse-Sipsu SNH (0-49)km			
Kuchi Diana Bridge	Pl-7	Samtse-Sipsu SNH (0-49)km			
Lengthey Bridge	Pl-8	Samtse-Sipsu SNH (0-49)km			
Gathia Bridge	Pl-9	Samtse-Sipsu SNH (0-49)km			
Jitti A	Pl-10	Samtse-Sipsu SNH (0-49)km			
Jitti B	Pl-11	Samtse-Sipsu SNH (0-49)km			
Jitti C	Pl-12	Samtse-Sipsu SNH (0-49)km			
Jitti D	Pl-13	Samtse-Sipsu SNH (0-49)km			
Tashicholing Bridge	Pl-14	Samtse-Sipsu SNH (0-49)km			
Biru	Pl-15	Samtse-Sipsu SNH (0-49)km	Sipsu		
Pakpey Bridge	Pl-16	Samtse-Sipsu SNH (0-49)km			
Bindu Bridge	Pl-17	Samtse-Sipsu SNH (0-49)km			
Bhalujhora bridge	Pl-18	Rinchending-Pasakha PNH	Rinchending	Darla	Chukha
Padazekha Steel bridge	Pl-19	Rinchending-Pasakha PNH			
Shingkhola Zam	Pl-20	Pasakha-Manitar PNH			
Ademchhu Zam	Pl-21	Ganglakha-Dungna GC Road	Dungna		
Tomichu Zam	Pl-22	Ganglakha-Dungna GC Road			
Mailumchu Zam	Pl-23	Ganglakha-Dungna GC Road			
Wangchu Bailey bridge	Pl-24	Gedu-Jungley Dzongkhag Road	Mirchim		
Hobjelum Bailey bridge	Pl-25	Gedu-Jungley Dzongkhag Road			
Satholumpa steel bridge (1)	Pl-26	Geduchu Dzongkhag Road			
Raidak bridge	Pl-27	Manitar-Raidak PNH	Darla		
Outsholumpa Bridge (1)	Pl-28	Geduchu Dzongkhag Road	Mirchim		
Outsholumpa Bridge (2)	Pl-29	Geduchu Dzongkhag Road			
Satholumpa steel Bridge (2)	Pl-30	Geduchu Dzongkhag Road			
Geduchu Steel bridge	Pl-31	Geduchu Dzongkhag Road			
Kalikhola bridge	Pl-32	Raidak-Lhamoizingkha PNH	Darla		

1.4 Sarpang

Bridges under Regional Office, DoR, Sarpang

Name of Bridge	Bridge No.	Load	Section	Sub Division	Dzongkhag
Katley I	Sa-1	Gelephu-Trongsa PNH	Lungsaygang	Lungsaygang	Sarpang
Katley II	Sa-2	Gelephu-Trongsa PNH			
Katley III	Sa-3	Gelephu-Trongsa PNH			
Samkhara Zam	Sa-4	Gelephu-Trongsa PNH			
Beteni Zam	Sa-5	Gelephu-Trongsa PNH			
Passang Zam	Sa-6	Gelephu-Trongsa PNH	Pelrithang		
Geleg Zam	Sa-7	Gelephu-Trongsa PNH			
Barsong Zam	Sa-8	Gewog Connectivity Road			
Paithachu Bridge	Sa-9	Gelephu-Sarpang PNH (2.95km to 30km)	Bhur	Sarpang	
Goikolche Bridge	Sa-10	Gelephu-Sarpang PNH (2.95km to 30km)			
Kopche Bridge	Sa-11	Gelephu-Sarpang PNH (2.95km to 30km)			
Dolkhola Bridge	Sa-12	Gelephu-Sarpang PNH (2.95km to 30km)			
Panditchu Bridge	Sa-13	Gelephu-Sarpang PNH (2.95km to 30km)			
Leukhola Bridge	Sa-14	Gelephu-Sarpang PNH (2.95km to 30km)			
Lampathey Bridge	Sa-15	Gelephu-Sarpang PNH (2.95km to 30km)			
Jigmeling	Sa-16	Gelephu-Sarpang PNH (2.95km to 30km)			
Jigmeling 2	Sa-17	Gelephu-Sarpang PNH (2.95km to 30km)			
Chokorling Bridge	Sa-18	Gelephu-Sarpang PNH (2.95km to 30km)			
Kami Khola Bridge	Sa-19	Sarpang-Darachu PNH (30-67km)	Ranibagan		
Butabari 1 Zam	Sa-20	Sarpang-Darachu PNH (30-67km)			
Butabari 2 Zam	Sa-21	Sarpang-Darachu PNH (30-67km)			
Kharey Zam 1	Sa-22	Sarpang-Darachu PNH (30-67km)			
Kharey Zam 2	Sa-23	Sarpang-Darachu PNH (30-67km)			
Shompangkha Bridge	Sa-24	Sarpang-Darachu PNH (30-67km)			
Loring Bridge	Sa-25	Sarpang-Darachu PNH (30-67km)			
Budhichu Zam	Sa-26	Sunkosh-Dagana SNH	Youngsibi	Tshendagang	Dagana
Dagachu Zam .	Sa-27	Sunkosh-Dagana SNH			
Ampichu Zam	Sa-28	Sunkosh-Dagana SNH	Tshendagang		
Panachu Zam	Sa-29	Sunkosh-Dagana SNH			
Samarchu Zam	Sa-30	Dorona GC Road			
Nimtolachu Zam	Sa-31	Dorona GC Road			
Goshichu Zam	Sa-32	Sunkosh-Dagana SNH	Khagochen		
Bidulung Zam	Sa-33	Sunkosh-Dagana SNH			
Baleygangchu Zam	Sa-34	Sunkosh-Dagana SNH			
Zharingaychu Zam	Sa-35	Sunkosh-Dagana SNH			
Lemichu Zam	Sa-36	Sunkosh-Dagana SNH			
Tangrachu Zam	Sa-37	Sunkosh-Dagana SNH			
Darachu Zam	Sa-38	Sunkosh-Dagana SNH			
Chanchey Bailey Bridge	Sa-39	Semjong GCC Road	Damphu	Tsirang	Tsriang
Rateykhola Bailey Bridge	Sa-40	Tsirangtoeh GCC Road			
Burichhu Bailey Bridge	Sa-41	Sergithang GCC Road	Waklaytar		
Lhari Zam	Sa-42	Sergithang GCC Road			
Sunkosh Bridge	Sa-43	Dagana-Sunkosh SNH			
Changchey Bridge	Sa-44	Wakleytar-Changchey PNH			
Burichu Bridge	Sa-45	Wakleytar-Changchey PNH			
Mechichu Bridge	Sa-46	Wakleytar-Changchey PNH			
Wakleytar Bridge	Sa-47	Wakleytar-Changchey PNH			

1.5 Trongsa

Bridges under Regional Office, DoR, Trongsa

Name of Bridge	Bridge No.	Road	Section	Sub Division	Dzongkhag
Tyelegangchu Bridge	Tr-1	Trongsa – Gelegphu PNH	Trongsa	Trongsa	Trongsa
Chamdhegang Bailey Bridge	Tr-2	Bjeezam to Bemji GC Road			
Chela RCC Bridge	Tr-3	Bjeezam to Bemji GC Road			
Kaba Daba Bailey Bridge	Tr-4	Bjeezam to Bemji GC Road			
Bjee zam	Tr-5	Trongsa to Thimphu			
Yesheygangchu Bridge	Tr-6	Trongsa – Gelegphu PNH			
Chuserbu Zam	Tr-7	Chuserbu – Trongsa PNH	Tshangkha		
Chendebji Zam	Tr-8	Chuserbu – Trongsa PNH			
Nyala Zam	Tr-9	Chuserbu – Trongsa PNH			
Nagina Zam	Tr-10	Chuserbu – Trongsa PNH			
Tashiling Zam	Tr-11	Chuserbu – Trongsa PNH			
Gazamche	Tr-12	Serpang -Tang PNH	Ura	Ura	Bumthang
Leri Zam	Tr-13	Serpang -Tang PNH			
Gaktong Zam	Tr-14	Nangar-Ura PNH			
Chamkhar Zam	Tr-15	Nangar-Ura PNH	Jakar	Jakar	
Tangchhu Zam	Tr-16	Jakar-Ura PNH			
Babzur RCC Bridge	Tr-17	Tang GC Road PNH			
Pangshing Bailey Bridge	Tr-18	Tang GC Road PNH			
Tazambi Bridge	Tr-19	Tang Dzongkhag Road			
Bongzam	Tr-20	y/la-Jakar			
Gaytsha	Tr-21	y/la-Jakar			
Domkhar	Tr-22	y/la-Jakar			
Hurjee	Tr-23	y/la-Jakar			
Rubee	Tr-24	y/la-Jakar			
Yamthrak	Tr-25	y/la-Jakar			
Rabteen	Tr-26	y/la-Jakar			
Reotala	Tr-27	Wangdigang- Nabji GC Road	Khosela	Khosela	Trongsa
Wangdigang Zam	Tr-28	Wangdigang- Nabji GC Road			
Kartigang Zam	Tr-29	Gelephu-Trongsa PNH			
Dangdung Zam	Tr-30	Gelephu-Trongsa PNH			

1.6 Tingtibi

Bridges under Regional Office, DoR, Tingtibi

<table>
<tr><th>Name of Bridge</th><th>Bridge No.</th><th>Load</th><th>Section</th><th>Sub Division</th><th>Dzongkhag</th></tr>
<tr><td>Ringdigang Zam</td><td>Ti-1</td><td rowspan="8">Gomphu-Panbang Highway</td><td rowspan="7">Pantang</td><td rowspan="12">Panbang</td><td rowspan="23">Zhemgang</td></tr>
<tr><td>Tikiring Zam</td><td>Ti-2</td></tr>
<tr><td>Pantang Zam</td><td>Ti-3</td></tr>
<tr><td>Morongang Zam</td><td>Ti-4</td></tr>
<tr><td>Gramlanggang Zam</td><td>Ti-5</td></tr>
<tr><td>Darangang Zam</td><td>Ti-6</td></tr>
<tr><td>Jirangang Zam</td><td>Ti-7</td></tr>
<tr><td>Panbang Zam</td><td>Ti-8</td><td rowspan="5">Panbang</td></tr>
<tr><td>Tshasapani Bridge</td><td>Ti-9</td><td rowspan="2">Mathangguri-Panbang-Galabe Feeder road</td></tr>
<tr><td>Nangchu Bridge</td><td>Ti-10</td></tr>
<tr><td>Marangdutt Bridge</td><td>Ti-11</td><td rowspan="2">Bjoka GC road</td></tr>
<tr><td>Chakchawa Bridge</td><td>Ti-12</td></tr>
<tr><td>Mangdi Zam</td><td>Ti-13</td><td rowspan="5">Gelephu-Trongsa Highway</td><td rowspan="2">Mangdichu</td><td rowspan="10">Mangdichu</td></tr>
<tr><td>Wangdigangchu Zam</td><td>Ti-14</td></tr>
<tr><td>Wangdigang Zam</td><td>Ti-15</td><td>Zhemgang</td></tr>
<tr><td>Chablechu bridge</td><td>Ti-16</td><td rowspan="2">Tama</td></tr>
<tr><td>Golipong bridge</td><td>Ti-17</td></tr>
<tr><td>Kikhar Bailey bridge</td><td>Ti-18</td><td rowspan="2">Dhakphel-Buli feeder road</td><td rowspan="2">Buli</td></tr>
<tr><td>Bomdeling bailey bridge</td><td>Ti-19</td></tr>
<tr><td>Andhigangchu Zam</td><td>Ti-20</td><td rowspan="3">Tingtibi-Praling Highway</td><td rowspan="3">Goling</td></tr>
<tr><td>Yebigangchu Zam</td><td>Ti-21</td></tr>
<tr><td>Chendigangchu Zam</td><td>Ti-22</td></tr>
<tr><td>Chamkharchu Bailey Bridge</td><td>Ti-23</td><td>Nimshong-Therang GC road</td><td>Nimshong</td><td>Nimshong</td></tr>
</table>

1.7 Lingmethang

Bridges under Regional Office, DoR, Lingmetang

Name of Bridge	Bridge No.	Road	Section	Sub Division	Dzongkhag
Gangola Bridge	Li-1	Gangola-Lhuntse SNH	Chali	Autsho	Mongar
Horong Bridge	Li-2	Gangola-Lhuntse SNH			
Dorjilung Bridg	Li-3	Gangola-Lhuntse SNH			
Rewanchu Bridge	Li-4	Gangola-Lhuntse SNH			
Phawanchu Bridge	Li-5	Gangola-Lhuntse SNH	Autsho-I		
Karma Shangshong Bridge	Li-6	Gangola-Lhuntse SNH			
Rongmanchu Bridge	Li-7	Gangola-Lhuntse SNH			
Tangmachu Bridge	Li-8	Gangola-Lhuntse SNH			
Chhumedang Bridge	Li-9	Lhuntse-Dungkar GC Road	Lhuntshe		
Kelung Bridge	Li-10	Lhuntse-Dungkar GC Road			
Lingabi Bridge	Li-11	Lhuntse-Dungkar GC Road			
Chudeygangchu Bridge	Li-12	Lhuntse-Dungkar GC Road			
Khoma Zam	Li-13	Khoma GC Road			
Gorgan Bridge	Li-14	Shingkhar-Gorgan Road	Autsho-II		
Silbi Bridge	Li-15	Shingkhar-Gorgan Road			
Zhongmey Zam	Li-16	Silbi-Gorsum Road			
Jaray Bridge	Li-17	Autsho-Jaray Road			
Kerong Zam	Li-18	Nganglam-Gyelposhing Highway	Nganglam	Nganglam	Pemagatshel
Kurung Zam	Li-19	Nganglam-Gyelposhing Highway			
Khakhari Zam	Li-20	Nganglam-Gyelposhing Highway			
Shumari Zam	Li-21	Nganglam-Gyelposhing Highway			
Sokporong Zam	Li-22	Nganglam-Gyelposhing Highway			
Brongri Zam	Li-23	Nganglam-Gyelposhing Highway			
Wangchuk Zam	Li-24	Daksa GC Road			
Gyelposhing Zam	Li-25	Gyelposhing-Nganglam Highway	Gyelposhing Side	Gyelposhing	Pemagatshel
Yongri Zam	Li-26	Gyelposhing-Nganglam Highway			
Zimzorong Zam	Li-27	Gyelposhing-Nganglam Highway			
Sangpoyhai Zam	Li-28	Gyelposhing-Nganglam Highway			
Desuma Zam	Li-29	Gyelposhing-Nganglam Highway			
Kuri Zam	Li-30	Yadi-Serpang PNH	Lingmethang	Lingmethang	Mongar
Powerhouse Zam	Li-31	Gyelposhing-Nganglam Highway			
Zimzorong Zam	Li-32	Zimzorong-kengkhar GC road			
Brizingdang Zam	Li-33	Yadi-Sershong GC Road	Ningala		
Kaphu Zam	Li-34	Kaphu-Balam GC road			
Marungdang Zam	Li-35	Kaphu-Balam GC road			
Yauri Bridge	Li-36	Kaphu-Balam GC road			
Morichu zam (Manchugang)	Li-37	Silambi GC Road	Silam Road	Silambi	Mongar
Drogsar Bridge	Li-38	Silambi GC Road			
Namling Zam	Li-39	Yadi-Serpang PNH	Sengor		
Tsamang Bridge	Li-40	Yadi-Serpang PNH	Selshithang		

1.8 Trashigang

Bridges under Regional Office, DoR, Trashigang

Name of Bridge	Bridge No.	Road	Section	Sub Division	Dzongkhag
Johari bdge	Tg-1	Yadi-Chaskhar GC	Chaskhar	RoTong SD	Mongar
Jabrakhey bdge	Tg-2				
Gudhari Bailey Bridge	Tg-3				
Tshaling RCC	Tg-4	Doksum-Trashiyangtse SNH	Tyangtse	Duksum SD	Trashiyangtse
Tsherzam Bridge	Tg-5				
Buyang RCC	Tg-6				
Chumdu bridge	Tg-7				
Wangrimo Bridge	Tg-8		Ramjar		
Duksum bridge	Tg-9		Chazam-Duksum		
Gomkora RCC	Tg-10	Chazam-Duksum SNH			
Tsergom bridge	Tg-11				
Jamkhardhang RCC	Tg-12				
Reju bridge	Tg-13	Barthsam GC	Bartsham	Rangjung SD	Trashigang
Thungdari bridge	Tg-14	Tgang-Rangjung Dz Road	Rangjung		
Rangjung Bridge	Tg-15				
Chongdhiri Bridge	Tg-16	Radhi-Phongmey GC	Merak		
Gamrichu bridge	Tg-17	Bidung GC	Bartsham		
Yamkhardrang bridge	Tg-18	Sakteng GC	Sakteng		
Minjiri Bridge	Tg-19				
Thongrong Bridge	Tg-20				
Kubrangchu Bridge	Tg-21				
Sertherongchu Bridge	Tg-22				
Dhak Bridge	Tg-23				
Sona Drang Bridge	Tg-24				
Sherporongchu Bridge	Tg-25	Kharungla-Kangpar GC	Tsangpo	Tsangpo SD	Trashigang
Zachhu Bridge	Tg-26				
Nyera Ama Bridge	Tg-27				
Phekpari Bridge	Tg-28	Thrimshing GC			

1.9 Samdrup Jongkhar

Bridges under Regional Office, DoR, Samdrupjongkhar

Name of Bridge	Bridge No.	Road	Section	Sub Division	Dzongkhag
Rechanglu	Sj-1	Martshala GC road	Pemathang	Dewathang	SamdrupJongkhar
Warongkhola	Sj-2	Samrang SNH			
Kathubdrang 1	Sj-3	Samrang SNH			
Kathubdrang 2	Sj-4	Samrang SNH			
Kathubdrang 3	Sj-5	Samrang SNH			
Neuli	Sj-6	Samrang SNH			
Samrang	Sj-7	Samrang SNH			
Tshangchilo	Sj-8	Narphung-Gomdar GC road	Narphung		
Sanguri	Sj-9	Dewathang-Samdrupchoeling SNH	Dewathang		
Martang	Sj-10	Dewathang-Samdrupchoeling SNH			
Demola	Sj-11	Dewathang-Samdrupchoeling SNH			
Tshangchuthama 1	Sj-12	Dewathang-Samdrupchoeling SNH			
Tshangchuthama 2	Sj-13	Dewathang-Samdrupchoeling SNH			
Tshalari	Sj-14	Kherigonpa-Yelchen (Nanong) GC road	Kherigonpa	Pemagatshel	Pemagatshel
Denchi	Sj-15	Yurung GC road	Yurung		
Nagpheldrang	Sj-16	Khar-Khotakpa-Tsebar-Yurung DR			
Marung	Sj-17	Khar-Khotakpa-Tsebar-Yurung DR			
Yuri	Sj-18	Tsebar-Mikure-Durungree SNH			
Chumo Dhur	Sj-19	Lauri GC road	Minjeywoong	Jomotshangkha	SamdrupJongkhar
Chukarpo	Sj-20	Langchenphu GC road	Jomotshangkha		
Linzin	Sj-21	Linzin - Tshengkhari PNH	Nganglam	Nganglam	Pemagatshel
Nganglam	Sj-22	Linzin - Tshengkhari PNH			
Menchu	Sj-23	Linzin - Tshengkhari PNH			
Dhop	Sj-24	Linzin - Tshengkhari PNH			
Dezama	Sj-25	Chhoekhorling GC road			
Kurungdrang	Sj-26	Decheling GC road	Mekuri		

Appendix-6 Sample of Bridges

1. Sample of Steel Bridge

Photograph			
No.1	From the right	No.2	From the left
			
No.3	From the right downstream	No.4	From the left downstream
			
No.5	From the right upstream	No.6	From the left upstream
			
No.7	From the center to downstream	No.8	From the center to upstream
			

2. Sample of Concrete Bridge

Photograph			
No.1	From the right	No.2	From the left
			
No.3	From the right downstream	No.4	From the left downstream
			
No.5	From the right upstream	No.6	From the left upstream
			
No.7	From the center to downstream	No.8	From the center to upstream
			

3. Sample of Bailey Bridge

Photograph			
No.1	From the right	No.2	From the left
			
No.3	From the right downstream	No.4	From the left downstream
			
No.5	From the right upstream	No.6	From the left upstream
			
No.7	From the center to downstream	No.8	From the center to upstream
			

MANUAL 2 : Technical Manual on Repair and Strengthening of Bridge

CAMBRIDGE

Technical Cooperation Project for Capacity Development in Construction and Maintenance of Bridges in the Kingdom of Bhutan

Technical Manual on Repair and Strengthening of Bridge

April 2022

Department of Road
Ministry of Works & Human Settlement
Royal Government of Bhutan

Japan International Cooperation Agency

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APPNDIX

1. Introduction

1.1. Purpose

There are over 300 bridges on National and Dzongkhag highways and some of them are in dangerous condition due to the damages by natural disaster, overloaded vehicles, and serious deterioration. Maintaining the condition of the bridge is indispensable to maintain the highway network nationwide and to sustain the regional economic development. Since Bhutan faces heavy rain caused by monsoon every summer, bridges in Bhutan tends to deteriorate more rapidly than in other mild climate and environment. Therefore, the bridges in Bhutan requires very careful observation and treatments to maintain its soundness so that the road users, such as vehicle drivers, pedestrians, as well as those who are deeply depend upon the transportation of goods by roads.

This manual follows the policy, technical standard, technical skills of bridge repair and strengthening and aims to improve current and future level of Bhutanese bridge management on highways. It covers the planning of repair and strengthening based on the inspection results, detailed design and construction work on repair and strengthening. It also covers some of the maintenance works which are important to secure the safety of the road users.

This manual guides the personnel and engineers who are involved in operation and maintenance of the highway bridges, how to deal with and recover the damages efficiently and effectively which are occurred on the bridge members and also the entire bridge.

This manual targets to improve the current Bhutanese operation and maintenance of the highway bridges not only technically but also in procedure so that the damages would be repaired more rapidly than current procedure. It can be referred to the situation for other bridges in minor/local roads and would improve the technical and administration level of local governmental organization for operation and maintenance of bridges.

1.2. Scope

This manual treats bridge with more than 5m of length on national and dzongkhag highways. It treats concrete slab, concrete girder, steel girder, steel truss and single and multi-span bailey bridges. It does not treat bridges with other superstructure types, such as suspension bridge, cable stayed bridge, extra dozed bridge, composite girder bridge, and other bridges which requires special treatment to execute repair and strengthening.

This manual treats repair and strengthening methods of limited types of damages. There are other damages of bridge and bridge members which are not explained in this manual. If responsible personnel or engineer faces the requirement of repairing and strengthening such damages, they shall refer to other documents or advises from experienced experts from other organization to solve the issues.

1.3. Target

This manual targets to improve the level of repair and strengthening of national and dzongkhag highways to secure the safety for road users including immediate action to the damages. It also targets to demonstrate the preventive methods to have a further target for future.

1.4. Structure

Chapter 2 explains the overall maintenance of bridges. It explains the cycle of maintenance to improve the knowledge of the responsible personnel and engineers. It also emphasizes that maintenance is continuous work to maintain the soundness and safety of bridges. Ad-hoc treatment shall not be executed to the remarkable damages which are found on the members of bridges.

Chapter 3 notes the definition of repair and strengthening.

Chapter 4 demonstrates the details of maintenance works which are important to prevent the rapid deterioration of the bridge members.

Chapter 5 demonstrates the details of repair works by materials and members.

Chapter 6 demonstrates the details of strengthening works by materials and members.

And appendix introduces some samples of new technologies of repair and maintenance from Japan's experiences.

1.5. Definition

Technical terms mentioned in this manual is defined as follows,

[Repair]: Recovery of structural/functional damage of bridge member(s) up to its original condition which meets original design condition.

[Strengthening]: Making the existing bridge member stronger than its original design/construction in terms of strength and durability. It could be better-known as 'Retrofitting' in Bhutan or well-known as 'Reinforcement' worldwide. The term 'Strengthening' is applied in this manual.

[Maintenance Work]: Activity which keeps bridge member strong, durable, and functional or retard the deterioration.

[Inspection]: Recognizing the status and condition of the bridge and its members to collect the data/information for check/definition of its current condition and soundness of the bridge. It is divided into three phases. The most frequent is [Routine Inspection] which shall be done once a week, less frequent is [Periodic Inspection] which shall be done once in every 2 to 5 years. The last one is [Inspection at the time of abnormality] which shall be done just after when the bridge is heavily damaged. It is more well-known as 'Emergency Inspection' to check whether the bridge is in safe condition for traffic, has enough soundness to bear the internal/external loads.

[Inventory]: Record the initial and current status of the bridge

[Evaluation]: Based on the results of inspection, the bridge members are checked/defined its current condition and soundness. Each member would be evaluated and defined the damage degree following the Technical Manual on Inspection and Diagnosis of Bridge.

[Diagnosis]:	Based on the result of evaluation, each damage shall be judged and decided how to treat the damage for the safety of the traffic. Diagnosis clarify the cause of the damage and forecast the near future deterioration roughly to judge whether the emergent/immediate treatment is necessary or not.
[Bailey Bridge]:	Bailey bridge is a segmental steel superstructure which was originally developed for the military troops to cross the water flow without constructing abutments at the both ends of it. It is applied as semi-permanent bridge in many developing countries as well as Bhutan placed on the abutments at the both ends.

Figure 1.1 Bailey Bridge

[Damage]:	Condition of members with insufficient specification, such as scale, strength, durability, and function. It is the generic term of structure/members with functional decline, including time deterioration, defect, and fatigue
[Deterioration]:	Functional decline of members related over time
[Defect]:	Lack of quality which structure/members shall maintain from initial condition by exceeding the permissible limit.
[Fatigue Crack]:	Damage of steel members caused by repeated load. It often occurs at the connecting section and sudden change of cross section as a crack.
[Durability]:	Quality which shows how long the member could bear expected load and external environment. It depends on the initial specification of the member. However, it can be prolonged by appropriate and sufficient maintenance.
[Strength]:	Quality which shows how strong the member could bear stress and sectional force.
[Service Life Prolongation]:	Concept of prolonging service life of bridge/members by executing appropriate and sufficient maintenance. It is considered that it could prolong the durability and reduce life cycle cost. It is also expected to average the maintenance cost to maintain sufficient service level of the bridge.

[Maintenance]: Cycle of activities which maintain traffic safety, durability, strength, of bridge and prevent the 3rd party from injury, such as inventory, inspection, investigation, evaluation, diagnosis, repair, and strengthening.

[Site Reconnaissance]: Field activity which confirm the site condition, method to access the bridge members, construction planning of repair/strengthening

[Detailed Observation]: Close investigation of damaged/deformed members which could not be clearly inspected in the periodic inspection. It often requires non-destructive inspection to investigate the internal condition of the member.

[Non-destructive inspection]: Method of inspection to investigate the internal condition of the members without direct observation. It includes methods utilizing ultrasonic wave, radiation, electromagnetic induction, and etc.

[Emergency Measures]: Measures to be taken when damage(s) which threaten safety of traffic and/or stability of bridge are found. It includes temporary treatment to prevent the collapse of the bridge, traffic regulation, traffic closure, and etc.

[Follow-up Monitoring]: Treatment for damages which are not serious and diagnosed that the repair/strengthening is not necessary until next periodic inspection. The road operator shall observe these damages regularly and monitor the condition. If there is a considerable change of the damages, it shall be reported and countermeasures shall be executed.

[Aseismic Strengthening]: Measure of strengthening of bridge/members to gain the capacity to resist against expected earthquake. It is often applied to old bridges which are designed with outdated design standard.

[Superstructure]: Bridge member above bearings, such as girder, slab, and other miscellaneous members. This manual treats RCC girders, RCC slabs, Steel girder, and Bailey bridge superstructure.

[Substructure]: Bridge members below bearings, such as piers and abutments. This manual treats substructure which are made of RCC or Masonry.

[Steel structure]: This manual treats steel girder bridge and Bailey bridge as steel structure.

[Concrete structure]: This manual treats members made of RCC, PSC, and plain concrete as concrete structure.

[Masonry]: This manual treats masonry which forms abutments, piers, and revetments.

2. Maintenance of Bridges

2.1. Purpose

No matter what material the bridge is made of, all the members start to deteriorate by the traffic and external environment right after it is constructed. The bridge shall be taken care of by its operator from the beginning of its service life till its closure. However, the period of the service life could be different not only by the quality of design and construction but also the quality of operation and maintenance. This chapter's purpose is to define the cycle of maintenance activities for installing and improving the maintenance system and structure of bridges on Bhutanese national and dzongkhag highway network.

2.2. Scope

Maintenance of bridge is required to be executed during the entire service life. It is divided into 4 categories, such as [Routine], [Periodic], [Corrective], and [Emergency] maintenance. [Routine] maintenance is a set of relatively small works, such as patrol, removing obstacles of traffic (animal carcass, fallen freight, fallen branch, etc.) and etc. [Periodic] maintenance is a set of the activities which are executed periodically such as periodic inspection, evaluation, diagnosis, design, repair, recording and updating the inventory. Periodic replacement of certain equipment such as light bulbs is included. [Corrective] is treatment which is done to repair the damage found in inspection or patrol. Repair of the damages based on the periodic maintenance is also a type of [Periodic] maintenance, and based on the routine patrol is also a part of [Routine] Maintenance. The last is [Emergency] maintenance which are done after very severe damage is found at any time of the service life. It is often found after the natural disaster, such as flood, land slide, earthquake, storm, lightning, and etc. Vehicle or vessel accident is another cause of necessary [Emergency] maintenance.

There is new concept of maintenance which are called [Preventive] maintenance. This is a concept of repair and maintenance works which applies repair methods and materials that retard the deterioration. It leads to the condition with less repair works and prolong the service life. It is expected to reduce life cycle cost of the bridge.

This manual focuses on the [Routine], [Periodic], and [Corrective] maintenance and describe the procedure and details of the maintenance and repair methods. It also introduces [Preventive] maintenance methods for future improvement.

2.3. Target

Considering the bridge maintenance level, the target for near future is to complete the maintenance cycle to realize [Routine], [Periodic] maintenance by installing BMS and several manuals for maintenance.

By realizing the [Routine], [Periodic] maintenance, [Corrective] and [Emergency] maintenance can be executed by applying similar procedures and details.

Methods of [Preventive] maintenance is for long-span future improvement which can be applied gradually judging the necessity of each method.

2.4. Maintenance Cycle

Maintenance shall be executed in several cycles. [Routine] maintenance is started basically by patrolling the bridge and checking its condition from the surface. If severe damage which requires [immediate] treatment, it will be done by appropriate methods. If the damage requires continuous [follow-up monitoring], it will be monitored in routine patrols since then. [Immediate] treatments are such as refilling the pot-hole of the surface, removing obstacles of traffic, or installing alert signs to keep away the road users from danger until the sufficient treatment is done. [Emergency] treatment, such as traffic control or tentative repair works, are done to secure the safety of traffic and the basic soundness of the bridge when the recognized damage is severe and dangerous. It would be followed by appropriate repair works to recover the strength/durability of the member(s). (Refer to Figure 2.1)

There are 4 options for necessary treatment in routine maintenance, one is to execute [immediate] treatment, next is to execute continuous [follow-up monitoring], next is to execute [emergency] treatment, and the last is to [repair immediately]. Any damages recognized and treatment executed shall be recorded with the results to database.

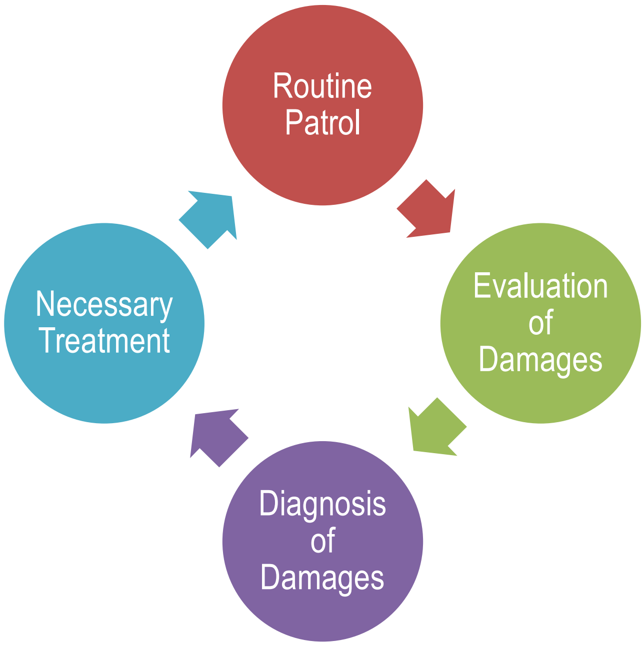


Figure 2.1 Maintenance Cycle of Routine Maintenance

[Periodic] maintenance is started by checking the most of the members of the bridge, theoretically and ideally it shall be checking all the members of the bridge directly/indirectly, in periodic inspection. The collected data/information of the periodic inspection is the very basic data/information. The collected data/information are recorded as the results of periodic inspection and evaluated and diagnosed to plan the maintenance implementation plan till next periodic inspection. Based on the result of diagnosis, every damage is planned to be treated necessarily, whether it would monitored in routine inspection, continuously monitored specifically, or repaid including replacement. (Refer to Figure 2.2)

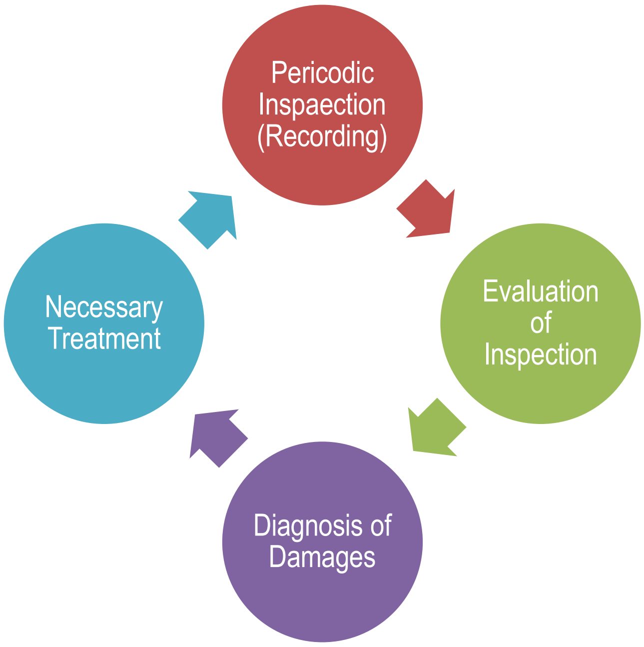


Figure 2.2 Maintenance Cycle of Periodic Maintenance

If the damage requires repair, it shall be planned to be repaired and executed as it is planned. The repair shall include removing the cause of deterioration/damage. Therefore, in planning and designing of the repair works, the cause shall be carefully investigated and defined.

Not only the technical aspect, but also the financial procurement shall be considered to realize the actual repair works, including the detailed design. After the repair works are completed and the damages are recovered, the details of repair works and its result shall be recorded to the inventory of the bridge. (Refer to Figure 2.3) If the damage is judged that it does not require the repair until the next periodic inspection, it will be continuously monitored as follow-up of the inspection results till next periodic inspection. The condition of these damages shall be carefully checked specifically after the natural disaster, such as flood, land slide, earth quake, storm, lightning, and etc. It shall be checked by site after a monsoon season.

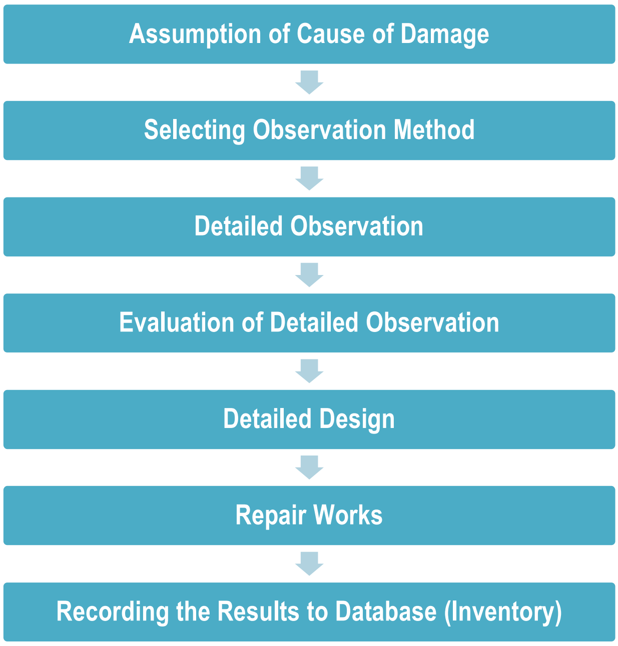


Figure 2.3 Procedure of Necessary Treatment (Repair)

[Emergency] maintenance is done after the sudden occurrence of damages which aggravate the safety of traffic or soundness of the members of bridge. Basic procedure of the cycle is similar to that of the [Periodic] maintenance. However, it shall be done much more rapidly to execute the emergency measures.

2.4.1. Inventory

Inventory is the data/information of bridge including bridge ledger, periodic inspection result, replace/repair/strengthening history of the members, and other important remarks related to the bridge. It is the very basic record of the bridge from its opening to the present. Since repair works targets the initial condition of the member/bridge, it is very important to archive the history of the member/bridge, such as the initial condition, details of inspection results, and details of replace/repair/strengthening history of the members.

2.4.2. Inspection

Inspection is divided into 3 phases, [Routine Inspection], [Periodic Inspection], and [Inspection at the time of abnormality] (‘Emergency Inspection’). Chapter 1 of the ‘Technical Manual on Inspection and Diagnosis of Bridge’ prepared by CAMBRIDGE, JICA shall be referred to for the details of each phase and overall inspection. Any damage or change from the initial condition shall be recorded in drawings and in texts, which describes the details of the damage/deformation. There are ‘Inspection Sheet’ prepared by CAMBRIDGE, JICA for recording the inspection. However, if other documents are necessary to record the details of damage/deformation, it shall be prepared.

2.4.3. Evaluation

Each damage/deformation of the members of the bridge shall be evaluated to define the degree of damage. The details of the evaluation standard are described in apeendix-2 of the 'Technical Manual on Inspection and Diagnosis of Bridge' prepared by CAMBRIDGE, JICA. The degree is divided into from 2 to 4 categories for each damage/deformation. Result of the evaluation is the basis of the following diagnosis of each members with damage/deformation.

2.4.4. Diagnosis

The results of each damage/deformation shall be diagnosed to define the policy of treatment. Study and definition of the cause of each damage/deformation is very important in diagnosis. If the damage/deformation is severe and obligating the users to face the danger, or the soundness of the bridge is in critical condition, it would need 'emergency measures'. If the deterioration progress is rapid, it also requires 'emergency measures'. Therefore, not only the degree of damage/deformation is important but also the speed of deterioration progress is very important in diagnosis.

The details of the diagnosis standard are described in apeendix-3 of the 'Technical Manual on Inspection and Diagnosis of Bridge' prepared by CAMBRIDGE, JICA.

2.4.5. Planning

The most important result in planning the maintenance is whether the treatment to each replace/repair/strengthening works be executed before next periodic inspection or not. If the results of diagnosis of each damage/deformation indicates the necessity of treatment, it shall be planned to execute the treatment before next periodic inspection.

In planning the treatment in detail, it shall be defined that what kind of works shall be required for each damage/deformation and how important to execute the works. If the details of works is relatively simple and easy to execute, and also it is on very important bridge, one of the top priority shall be given to procure the financial resource for the works. Rough prioritization process is performed in BMS which is installed to DOH, MoWHS by CAMBRIDGE, JICA, and the policy is described in the final report of the CAMBRIDGE project.

2.4.6. Maintenance Works

Maintenance works are relatively small in quantity and easy to execute. Therefore, it shall be executed relatively quickly. This manual focuses on cleaning and pruning around the bridge. The details are shown in Chapter 4 in this manual.

2.4.7. Design

Designing the repair works, the member shall regain its initial strength and function. Therefore first step of the design is to define the initial strength of the members which will be repaired. This is setting the target of repair works of members which will be repaired.

The next step is to define the current condition of the members which will be repaired. The data/information collected in periodic inspection is not sufficient for definition of the current status in detail. Detailed observation is required in this case. This is setting the beginning point of repair works of members which will be repaired.

Selecting repair method is shown in Chapter 5 in this manual.

Moreover, if the cause of damage/deformation is aggravating the damaged/deformed member severely, it shall be removed before the replace/repair/strengthening works are executed. If this process is ignored or depreciated, repaired member would be re-deteriorated rapidly after the completion of the repair works.

In designing the strengthening works, the target strength and durability shall be defined to set the target of the strengthening works. Other procedure would be similar to that of repair works.

2.4.8. Repair Works

Repair works are relatively with larger quantity and require more and larger equipment to execute than maintenance works. It also require more budget than maintenance works. This manual focuses on repair works of each damage/deformation which are recorded in periodic inspection. The details are shown in Chapter 5 in this manual.

2.4.9. Strengthening Works

Strengthening works are relatively with larger quantity, require specific materials, and more and larger equipment to execute than repair works. It also require more budget than maintenance works. This manual focuses on strengthening works utilizing PC strand/cable, CFRP, and aseismic strengthening. The details are shown in Chapter 6 in this manual.

2.4.10. Recording and Updating

Results and details of periodic inspection, Detailed observation, maintenance/repair/strengthening works shall be recorded the bridge database utilizing the Bridge Ledger and BMS installed by CAMBRIDGE, JICA, to upgrade the inventory of the bridge. This upgrade is very important and indispensable to start the next maintenance cycle of the bridge.

2.5. Policy

It is very important to set the policy of bridge management/maintenance to execute the maintenance cycle of the bridge effectively and efficiently. If there is not any specific policy the treatment would be ad-hoc and severe damage/deformation would remain on bridges in same route with the bridge that the treatment works has been executed. This would cut the road network very easily and leave negative impact to reginal economy.

Moreover, designing extraordinary level in repair works would spent wasteful budget which could be spent on repair works for other bridges. This could leave similar unintended condition of the road network with the condition mentioned in previous paragraph.

It is required to set a certain service level as a minimum level of maintenance. It means that if the bridge/member is below this minimum service level, all the damage shall be repaired or replaced by new bridge/member. Ideally speaking, all the damage below this minimum service level shall be repaired immediately. However, it is not easy for any road operator due to their budget constraints. Therefore prioritization of the repair works is very important in actual implementation of maintenance projects, including maintenance works, repair works, strengthening works, and replacement.

3. Repair and Strengthening

3.1. Repair

3.1.1. Purpose

Is it true that all the damages found on the members of bridge shall be repaired? To be honest, it is not true. Damages which needs to be repaired shall be selected by the road operator's maintenance policy and also repair policy. For instance, the damage with low level of damage and hardly any progress of deterioration, it does not need any physical treatment. However, it is necessary to plan how to execute all the repair works which is beyond the service level of the bridge which are shown in the road operator's maintenance policy. This subchapter 3.1 aims to instruct the necessity of setting repair policy based on the maintenance policy.

3.1.2. Scope

Repair as its definition in Chapter 1, it is a recovery of structural/functional damage of bridge member(s) up to its original design condition. However, it is not possible to recover all the necessary damages up to its original design condition due to limitation of time, budget, and technical skills. Therefore, [Emergency] repair is executed as emergency measure to prevent fatal collapse of the bridge. On the other hand, repair methods which recover to the original design condition, is regular repair methods.

In the repair woks, there are [Corrective] and [Preventive] methods. The former is the most simple repair method for any members of the bridge. Frankly speaking, it does not consider after the completion of repair works and it often does not remove the cause of the deterioration. Therefore, the same damage tends to occur again in short period. The latter is the repair method which has function of retarding the deterioration. It usually removes the cause of deterioration to the maximum. It often have stronger materials to external environment and bear the strong load, repetition of load, severe environment condition.

Bridge is a complex structure formed by numerous members made by different materials. Damages are often composed of several damages at the same location/member. This makes the selection of the repair methods very difficult and complicated.

This manual treats the repair methods which recover the damage to the original design condition, and mainly [corrective] repair method referring the cause of the deterioration. And it also deals with the single damage, not complicated damages composed of several damages. To repair the complex damages, all the types of damages must be repaired. If the repair method become too complicated and expensive, the member shall be replaced by new members with removing the cause of the deterioration. [Preventive] methods are also treated in this manual, however it is demonstrated as methods which shall be considered as an alternative in selecting the repair method. [Preventive] methods are provided as a reference which are realized in special occasions with sufficient budget and well experienced engineers involved in the project.

3.1.3. Target

Target for repair works is always its initial design condition. Therefore, it is extremely important to define the original condition. Defining the original condition incorrectly misleads the design and construction of repair to inappropriate result. The responsible engineer of designing the repair works shall put all his effort to define original condition correctly with scarce difference. The alternative methods to define the original condition are described in Chapter 5.

However, in case of [Emergency] repair or the road operator's maintenance policy permits lower service level temporarily or permanently than its initial condition to prevent the collapse of the bridge, the target shall be set individually.

3.1.4. Policy

Policy of repair shall be recovering the damage to its initial design condition of repaired member ideally. If the top priority to sustain the soundness of the bridge to keep the basic safety of the traffic, the target level is lower than the initial design condition. If the road operator's operation policy is to minimize the disconnection of road network, the target level is also lower than the initial design condition. Therefore, operation & maintenance policy for road network, the entire route, crossing of the major rivers, and individual bridge affects the target of repair works. The policy shall be set considering the financial and technical condition of the road operator. When the policy is made, it is not difficult to fix the target to fulfil the policy.

3.1.5. Applied Codes

Design Code of India published by IRC is equivalent to Design Code of Bhutanese Highway Bridges. It shall be applied to set the initial design condition. If the bridge's initial design condition does not satisfy the conditions which are mentioned in this code. The bridge shall be strengthened to satisfy this code.

3.2. Strengthening

3.2.1. Purpose

What is the difference between Strengthening and Repair? As the definition of the term in Chapter 1, Strengthening requires improvement of strength/durability. On the other hand, repair just recover the damage to original condition mainly in strength and function. Therefore, the needs of repair depends on the current condition of members of the bridge, and the needs of the strengthening depends on the original condition of members of the bridge.

Based on this fact mentioned in the paragraph above, the necessity of the strengthening is dependent on the existence of the bridge which has members with insufficient strength/function. Bridge with this condition shall be immediately strengthened ideally. The reasons are that members with insufficient strength would easily be deteriorated/damaged if it is left as it is, and also could make dangerous situation for road users, such as collapse of superstructure, invert of substructure, big gap on the bridge surface, or etc.

On the other hand, the needs of road users including inhabitants of areas around the bridge grow gradually, for instance the needs of heavier trucks and buses, strong resistance to natural disaster (flood, earthquake, land slide, etc.). This growth of needs affects the design policy and force, also upgrades the design code. In completion of upgrading the code, all the existing bridges become the bridges which has members with insufficient strength/function.

Therefore, strengthening have 2 aspects, one is to improve the condition of bridge, specifically old bridges, to satisfy current design code, and the other is to improve the condition of all the existing bridge to meet the latest needs of road users. This subchapter aims to instruct the importance of strengthening works and prioritization of execution by setting the strengthening policy.

3.2.2. Scope

Scope of strengthening is very simple. It is to improve the strength/durability of members of bridge up to the level to satisfy the current design code. If the superstructure does not have capacity to bear the design live load, it shall be strengthened. If the substructure does not have capacity to bear the design earthquake, it shall be improved to bear the maximum seismic load defined in the design code. If the opening of the river flow is not sufficient, it shall be increased whether by adding extra span(s) or raising the elevation of superstructure.

In selecting the strengthening method and its materials, there are [Corrective] and [Preventive] methods similar to the scope of repair.

Bridge is a complex structure formed by numerous members made by different materials. Strengthening a member could involve several smaller members which forms the member to be strengthened. This makes the selection of the strengthening methods very difficult and complicated.

This manual treats the strengthening of single unit of members, such as girders, superstructure, substructure, the entire bridge, for instance. The methods are basically [Corrective] methods which satisfy the minimum requirement. [Preventive] methods are demonstrated as a reference which are realized in special occasions with sufficient budget and well experienced engineers involved in the project.

3.2.3. Target

Target for the strengthening works is always the current design code. Since strengthening shall be done to the members with insufficient strength/durability, the design engineer shall define the extent of improvement. To define the extent of improvement, it is very important to define the current condition of the member, which identify the capacity of the current member which is to be strengthened. The responsible engineer of designing the strengthening works shall put all his effort to define the capacity of current member correctly with scarce difference. The alternative methods to define the capacity of current members are described in Chapter 5.

Moreover, strengthening works are done to all the members without sufficient strength/durability and it does not matter how sound the members are. If the member is sufficiently sound, the strengthening work can be executed immediately. However, if the member is damaged or deteriorated above certain level, it shall be repaired to recover the soundness prior to execution of strengthening works. Therefore, the responsible engineer of designing the strengthening works shall consider carefully the soundness of the member and the repair work shall be added if the soundness is defined as below the sufficient level.

3.2.4. Policy

Policy of Strengthening shall be improving the strength/durability of the member of the bridge from its original to upgraded level. Ideally all the bridges shall be strengthened if the design code is upgraded with new design condition which existing bridges does not have the capacity to bear it. If the design seismic load is increased due to the occurrence of historical record breaking earthquake in the region, all the bridges shall be strengthened if the road operator’s strengthening policy is to make all the bridge bearable to the historical largest earthquake.

However, there would require considerable amount of budget and period of time to realize this policy.

Therefore, there shall be prioritization of execution by importance of the bridge, judged by traffic volume, importance of the route, existence of detour route, or etc. Road operator could decide not to strengthen the bridge of feeder route of main axis/arterial routes until all the bridges of arterial routes are strengthen due to budget constraints, for instance. If the strengthening is due to increase of live load, road operator could give up the strengthening of feeder road and execute the traffic control and regulate the maximum weight of the vehicles. Since upgrading the design code require so much budget to fulfil the new code, it can be executed gradually by setting the policy as is mentioned above.

On the other hand, there are needs of strengthening of old bridges which does not satisfy current design code to satisfy the design condition of current code. This situation can be solved by setting the prioritization to the bridges by importance of the bridge when there are various number of bridge to be strengthened.

The policy reflects to prioritization procedure. It shall be set considering the financial and technical condition of the road operator. When the policy is made, it is not difficult to prioritize the bridge to be strengthened and plan the execution.

3.2.5. Applied Codes

There are no new upgraded design code for road bridges recently in Bhutan. Therefore, there are no needs to strengthene all the bridges which are operated by DOR in this moment. However, there are many bridges which does not satisfy current design code. Design Code of Bhutanese Highway Bridges shall be applied to set the target in designing the strengthening work.

4. Maintenance Works

4.1. Purpose

Maintenance works are applied to the damage which are repaired relatively easily and occurred to small equipment. It is also done to improve the condition of the bridge to keep bridge member strong, durable, and functional or retard the deterioration. Moreover, it is executed to maintain the safety of the traffic.

The works described in this chapter are as follows, cleaning the clogging of the drainage basin, pipes, expansion joint, and bearings, removing obstacles on surface, cutting the plants extending over the bridge, removing debris flown by flood, replacing the small facilities on the bridge, and patching the asphalt pavement on the surface.

4.2. Planning

There are 3 patterns of planning the maintenance works. One is [Regular] maintenance works, next is [Prior] and the last is [Subsequent]. [Regular] maintenance work is to be done in the period set by the works, replacing the light bulbs every 5 year for lighting, for instance. [Prior] maintenance works are done irregularly but before the damage/situation gets severe. [Subsequent] maintenance works are done irregularly and after the damage/situation is in serious condition. Either of them can be applied for 1 maintenance work. For instance, cleaning the clogging of the drainage basin can be done regularly, provided once in every 6 months, the period can be shorten when the drainage basin is clogged more than 80% of its cross section and clean it immediately. The former is [Regular] and the latter is [Prior]. It can be executed after the heavy rain with its cross section totally clogged. This case is [Subsequent]

4.3. Maintenance Works

In this subchapter, the points to be checked in the Routine Patrol, emergency treatment and maintenance works which shall be made after recognition of the damage is described. The damages are of ‘drainage facilities’, ‘sediment deposition (debris and soil)’, ‘plantation, obstacles on the bridge surface’, ‘road facilities’, and ‘wearing course, pavement’.

4.3.1. Drainage Facilities

Check points of drainage facilities is clogging of the drainage basin and pipes and water leakage from the drainage system. If there is puddle on the surface after the rain for long period of time, it shall be recorded.

Clogging of drainage basin and pipes leaves rain water on the surface of the bridge as puddles or concentration of drainage to the lower side of the superstructure (girder/slab). Puddles can supply water into the slab and infiltrated water deteriorates the rebar inside the slab. This would produce cracks on the slab, peeling off and rebar exposure, and end up with partial loss of the slab (Hole(s) fully pass through the slab).

Concentration of the drained water to the lower end of the superstructure produce clogging at the expansion joint and sediment deposition around the bearings. It would accelerate the corrosion and deterioration of the expansion joint and bearings and end up with a considerable amount of superstructures’ drop and leaves gap on the surface. It would make the traffic to face the danger in crossing the bridge.

The following figures shows the examples of the damages of drainage basin. It sometimes has plants growing from the dirt clogging the basin.


Figure 4.1 Example of clogging of drainage basin

The following figures shows the examples of water leakage due to the missing drainage pipes. It will wet the girder and other members and accelerates the deterioration.


Figure 4.2 Example of Water Leakage (missing drainage pipes)

Maintenance work for clogging can be executed on the surface of the bridge. If it can be removed by hand, the dirt can be removed immediately. If the dirt is well compacted, special equipment like water jet cleaner shall be prepared for cleaning. Both examples above requires water jet cleaner for maintenance works.

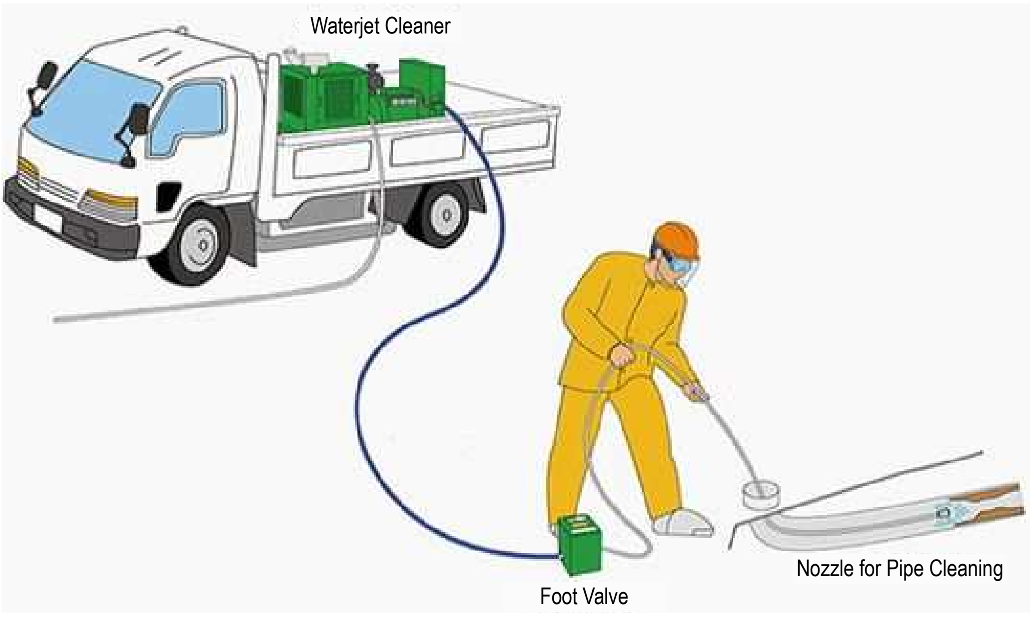


Figure 4.3 Example of Cleaning Drainage Pipes by Waterjet Cleaner

Water leakage from the drainage system requires replacement or reinstallation. Both example above require reinstallation of the drainage pipes. This work is beyond maintenance works and shall be considered as repair works, which require scaffoldings for the workers to access. Cleaning of the drainage basin and pipes of upstream shall be done prior to the reinstallation works. The bottom end of the drainage pipe, which is the flow end of the drainage system, shall be placed where the drainage flow does not wet bridge structures, such as substructures, revetment. If the pipe is short with wind blowing from bottom of the valley, the flow would be blown up to wet the superstructure. In this case, sufficient length shall be secured in reinstallation. The figure below shows the standard scale of placing the drainage pipe by the outer girder in the middle of spans. If the drainage pie is near the substructure, the end of drainage pipe shall be extended to the height which does not wet the substructure.

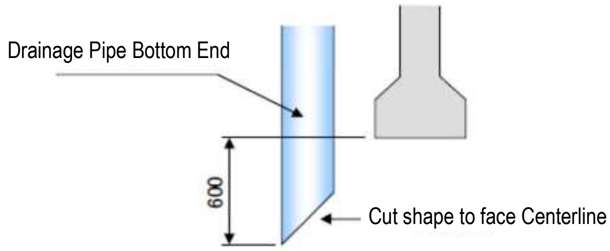


Figure 4.4 Example of Bottom End of Drainage Pipe

4.3.2. Sedimentation Deposition (Debris and Soil)

Sedimentation of debris and soil can be happened on the surface of the bridge, on the bridge seat of abutment and/or pier, and around the pier. It shall be cleaned as early as possible to prevent the member from touching the sedimentation for preventive treatment to retard deterioration. Figure below shows the example of sedimentation. Sedimentation on the bridge seat is most difficult and some of the sedimentation cannot be removed without scaffoldings. However, the section which is accessible from the bridge surface using water jet cleaner shall be removed as early as possible. The section cannot be removed from the bridge surface shall be removed in periodic inspection, detailed observation for design of repair work, or during the execution of repair works. Sedimentation around the pier often occurs with other damage, such as scour, inclination, settlement.

(on Surface)

(on Bride Seat)

(around Pier)

Figure 4.5 Example of Sediment Deposition

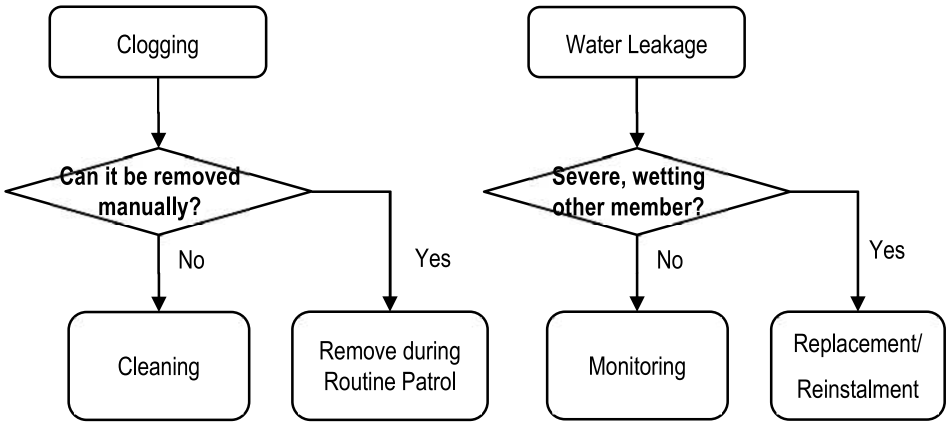


Figure 4.6 Flowchart of selecting Repair Method of Drainage Facilities

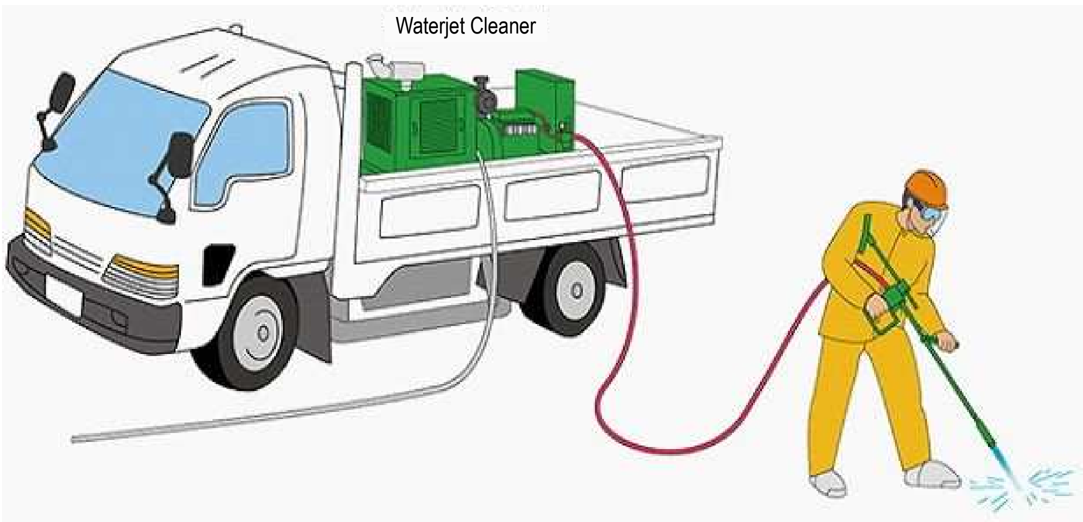


Figure 4.7 Example of Cleaning Sediment Deposition by Waterjet Cleaner

4.3.3. Plantation, Obstacles on the Bridge Surface

If the branches of the plant around the bridge grow and invades the clearance for traffic including the pedestrians, it shall be removed by pruning them immediately after it is found.

If the obstacles are left on the surface of carriageway or foot path of the bridge, it shall be removed immediately after it is found. The obstacles could be fallen rocks, cut branches, dead animals, and fallen packages. Leaving these could cause traffic accident which the road operators to be blamed.

4.3.4. Road Facilities

Road facilities which shall be checked in the routine patrol are lighting (bulbs, poles), bridge name plate, traffic sign boards, road markings, and etc. If the light bulbs are out, it shall be reinstalled immediately. If it is old enough and could be out any time, it can be replaced in routine patrol. It the lighting or sign board post are damaged/corroded and in dangerous condition, emergency treatment shall be done to secure the safety of the traffic. If the road sign or road markings are dirty and cannot be seen by the road users, it shall be cleaned immediately. Other broken facilities which are not bothering the traffic safety, can be left and repaired when other repair works are executed.

4.3.5. Wearing Course, Pavement

Check points of the wearing course, pavement for the routine patrol is crack, and pot holes. It shall be checked whether sand is coming out from crack of not. The following figure shows the image of the check point of wearing course for routine patrol.

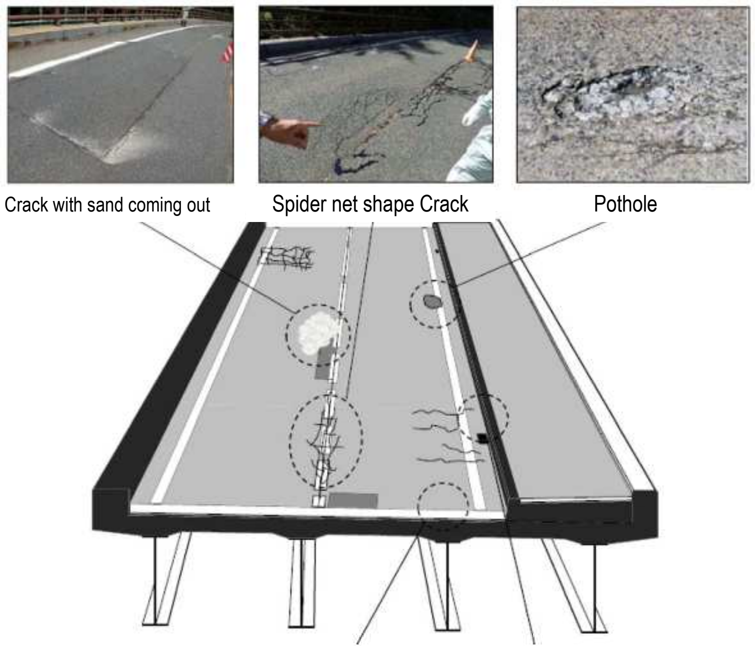


Figure 4.8 Example of Damages of Wearing Course, Pavement

Both abnormity and unevenness shall be repaired by repavement. Before the repavement, the cause of the damage shall be observed by removing the pavement and check the condition of the slab. It shall be checked whether the waterproof layer is installed and still stays in sound condition or not. If the concrete is cracked or the cement is washed away, RCC slab shall be repaired before the repavement. After the RCC slab is repaired, it shall be made sure that the waterproof layer is installed covering the RCC slab, in other words between RCC slab and wearing course.

If the abnormity is just the cracks, and unevenness is less than 2cm, it shall be observed in detail whether the damage is enlarging rapidly or not. If the damage is enlarging rapidly, the cause shall quickly be removed and the wearing course be repaved. If it is not enlarging so much, it can be monitored in routine patrol.

If the crack is not spread in the spider net form and the RCC slab condition is sound with waterproof layer installed, crack can be patched by inserting asphalt emulsion. The figure below shows the example of the treatment. Repairing the crack as early as possible could prevent or retard the deterioration of deck slab and girder which are located underneath the deck surface. It is better to treat it as early as possible and recover the soundness of the wearing course in terms of preventive maintenance.

Figure 4.9 Example of Crack Patching of Wearing Course

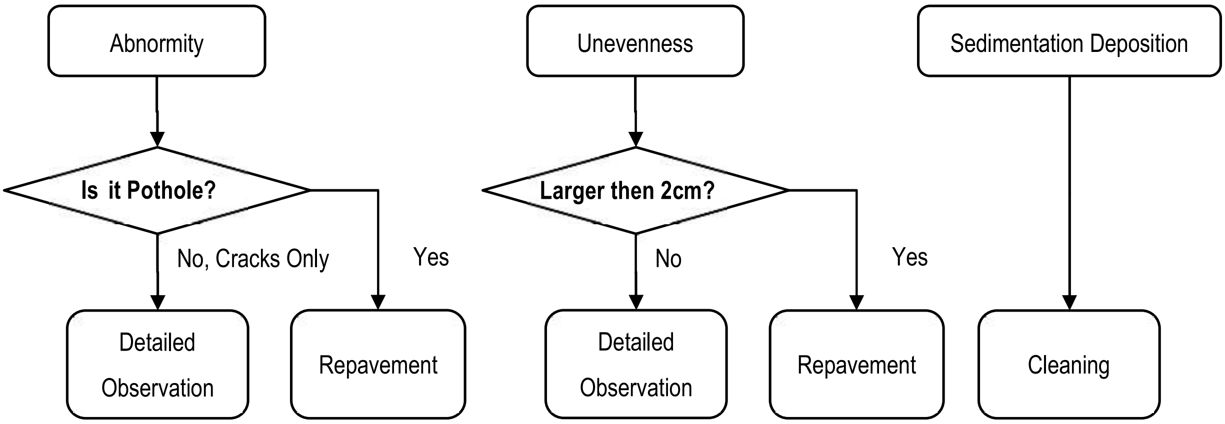


Figure 4.10 Flowchart of selecting Repair Method of Wearing Course, Pavement

The workflow of repavement is shown in the figure below.

Preparation	· Regulate the traffic during the construction · Install the temporary bridge if necessary
Remove Existing Wearing Course	· Remove the existing wearing course, waterproofing layer · Clean remaining stains on the RCC deck slab surface
Remove the Cause	· Remove the cause of the damage · Repair RCC deck slab if it is damaged
Waterproof RCC Deck Slab	· Waterproof RCC deck slab by sheet type or coating type · Waterproof carefully the corner with curb and expansion joint · Refer to the following clause 6.3.4. (1) 'RCC Deck Slab' for details
Repaving	· Repave the waring course (base course and surface course) · Cure the waring course till it is hardened and cooled down
Finishing	· Mark the road marking · Open bridge to the traffic

Figure 4.11 Workflow of Repavement

5. Repair Works

5.1. Planning

Based on the characteristic of each bridge and its damage, selecting appropriate repair method and timing shall be considered in planning the mid-term plan of repair works of the bridges after getting the results of periodic inspection. Justification evidence with top priority shall be the measures category which is defined in diagnosis of periodic inspection. If the damages defined as ‘E1’, those damages shall be in the group at the top of the list of damages/bridges to be repaired. The next important measures category is ‘E2’ followed by ‘C’ then ‘B’. Details are described in Appendix 2, Technical Manual on Inspection and Diagnosis of Bridge, which is prepared by CAMBRIDGE, JICA

Moreover, damages which affects to large volume of traffic, on the bridge without any detour, damage with rapid deterioration progress, and etc. shall be given priority for the planning the repair works plan of group of the bridges with damages. It shall view for at least 5 years or more ahead to level up the soundness of bridges and service level of the highway network. The prioritization shall follow the maintenance policy of bridges on highways.

Not only the technical issues to be solved, but also financial procurement shall be obtained to realize the plan. If the plan is very difficult to be realized with the budget possibly procured, policy shall be revised to the realistic level. The original policy can be developed as a spring board and modified to realistic policy for establishing mid-term repair plan. This solution could be an alternative to face the budget shortage problem.

On the other hand, in planning the repair works of individual bridge/damage, the plan of repair project shall be established based on the mid-term maintenance plan. The procedure is described in the figure below.

Figure 5.1 Procedure of Repair Works (Individual Bridge/Damage)

In planning the repair project, the following item shall be assumed additional to the results of the periodic inspection. i) to v) shall be done in detail with accuracy and vi) to ix) could be in tentative level.

i) Scale of Damaged Member and Bridge
ii) Cause of the Damage
iii) Rapidness of the Deterioration Progress
iv) Method of Detailed Observation
v) Quantity and Cost of Detailed Observation
vi) Quantity and Cost of Detailed Design
vii) Alternatives of Repair Method
viii) Quantity and Cost of Repair works
ix) Overall Schedule of Repair Project

The contents of determining each step of the planning the repair project is as follows,

i) Scale of Damaged Member and Bridge

Scale of damaged member and bridge shall be well-known to the road operator to plan the repair project. The best material to define this item is As-built drawing of initial construction, and repair/strengthening works if it has been executed. If there is not any as-built drawing preserved, the design drawing could give the clue of the scale of the member/bridge. However, there often are major/minor amendments in construction stage, therefore the responsible engineer of road operator shall not believe that the design drawing reflects the current condition of the member/bridge. If there is not any drawing available, the detailed topographic survey shall be executed to collect necessary data of scale of damaged member/bridge in detailed observation. It will be very basic data to set the quantity of detailed observation, perform detailed design in sufficient technical level. Missing this data, it is impossible to complete the repair works to recover the strength/durability of the member.

ii) Cause of the Damage

This is done by result of periodic inspection basically. If the evidence of the cause is not mentioned in the result, it shall be checked directly by sight and approved by responsible engineer of road operator. The details of the causes of damage is described in subchapter 5.3.

iii) Rapidness of the Deterioration Progress

To define the rapidness of deterioration progress, the inspection shall be executed at least twice before planning the repair project. If there is only 1 results of inspection which represent the damage, additional inspection is required to compare the damage level of 2 points of time to define the rapidness (speed) of deterioration progress. Ideally it is better to have the results of 3 points of time. If there are results of 3 points of time, it can be defined that the deterioration progress is accelerating or decelerating.

iv) Method of Detailed Observation

Method of detailed observation depends on the type, location, cause of damage, and material of damage. The details is explained in subchapter 5.2.

v) Quantity and Cost of Detailed Observation

Based on the results of periodic inspection data and scale of damaged member, the quantity of detailed observation by specific method is defined. To complete the quantity calculation, the results of periodic inspection shall include the scale of damage. If there is not any scale data, it shall be checked directly by sight to collect necessary scale data and approved by responsible engineer of highway operator. However, if there are rough scale data from reliable source, the detailed observation can be started with rough quantity, and amended during the execution of observation.

vi) Quantity and Cost of Detailed Design

This estimate is made based on assumption made by the results of periodic inspection, and shall be amended by the quantity of detailed observation. If the result of detailed observation indicates the revision of quantity of detailed design, it shall be amended during the contract since detailed design is usually contracted together with detailed observation. If it is contracted separately, it could be adjusted before the contract.

vii) Alternatives of Repair Method

This assumption is made to assume the repair works quantity and cost. However, the repair method would be defined based on the result of detailed observation. Therefore, several alternatives of repair method shall be prepared for planning the repair works. If the results of periodic inspection is so detailed that it is so obvious to define the repair method, single specific repair method is sufficient for this assumption.

viii) Quantity and Cost of Repair works

This assumption is just to grasp the project scale in terms of material and budget. It is done based on the other assumptions which would be fixed after this assumption is made. Since the damages of members of bridge are mostly invisible, there would be revision of assumption made in this stage. Bridge operator shall be ready to revise the initial plan of repair project by new findings which are going to be defined during the project. It is important for fulfilling the necessary recovery of member/bridge in terms of strength/durability. If there is difficulty of additional budget in short term, schedule of project shall be amended to satisfy the technical requirements of repair works.

ix) Overall Schedule of Repair Project

This is also to grasp the scale of the project, and it is also facing the high possibility of revision. However, revising the schedule shall be done flexibly if the procuring the additional budget is difficult as is mentioned in the previous paragraph. Technical level of the repair works shall not be degraded since re-deterioration would happen very rapidly. It would end up wasting the cost of the repair works with low technical level which does not satisfy technical requirements.

5.2. Detailed Observation

Each damage with different cause shall be observed with appropriate observation method. In this subchapter, the details of detailed observation method is explained by type, category, and cause of damage. All the inspection within accessible distance with scaffolding could be considered detailed observation. However, the methods of inspection with very simple equipment, such as Crack Gauge and Steel Tape, to measure the external surface of damages are basically excluded from the contents of this subchapter.

Detailed Observation is basically executed for the damages which are deteriorated/broken including the internal section of the member. Therefore, there are basically 2 types of methods, one is non-destructive test, and the other is direct testing of actual member or sample parts which requires collecting sample from the member. Both methods basically require special equipment. These tests would reveal the area, category, cause of the damage much more clearly than periodic inspection. In case the data/information of full picture of the damage is not collected enough and was not reflected sufficiently to the result of the periodic inspection, appropriate detailed observation shall be executed to the damages to be repaired for providing the data/information for detailed design.

If the detailed observation is execute for more than twice in mid-term, rapidness of the deterioration progress can be assumed and could be referred to planning the mid and long-term maintenance plan. The damage with rapid deterioration progress shall be given higher priority to repair then the bridge with slower progress.

5.2.1. Whole Bridge

If there is not any general view as-built drawings or design drawings of the bridge, it shall be reproduced by executing topographic survey. It could be done by using simple total station but it is recommended to utilize 3D laser scanner for quick implementation. There is mobile 3D laser scanner which can be carried at the back of human and would not have to be placed at the level condition as ordinary scanner. This reproduced general view is the very basic information to define the category of damage for whole bridge.

To realize the status of completion of construction, necessary adjustment shall be done in reproducing the general view. Abnormal gaps, inline, position, deflection, and etc. is the damage which shall be adjusted. Reproducing the general view could find the damage of whole bridge which could not be recognized by sight observation.

Figure 5.2 Example of Mobile 3D Laser Scanner

Figure 5.3 Example of Collected Data of Mobile 3D Laser Scanner

(1) Extraordinary Deflection

Girder and slab bridges are normally designed and constructed without deflection sagging downwards. However, if the deflection is observed, it shall be surveyed with equipment to define the scale of deflection. If it exceed the acceptable limit of design code, it shall be immediately repaired or treated in emergency. If deflection is enlarging, observation shall be executed twice to recognize the rapidness of enlarging deflection.

The cause of extraordinary deflection could be damaged superstructure/bearings by heavy vehicle or other reason, or settlement, displacement, or inclination of substructure. Therefore, not only the condition of deflection shall be observed but also the condition of superstructure, substructure, and bearing shall be observed and drawn to drawings and recorded as observation report.

(2) Settlement, Movement, Inclination

Reproducing the general view is the most effective detailed observation of the damage. Survey by equipment of topographic survey indicate the settlement, movement, inclination by comparing with the general view. Therefore, surveying the suspicious member/bridge is recommended to clarify the details of damage.

If the foundation is suspected to be damaged and cannot be observed by sight, it shall be observed by excavating or drain the water covering the foundation. If the damaged substructure has pile foundation, direct observation of very top section of piles shall be done by excavating the cover soil of the substructure.

If the bridge has pile bent substructure(s) with damage, and causing the settlement, movement, and inclination, it shall be observed in detail by its material. If the piles and/or pile cap is RCC, refer to clause 5.2.3.1, (1) Concrete, and if the piles and/or pile cap is made of steel, clause 5.2.3.1, (2) ‘Steel’ shall be referred to.

Figure 5.4 Example of Settlement/Inclination of Substructure which requires Detailed Observation

(Steel Pier) (RCC Pier)

Figure 5.5 Example of Damaged Piers with Pile Bent Structure

(3) Scouring

Reproducing the general view and surveying the substructure by equipment of topographic survey is also the most effective detailed observation. If the scouring is under the water level, the water shall be drained and observed to recognize the full picture of the scouring. If the scouring expands underneath the footing, the area of the scoured soil under the footing shall be surveyed,

The condition of the surface soil of the scoured riverbed shall be checked. If the soil is soft with small resistance compared to the surrounding soil, the depth of soil with limited resistance shall be observed and recorded. This lot of soil shall be removed and replaced by selected material in repair.

Figure 5.6 Example of Scouring which requires Detailed Observation

5.2.2. Common method for all the members of bridge

Addition to the reproduction of general view, actual and exact scale and the current situation of the member which would be repaired shall be defined to design and draw design drawings for repair works. The former is “Shape and Scale Survey” and the latter is “Deformation Survey”

(1) Shape and Scale Survey

Actual measurement of member(s) shall be executed at the site. Not only the member(s) to be repaired but also the surrounding members and adjacent objects shall be measured in this survey.

If there is as-built drawings or design drawings of the member which demonstrate the situation of the member including the surrounding members and adjacent objects, this survey shall be omitted. However, whatever necessary information is missing, it shall be collected by executing the survey.

Data/information collected by this survey is very basic data/information to understand the condition of damage precisely. It also indicates the clew to find out the cause of the damage and selecting appropriate repair method. Therefore it shall be executed as accurate as possible.

(2) Deformation Survey

Details of the damage shall be measured in this survey and recorded as drawings. Explanation to the drawings shall be noted on the drawings, depth of the crack to the drawings which show the location, shape, and scale of the crack for instance. To secure the accuracy, it shall be executed within accessible distance.

Not only the data/information of shape and scale but also other information of the damage shall be recorded as the result of the survey, such as colour of damage, details of adhered substance, and etc.

If there are settlement, movement, and inclination, the amount of those damage shall be surveyed. 3D scanner and laser range finder as well as total station can be used to measure the amount of these damages as well as distance and dimensional position with the surrounding members and adjacent objects. Not only the high-tech equipment but also analogue equipment is also useful in the survey.

(3D laser Scanner) (Laser Range Finder) (Total Station)

Figure 5.7 Examples of Equipment for Shape and Scale Survey and Deformation Survey

(Measuring Inclination by Plumb-bob and Steel Ruler)

(Measuring Scale with Steel Tape)

Figure 5.8 Examples of Measuring Members with Analogue Equipment

5.2.3. Superstructure

Detailed observation of the superstructure is divided by its member and material. The former is divided to 2 members, such as deck slab and main girder, and the latter is also divided to 2 materials, such as Concrete (including RCC and PSC) and Steel.

5.2.3.1. Deck Slab

(1) Concrete

Method of detailed observation of Concrete Deck Slab is divided by types of damage and cause of damage. The former is divided into 5 types of damage, such as crack, peeling/rebar exposure, water leakage/free lime, partial loss of concrete, and honeycomb which are the types of damage written in periodic inspection sheet (refer to Appendix 1, Technical Manual on Inspection and Diagnosis of Bridge, which is prepared by CAMBRIDGE, JICA), and the latter depends on the types of damages. It could be neutralization, chloride, alkali silica reaction, malconstruction (separation of cement and aggregate), bad drainage, physical external impact, overloaded vehicles, and etc.

1) Crack

Basic and common methods of detailed observation of concrete structure are as follows,

i) Compressive Strength Test
ii) Rebound Hardness Test
iii) Modulus of Static Elasticity Test
iv) Actual Rebar Arrangement Survey
v) Rebar Corrosion Survey

Details of these methods above is mentioned as follows,

i) Compressive Strength Test

Compressive Strength Test is executed in the laboratory with the compressive test equipment. The test piece is core sample collected from the actual RCC members of bridge. Diameter of the core sample shall be larger than 3 times of largest aggregate. It is set as 100mm for substructure since actual distance of the rebar of substructure is generally large. Diameter of the core from superstructure could be reduced to 3 times of aggregates. The height of the core sample shall be taller than twice of its diameter.

The special care shall be taken not to cut or harm rebar. Before collecting the sample, Actual Rebar Arrangement Survey shall be executed to confirm the location of the rebar.

The hole after the core sample is collected shall be refilled by mortar, such as polymer cement mortar.

Figure 5.9 Examples of Collecting Core Sample from Substructure

Figure 5.10 Examples of Refilling the Hole after Collecting the Core Sample

The appropriate section to collect core sample shall be set where the damage or deterioration is found. To check the condition of concrete, the standard section of collecting the core sample is as follows,

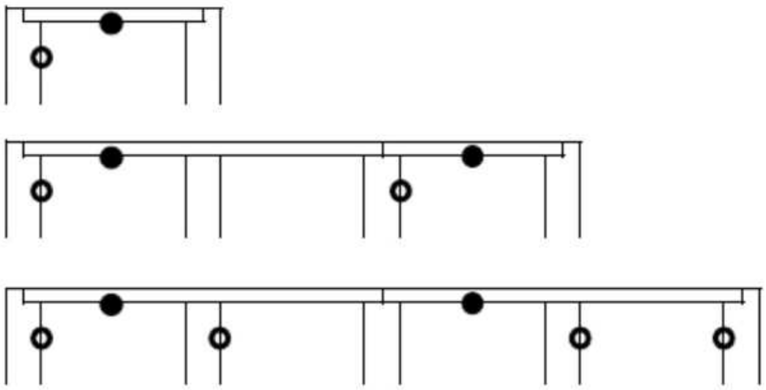


Figure 5.11 Standard Location of the Sections of Collecting Core Sample

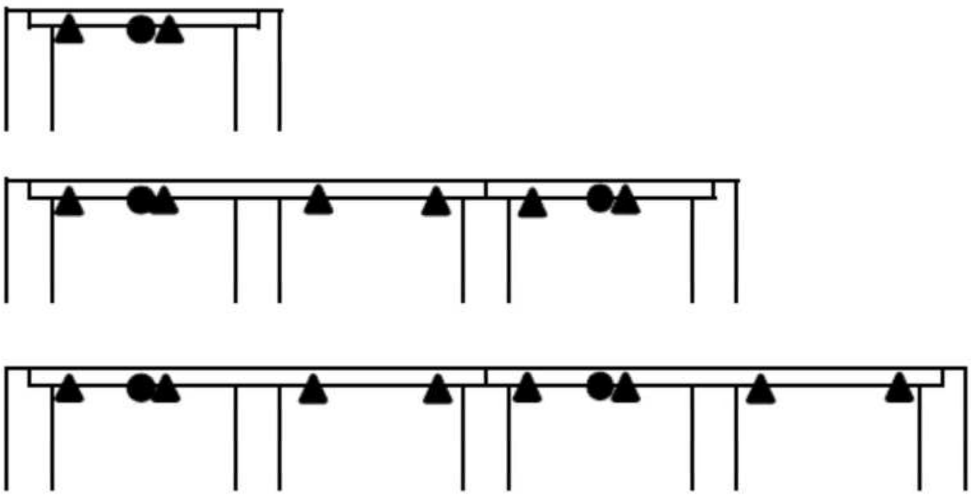
ii) Rebound Hardness Test

This test is very simple and easy to execute at site, also the equipment is handy and cheap to procure. The equipment is well known as “Schmitt Hammer”. Therefore it is executed very often. However, the accuracy is not as high as Compressive Strength Test in laboratory. The results of both test shall be compared to define the current compressive strength of the RCC member.

Since the result is not so accurate, the test shall be done at various points and the average value excluding the extreme values. Figure below show the example of Rebound Hardness Test by Schmitt Hammer. The grid is drawn on the surface of concrete to indicate the points of test.

Figure 5.12 Example of Rebound Hardness Test by Schmitt Hammer

Since it is very easily executed, it could be utilized to specify the deteriorated section and fix the location of collecting core sample. The following figure demonstrates the standard location of Rebound Hardness Test.



●Core Sample, ▲ Rebound Hardness Test

Figure 5.13 Standard Location of the Sections of Rebound Hardness Test

iii) Modulus of Static Elasticity Test

When RCC member is deteriorated severely, specifically by chloride and ASR, the modulus of static elasticity also becomes weak and accelerates the deterioration, deformation, and deflection. The results is utilized to define the cause of the deterioration and also grasp the rapidness of the deterioration. It is useful to plan the repair schedule of the damage.

This test is executed simultaneously with compressive strength test. Strain gauge is attached on the side surface of the core sample. Modulus of Static Elasticity is calculated by the value set of actual amount of load and strain.

(Strain Gauge attached on the Side Surface of the Core Sample) (Completion of the test)

Figure 5.14 Examples of Modulus of Static Elasticity Test

iv) Actual Rebar Arrangement Survey

There are 2 methods of surveying the actual rebar arrangement in the RCC member. One is Electromagnetic Wave Radar Method and the other is Electromagnetic Induction Method.

Electromagnetic Wave Radar Method can survey not only the depth of cover and rebar arrangement, but also the void and honeycomb in the RCC member.

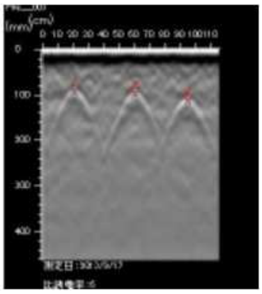
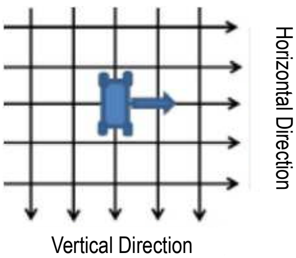


Figure 5.15 Examples of Electromagnetic Wave Radar Method

Electromagnetic Induction Method can survey the diameter of the rebar as well as the depth of cover and rebar arrangement. However, the accuracy decreased as the depth increases. It is more appropriate to survey the members with thin cover, such as superstructure.



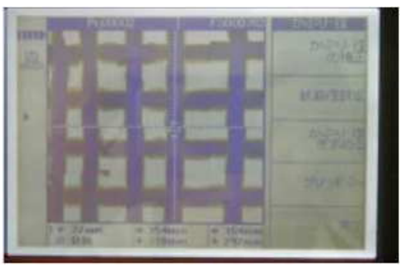


Figure 5.16 Examples of Electromagnetic Induction Method

Both method loses the accuracy when the rebar is arranged more densely and cover is thicker. It is also impossible to survey the lower layer of double layer rebar arrangement. To survey the double rebar arrangement, direct observation by chipping the cover is required.

v) Rebar Corrosion Survey

There are 2 methods of surveying Rebar Corrosion level and area. One is direct observation by chipping cover and the other is Spontaneous Electric Potential Method.

Direct observation by chipping cover can directly check the corrosion level and area. However, chipping area shall be carefully defined not to affect the stability of the member. If the area of corrosion is estimated considerably large, the only severe deteriorated area of concrete shall be chipped to prevent negative effect to the member.

Area of the chipping cover shall not be smaller than 20cm by 20cm. Depth of chipping shall be 10mm greater than the inner surface of the rebar.

This method can survey the area of void and honeycomb simultaneously.

Figure 5.17 Example of Direct Observation by Chipping Cover

Spontaneous Electric Potential Method can survey the level of condition which the rebar is easily corroded of concrete around the rebar. It is appropriate to apply when the area of corrosion is estimated relatively large.

The survey area shall include the damage of concrete and the size shall be around 2m by 2m.

The equipment records the difference of electric potential between the rebar and reference electrode. The results shall be compared with the actual corrosion level which is surveyed directly.

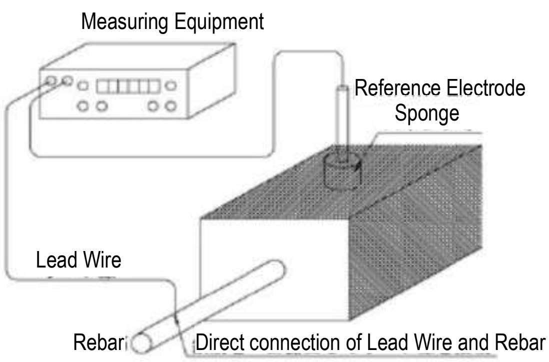


Figure 5.18 Example of Spontaneous Electric Potential Method

Based on the result of the periodic inspection, shape and scale survey, and deformation survey from accessible distance, the cause of the crack shall be assumed. The cause can be assumed how the crack is occurred.

Table 5.1 Major Cause of Crack

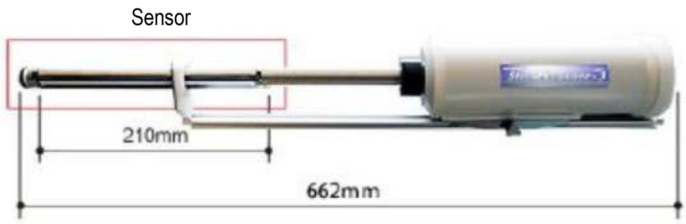
Type of Damage/Crack		Neutralization	Chloride	Alkali-Silica Reaction	Fatigue		Heat, Temperature, Frozen
					Slab	Girder	
Crack Condition	At cover near the rebar	High	High	High			
	Honeycomb shape			High			
	Hair crack						High
	Grid shape				High		High
	By bending moment & Shear				High	High	
	Deep & even distance						High

Table 5.2 Detailed Observation Method by Cause of Crack

Cause	Name	Details of Method	Remarks
Neutralization	Phenolphthalein Method	i) Direct Testing ii) Collecting core sample iii) Drilling a small holes iv) Minimal destructive	i) Chipping concrete required ii) Core Sample of member required iii) Test powder when drilling 3 holes iv) Stick Scanner is required
Chloride	Chloride Ion contained Amount Test	i) Collecting core sample ii) Drilling a small hole	i) Core Sample of member required ii) Test powder when drilling 3 holes
Alkali-Silica Reaction	i) Mortar-Bar Method ii) Chemical Method iii) Petrographic Examination iv) Rapid Mortar-Bar Test v) Concrete Prism Test vi) Scanning Electron Microscope Method vii) Energy dispersive X-ray spectrometry	i) Direct testing of Mortar Bar ii) Aggregate test iii) Examination by Microscope iv) Direct testing of Mortar Bar v) Direct testing of Concrete Prism vi) Examination by Electron Microscope vii) Examination by Electron Microscope	i) Refer to ASTM 227 ii) Refer to ASTM C 289 iii) Refer to ASTM C 295 iv) Refer to ASTM C 1260 v) Refer to ASTM C 1293 vi) Require Electron Microscope vii) Require Electron Microscope

(Direct Testing) (Collecting core sample)

Figure 5.19 Examples of Phenolphthalein Method (1)



(Drilling a small holes) (Stick Scanner)

Figure 5.20 Examples of Phenolphthalein Method (2)

Samples for Chloride Ion contained Amount Test shall be taken from the section where the drained water from the surface comes down, such as bridge seat under the expansion joint on pier and abutment, surroundings of drainage pipe outlet, which are shown in the figure below. These sections are prone to get soaked by drained water with snow melting agent which are calcium chloride. Despite that it is not common to use snow melting agent in Bhutan yet, there are fundamental needs of it considering the weather of winter which could freeze the surface of the bridge and endanger the traffic. It shall be kept in the engineers' of road operators mind that these section is very easily deteriorated by chloride in future.

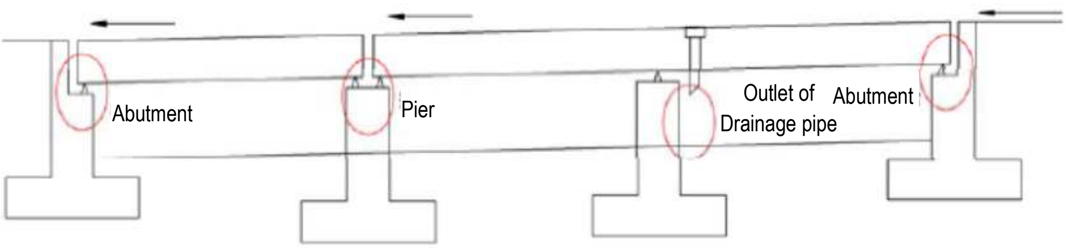


Figure 5.21 Sections where the Core shall be collected

Alkali-Silica Reaction (ASR) has not become one of major issues for the construction industry in Bhutan yet. However, using aggregate including rock which contains considerable amount of silicon dioxide (SiO_2), such as Chert (one of the sedimentary rocks), could cause serious damage. If the entire surface is filled with large crack with free lime, ASR shall be suspected to be a cause of the damage. Not only it leaves enormous amount of cracks, but also it could even tear the rebar in RCC members. Examples of the damage is shown in the figures below.

(Crack caused by ASR)

(Rebar torn by ASR)

Figure 5.22 Example of Damage caused by ASR

<u>REFERENCE</u>: Direct Observation of interior condition of RCC damage by Fiberscope

It is useful to observe directly the condition of concrete and rebar inside the RCC members. If the crack is large, it can be observed by micro fiberscope. There are industrial endoscope with very small diameter, such as less than 1mm.

Moreover, it is also useful to check the condition of members which is difficult to chip large area, such as PSC girder. Drilling holes of very small diameter and observe the interior condition directly by inserting the fiberscope to the drilled hole. It could be utilized for checking the condition of PC cable, sheath duct, grouted material.

(φ: 5.5mm)

(φ: 0.64mm)

Figure 5.23 Examples of Industrial Fiberscope

2) Peeling/Rebar Exposure

First observation which shall be executed for the damage is defining the area of peeling cover. This could be done by Hammering Test. When the tone is high and clear, it could be judged that the concrete has no peeling. On the other hand, when the tone is low and dull, it shall be considered that there are crack spreading in parallel to the surface and cover is peeling. The area must be clearly demonstrated by marking by chalk and recorded. If the cover peeling is very loose, it shall be stroked and removed. The rebar exposed newly by this stroke shall be treated by rustproof spray so as not to be rusted before the repair work is executed.

(Hammering Test) (Marking the area by Chalk) (Rust proof treatment)

Figure 5.24 Example of Hammering Test

After defining the area of peeling, the condition of the concrete and rebar shall be investigated by appropriate detailed observation methods described in the clause above, 1) ‘Crack’ and the cause of the damage shall also be identified. For the details of the observation methods, pervious clause 1) ‘Crack’ shall be referred to.

Table 5.3 Hammering Test

Sound	Condition
High and Clear	Sound without crack and peeling
Low and Dull	Damaged with crack and cover peeling

Table 5.4 Major Cause of Peeling/Rebar Exposure

<table>
<tr><th rowspan="2">Type of Damage/Crack</th><th rowspan="2">Neutralization</th><th rowspan="2">Chloride</th><th rowspan="2">Alkali-Silica Reaction</th><th colspan="2">Fatigue</th><th rowspan="2">Heat, Temperature, Frozen</th></tr>
<tr><th>Slab</th><th>Girder</th></tr>
<tr><td>Peeling/Rebar Exposure</td><td>High</td><td>High</td><td>Possible</td><td>In very bad condition</td><td></td><td></td></tr>
</table>

3) Water Leakage/Free Lime

Water leakage and Free Lime usually appears from cracks of the RCC members. Therefore, the detailed observation is basically as same as those of crack. For the details of the observation methods, pervious clause 1) 'Crack' shall be referred to. Major cause of water leakage and free lime is described in the table below.

The important point of the observation is whether the leaking water is with rust or not. If it contains the rust, it indicates that there is corroded rebar inside the RCC member. The cracks would grow and spread wider in near future and it could be happened rapidly in some cases if the cause is not quickly removed.

Table 5.5 Major Cause of Water Leakage/Free Lime

Type of Damage/Crack	Neutralization	Chloride	Alkali-Silica Reaction	Fatigue		Heat, Temperature, Frozen
				Slab	Girder	
Water Leakage w Rust	High	High	Possible	Possible		
Free Lime	Possible	Possible	Possible	Possible		

4) Partial Loss of Concrete

Partial Loss of Concrete of RCC Deck is also appears with other damages, such as crack, peeling off, and etc. It is rare that it happens alone. Therefore, for the details of the observation methods, pervious clause 1) 'Crack' shall be referred to.

However, if the damage is caused by physical impact, such as overloaded vehicles bump on the deck, falling rock crashes on the surface, and etc. it could appear without other major damages. If the loss is on the bridge surface within carriage way, it leaves the traffic in very dangerous condition. The emergency treatment shall be executed immediately, such as installing the alert sign. The damage could grow from the damaged section if it is left without any treatment. Therefore, it shall be planned to be repaired as quickly as possible

5) Honeycomb

Cause of honeycomb is mostly malconstruction. The large size aggregate sank to the bottom and cement did not reach to the surface. However, if the cement is washed away by rain, river flow, drained water from the bridge surface, or etc., it could grow and the area would enlarge. It could also accelerate the deterioration by neutralization and rebar corrosion since the water would infiltrate through the gaps between the large aggregate. If the deterioration proceeds, it would cause other major damages of concrete such as crack, peeling off, and etc. Therefore, existence of other major damages of concrete in and around the honeycomb area shall be carefully observed by direct sight and recorded in detail if any. It shall be planned to be repaired as quickly as possible if the damage is enlarging.

(2) Steel

Method of detailed observation of Steel Deck Slab is divided by types of damage and cause of damage. It is divided into 5 types of damage, such as corrosion, crack, looseness/omission, fracture, and deterioration of painting, which are the types of damage written in periodic inspection sheet (refer to Appendix 1, Technical Manual on Inspection and Diagnosis of Bridge, which is prepared by CAMBRIDGE, JICA), and the latter is divided into 4 causes of damages, such as neutralization, malconstruction (separation of cement and aggregate), bad drainage, and overloaded vehicles.

Detailed observation of steel structure is basically executed by direct sight observation. However, hair crack of the steel members under the paint or rust is very difficult to be recognized only by sight. Therefore, many detailed observation methods for hair cracks are developed to recognize the current condition of the members.

On the other hand, the cause of damage/deterioration to steel members are mainly the unexpected stress concentration, fatigue or/and chloride which accelerates the corrosion. If the chloride is not supplied from external environment, including scattering snow melting agent on the surface, the cause could be found in structural character or overloaded vehicles.

1) Corrosion

Detailed observation method of corrosion is to find out the thickness of member lost by corrosion. The current thickness of the member is measured directly/indirectly and compared with the initial thickness. Direct measurement is executed by special gauging tools, such as Vernier Calliper, Micrometre, or Dial Calliper Gauge. Thickness of web or steel pipe which cannot be measured directly by above mentioned tools, it is measured indirectly by ultrasonic wave. There are specific tool for this measurement.

Adhering substances including loose rust shall be removed before both measurement. It would increase the result and overvalue the strength of the member. Measurement by ultrasonic wave require adjustment by measuring plural points and calculating average for the result of the measurement. It has less accuracy than direct measurement. Thickness of paint and surface asperity shall be considered in calculating/adjusting the measuring result as result of the observation.

(Direct Measurement by Vernier Calliper) (Indirect Measurement by Ultrasonic Wave)

Figure 5.25 Example of Measuring Thickness of Steel Members

Chipping of concrete covering the steel member shall be done to measure the steel members berried to RCC members. Moreover, if it is caused by chloride, the source shall be measured. However, Bhutan being land locked mountainous country, natural chloride does not fly/income naturally. It must be because of human activities providing the chloride and it shall be controlled that the steel member are not exposed to the chloride from the activities.

2) Crack

Cracks of steel members are not like the cracks of RCC members that can be left as it is if there is no progress of enlarging. Even the hair cracks or invisibly thin cracks can be a cause of severe damage due to the appearance of stress concentration.

Visible crack is already in very dangerous condition which shall be treated rapidly. It shall be measured and precisely recorded to a drawings with scales and necessary notes. This can be done manually by vernier calliper, depth gauge, steel tape, and etc. Photos shall be taken for immediate preparation of the treatment. If the crack is growing, stop whole shall be drilled to stop the enlarging of the crack as an emergency maintenance method.

Finding invisible or very thin crack shall be executed in detailed observation. First method is direct sight observation after cleaning the adhering substances and loose rust. However, the thin/invisible crack are usually under the paint layers and it requires special methods in recognizing the existence and location of them. However there are sections which are prone to have cracks on the steel member. Welding section with discontinuous weld bead, sudden change of cross section, joint section of multiple members. It shall also be kept in mind that there could be inviable cracks around the visible crack. The special methods are as follows,

Table 5.6 Detailed Observation Methods of Crack of Steel Members

Name	Details of Method	Remarks
Magnetic Particle Test	Magnetic particles stick to the crack when artificial magnetic field is set to the member. Require trained skill and special equipment	Invisible cracks in shallow location can be visualized Useful to investigate suspicious sections or surrounding of visible crack in detail
Ultrasonic Test	Receiving reflection of artificial ultrasonic wave. Require trained skill and special equipment	Invisible cracks and crack depth can be visualized Useful to investigate suspicious sections or surrounding of visible crack in detail
Penetrant Test	Hair cracks are enlarged in visualization with specific chemical	Very simple method Can test very wide area Cannot visualize the invisible cracks Useful for primary testing
Eddy Current Test	Measuring the electric current's ampere induced by artificial magnetic field. Require special equipment	Very simple method Existence of crack is defined but cannot specify the location. Useful for primary testing
Cutting and Drilling	Remove necessary parts of the member to observe the crack directly by cutting or/and drilling	Necessary when the crack is invisible but found by the tests mentioned above. Temporary support member shall be installed before execution.

If the inviable crack is found by test mentioned above, it shall be observe directly and confirm the shape, scale (length, width, and depth), and corrosion (area, thickness of the member).

All the data/information shall be drawn in drawings and described in report.

3) Looseness/omission

Looseness is observed by direct sight observation, and observation of touch by fingers. Hammering test is also useful to find the looseness which is not found by sight or fingers. Similar to hammering test of concrete high and clear tone represent good condition and low and dull tone indicates the looseness or other damage. If the tone is low and dull, it shall be overserved carefully and judge the necessity of special methods which are mentioned in 2) Crack above.

Loosen bolts are often rusted and the size is decreased. Therefore the observation of corrosion shall be also executed when the rust is found. When the current size is smaller more than 4mm compared to the initial size, the bearable tension force is reduced to 75%. Replacing the bolts shall be considered.

Omission is easily observed by sight. It basically requires immediate reinstallation. However, when the member including splice plate is heavily damaged and requires repair/replacement, necessity of reinstallation of bolts before repair/replacement shall be studied.

4) Fracture

If there is a member with facture, the bridge could be in very dangerous condition. It shall be observed by close sight and confirm which member is fractured. There could be other surrounding members fractured due to the change of stress condition. The details of all fractured member shall be recorded and drawn to drawings.

It shall be immediately studied whether the bridge is in safe condition to bear the load of traffic. If the road operator cannot be sure for its safety, the bridge shall be temporarily stopped for traffic.

To prevent the fracture from happening for the next time, the cause shall be defined and removed with the replacement of the fractured member. The data/information shall be collected in close observation of the fractured member.

5) Deterioration of Painting

Deterioration of Painting is observed by direct sight observation, and observation of touch by fingers. Hammering test is also useful to find the looseness which is not found by sight or fingers. Colour change and pilling would appear in the damaged section.

Hammering test is useful for the pilling which is difficult to recognize by sight. Low and dull tone indicates the damage.

When there is pilling of the painting, there is often corrosion on the steel member underneath the primer coting layer. Therefore, the damaged painting shall be removed partially to observe the condition of the steel member. If the steel member is corroded, the detailed observation of the corrosion shall be executed at the same time.

Damage of the painting could be a crack as well. The crack of the painting indicates the damages of the steel members in most of the cases. The damage of the steel members could be crack or corrosion, or both. Therefore, if the inspector finds the crack on the paintings, it shall be suspected that there are damage on the steel member and the detailed observation is required. Specifically if there is not any rust at the crack, detailed observation test of crack shall be executed to identify the existence of the crack. Crack shall be treated rapidly so as not to enlarge and also become dangerous condition.

5.2.3.2. Main Girder

(1) Concrete

The observation of concrete girders is basically the same with the observation of RCC deck slab (Refer to clause 5.2.3.1. (1) 'Concrete'). Direct observation by fiberscope is useful to confirm the damage of the PSC girders/members since core samples are difficult to obtain from PSC girders/members (Refer to Figure 5.23)

In case there is a necessity of collecting core sample, the location near to the PC cable and sheath shall be avoided. It is because damaging PC cable or its sheath could be the cause of girder collapse. Special care is required to collect core sample of PSC girder or voided slab.

(2) Steel

The observation of steel girders is basically the same with the observation of steel deck slab (Refer to clause 5.2.3.1. (2) 'Steel').

5.2.4. Substructure

Detailed observation of the substructure is divided by its material. It is divided to 2 materials, such as Concrete (including RCC) and Masonry.

5.2.4.1. Concrete

The observation of concrete substructure are basically the same with the observation of RCC deck slab (Refer to clause 5.2.3.1. (1) 'Concrete').

1) Crack

Detailed observation method of crack on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.2.3.1. (1) 1) 'Crack').

2) Peeling/Exposure of rebar

Detailed observation method of peeling/rebar exposure on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.2.3.1. (1) 2) 'Peeling/Rebar Exposure').

3) Water leakage/Free lime

Detailed observation method of water leakage/free lime on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.2.3.1. (1) 3) 'Water leakage/Free lime').

4) Honeycomb

Detailed observation method of honeycomb on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.2.3.1. (1) 5) 'Honeycomb').

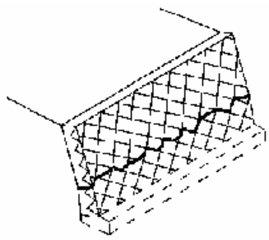
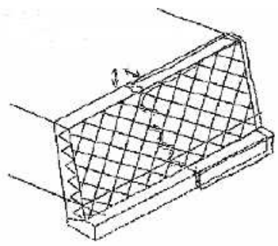
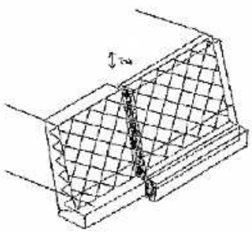
5.2.4.2. Masonry

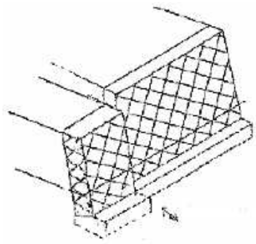
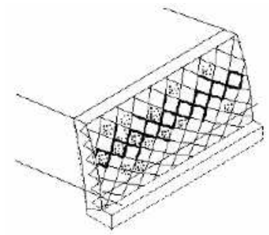
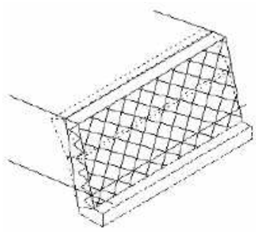
Masonry substructures shall be replaced by RCC substructures considering the flood discharge and earthquake of Bhutan in long term. However, it is not realistic to plan all the masonry substructures be replaced in short period since the numbers of masonry substructure is large. Although it does not have sufficient strength and durability, it shall be observed in detail and repaired as emergency maintenance.

1) Damage/Deformation

Detailed observation of the damages of masonry substructures is crack of horizontal direction, crack of vertical or diagonal direction, horizontal displacement, uneven settlement, heaving, inclination, and partial loss. All of these damage shall be recorded to report and drawn to drawings for designing and preparing for temporary repair works. Shape, scale (length, width, and depth) shall be measured and other remarkable findings shall be recorded. Image of types of damage are shown in the table below.

Table 5.7 Types of Damage of Masonry Substructure

Type of Damage	Image
crack of horizontal direction	
crack of vertical or diagonal direction	
Horizontal displacement	

uneven settlement	
heaving	
inclination	
partial loss	

5.2.5. Miscellaneous Members

Miscellaneous members which is explained in this subchapter are bearings, railings, wearing course, and expansion joint.

5.2.5.1. Bearing

(1) Bearing

Detailed observation of the bearing is divided to 2 material, such as steel and rubber. The basic observation method is close direct sight observation and observation by touch of fingers.

1) Defect

Detailed observation of steel bearings is basically the same with the observation of steel deck slab (Refer to clause 5.2.3.1 (2) 'Steel').

Detailed observation of rubber bearings is by sight and fingers. Crack, Partial loss, softened and easily broken into pieces, change of colour, and etc. to collect the information for making judgement that the rubber bearing still contains the sufficient elasticity.

2) Noise

If the bearing is making noise, it shall be observed to hear the actual sound and confirm the movement of bearing and surrounding members to find out that where the noise is coming from. This does not depend on the material of the bearings. The cause could be passing heavy vehicles, strong wind, and etc. The cause shall be identified and removed. Observing the phenomenon when heavy vehicle actually passes the bridge is very useful to identify the cause. If the noise does not sound in heavy vehicle passing, other cause shall be suspected and found. Interview to frequent user of the bridge or local residents living nearby could assist in identifying the cause.

If the steel bearing is making sound, it shall be observed by the observation method which is explained in clause 5.2.3.1. (2) 'Steel'

(2) Base Mortar (Bearing Sheet)

Detailed observation of the base mortar is divided to 2 phenomenon, one is sediment deposition of debris and/or dirt, and the other is deformation/loss

1) Sediment Deposition

Sediment Deposition shall be removed as much as possible in detailed observation as much as possible to the level that the sediments would not deteriorate the base mortar. If it is not possible to remove totally by hand in detailed observation, the data/information for selecting cleaning equipment, such as water jet cleaner, metal brush, or etc., shall be collected and recorded.

2) Deformation/Loss

Detailed observation of deformation/loss of base mortar is basically the same with the observation of concrete deck slab (Refer to clause 5.2. 3.1. (1) 'Concrete').

5.2.5.2. Ancillary Facilities

(1) Railing

1) Deformation/Damage

Detailed observation of RCC railings is basically the same with the observation of concrete deck slab (Refer to clause 5.2. 3.1. (1) 'Concrete').

Detailed observation of steel railings is basically the same with the observation of steel deck slab (Refer to clause 5.2. 3.1. (2) 'Steel').

5.2.5.3. Deck Surface

(1) Wearing Course

Refer to 4.3.5 Wearing Course, Pavement for details.

(2) Expansion Joint

1) Abnormity

If the abnormity of the expansion joint is clogged gap, refer to subchapter 4.3.1 'Drainage Facilities' for details.

Detailed observation points of expansion joints when it is broken are how it is broken (cracked, partial loss, bended, etc.), the scale of damage (length, width), and etc. However, broken expansion joints shall be replaced. Therefore, if the current expansion joint is separated into blocks and could be replaced by blocks, the type, location, length, and the numbers of block of current expansion joint shall be collected and recorded. If it has to be replaced the entire width of bridge, type, location and length (width of bridge) shall be collected and recorded.

2) Unevenness

Detailed observation points of expansion joints with unevenness of expansion joint are the depth of gap at the both end of the gap, length and width of the gap. And the information to indicate the direction of displacement shall be collected and recorded. Most of the cases, the abutment is moved and the gap is shortened/enlarged, the condition of the substructures, especially the abutments shall be carefully observed.

5.3. Detailed Design

Detailed design shall be executed based on the results of detailed observation explained in the previous subchapter 5.2 Detailed Observation. There shall be two types of works which shall be designed, one is the actual repair (including replacement) of the damaged member, and the other is the works which remove the causes of the damage, such as stress concentration, bad drainage, or other external factors. There are occasions which require considerable amount of treatments to other/surrounding members than/of the objected member of repair works so that the cause of damage is removed sufficiently. For instance, if the cause of the crack of RCC deck slab is infiltration of water from bridge surface, not only the RCC slab itself has to be repaired but also the waterproof layer and asperity of waring course shall be repaired to remove the cause. If the drainage basin is clogged, it shall be cleaned as well.

In this subchapter, the actual method of damaged member is described as the mainstream and of removing cause is explained briefly with typical preventive method to prolong the service life of the member/bridge by slowing down the deterioration progress.

5.3.1. Whole Bridge

Designing of repair method which can prevent whole bridge from being in dangerous condition are described in this subchapter. The methods are defined in the discussion among the members of DOR, MoWTHS and CAMBRIDGE, JICA. If the maintenance policy are updated to satisfy the increasing need of road users, then the repair method would be modified or other method shall be selected.

(1) Extraordinary Deflection

Deflection cannot be removed by removing deflection itself. It shall be removed by repairing the damage which is causing the deflection.

If the cause is damage of superstructure, the damage of the superstructure shall be repaired. If the extraordinary deflection is caused by superstructure, it shall be judged that the superstructure is in very bad condition and the traffic shall be regulated for crossing immediately. It could be unexpected release of prestress of the PSC cables or rebar fracture of the rebar of RCC superstructure.

If the cause is by collapse of bearings of middle of multi-span superstructure, it shall be replaced immediately. It is also considered that the superstructure is in very bad condition and the traffic shall be regulated for crossing immediately. It could be collapsed by the load of heavy vehicle, collision of debris, fatigue of the material, or defective product.

If the cause is by settlement, movement, or inclination of the substructure, the substructure shall be repaired. It shall be considered that the bridge is in very dangerous condition and the traffic shall be regulated for crossing immediately. The cause is normally the scour or the yield of foundation or body of the substructure.

These are the typical causes of extraordinary deflection and there are some other causes with minor possibility. However, all the cause cannot be defined just by surveying the condition of deflection itself. The detailed observation of suspicious member shall be executed and treated immediately. Most of the cases requires emergency treatment before the fundamental repair works are executed. In this case, selecting where to observe and planning of the detailed observation is equivalent to designing.

(2) Settlement, Movement, Inclination

If the substructure is settled, displaced and inclined, more likely that the bridge (or damaged spans) shall be replaced or construction of new bridge in adjacent area shall be considered. It is not easy to jack up the superstructure and shift substructure to initial position and repair to have the sufficient strength and durability.

However, if either of these damage is scarce and has possibility to be repaired, it shall be studied to judge and select the maintenance method whether to repair or replace the bridge. For this judgement, detailed observation is necessary. Since the foundation shall have the sufficient bearing capacity after the repair, countermeasure for the repair is constructing additional piles to pile foundation, enlarging footing area or/and soil improvement under and surroundings of footing. Consultation of well-experienced bridge engineer shall be necessary to select, design and construct these type of repair method due to its complicity.

If the bridge has pile bent structures and the damaged member is limited, only damaged section could be replaced ideally. However, it requires huge support facilities to sustain the superstructure while repairing. It shall be consulted by well-experienced bridge engineer for the judgement.

Replacing short span bridge with box-culvert is one of the alternative if the cross section of the flood flow can be secured with small numbers of diaphragm without disrupting the flood flow.

(3) Scouring

If the scouring is with the level which is not decreasing the bearing capacity of the foundation, it can be repaired by covering the foundation of the substructure and the surrounding riverbed surface. If the river flood velocity and discharge is rather small, it can be covered up by rip rap, gabion for riverbed and rip rap, gabion for revetment. If the flood velocity and discharge is large, riverbed shall be protected with larger protection materials such as large scale of precast concrete blocks, and revetment shall be RCC retaining wall.

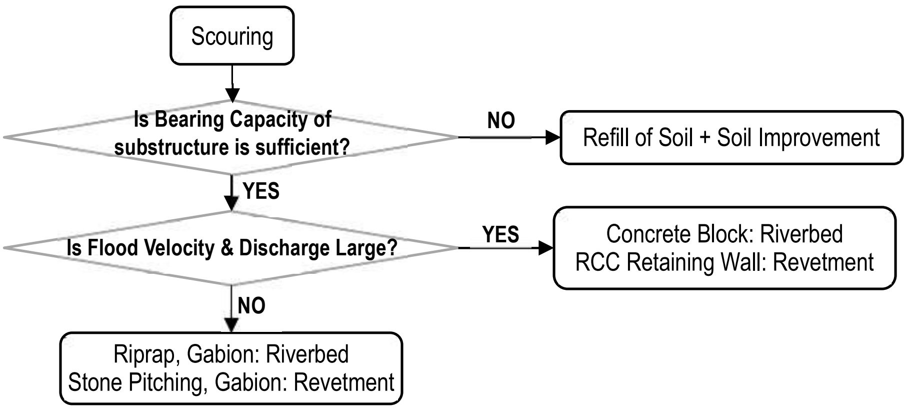


Figure 5.26 Flowchart of selecting Repair Method of Scouring

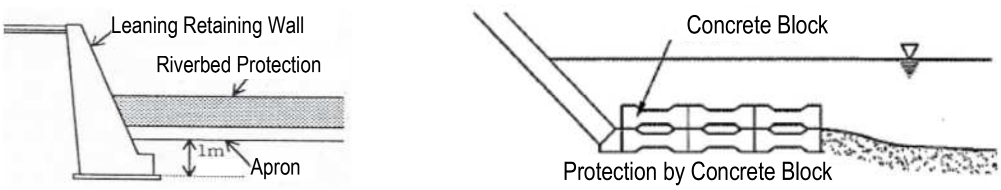


Figure 5.27 Examples of Repair Method of Scouring (with large flood velocity & discharge)

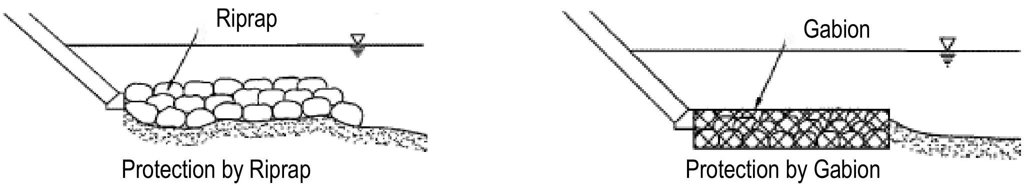


Figure 5.28 Examples of Repair Method of Scouring (with small flood velocity & discharge)

The area for protection shall be as shown in the following figure. The length L_1 is the length of the area which vortex is produced during flood. The length L_2 is from 3 to 5 times of flood depth. It is installed for reducing the scouring effect due to riverbed and revetment material. L_2 shall be installed at the upstream of the bridge as well for the same purpose.

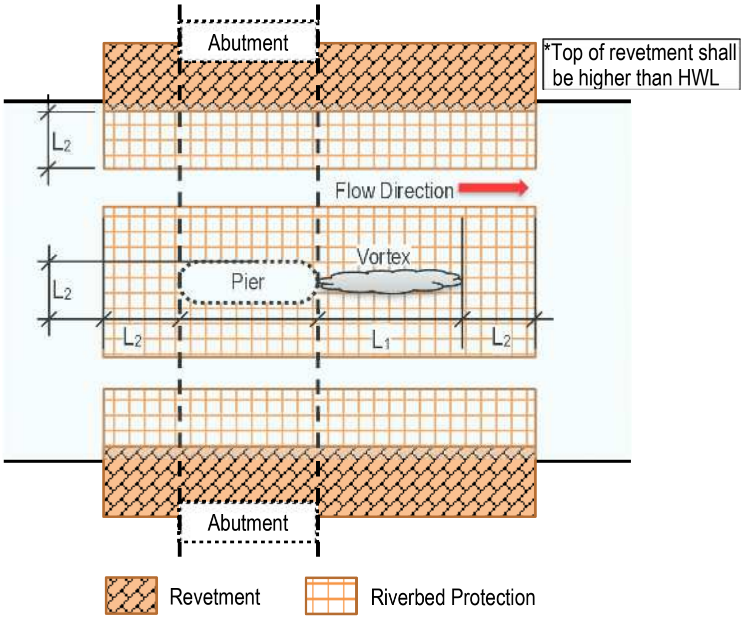


Figure 5.29 Area of Revetment and Riverbed Protection

If the scouring is with the level which decreases the bearing capacity, such as the soil underneath the footing or around the pile is washed away, just covering the foundation of the substructure is not enough to recover its bearing capacity. The soil shall be refilled with sufficient level of compaction to secure the bearing capacity of the soil layer. It requires injecting special materials with pressure so that there would not be any void in the bearing layer. Material could be cement based materials which hardens after injecting or urethane based material which hardens and inflates after injecting. The former require the condition that the water surroundings shall not flow, but the latter can be injected with the water leaking out considerably.

5.3.2. Superstructure

Design of repair works of the superstructure shall be based on the results of the detailed observation which are executed previously. The repair method and area/quantity of repair works shall be determined including the removal of the cause. Otherwise the deterioration would occur again after the completion of the repair works. The details of the design of repair works are explained in the following subchapters. The procedure of the section of the repair method is given priority in the explanation. Procedure during the works is described in the subchapter 5.4 Repair Works.

5.3.2.1. Deck Slab

Detailed design of the repair works of deck slab is explained by following the structure of clauses of subchapter 5.2.3.1 'Deck Slab'. It is divided by materials, such as concrete and steel. Both material is divided into smaller clauses by the types of damages.

(1) Concrete

Design of repair method of concrete deck slab is divided into 5 types of damages, such as crack, peeling/rebar exposure, water leakage/free lime, partial loss of concrete, and honeycomb

1) Crack

Repair methods of concrete crack is selected by the maximum width of the crack which would be repaired. The damage categories corresponds to the width of crack. Category 'c' which has the width up to 0.2mm, 'd' to width from more than 0.2mm to 1.0mm, and 'e' to width more than 1.0mm. The flowchart of selecting repair method of crack of RCC members is shown on the figure below.

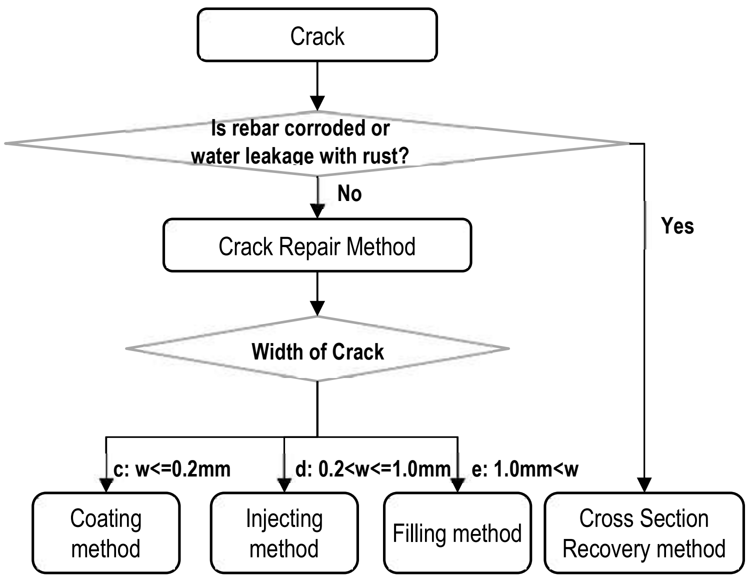


Figure 5.30 Flowchart of selecting Repair Method of Crack of RCC Members

If the crack is with its width up to 0.2mm and enlarging, it shall be coated by special coating materials, such as inorganic cement, epoxy putty, or etc. It is called coating method. If it is confirmed that it is not enlarging and the width remains less than 0.2mm, it doesn't need to be repaired.

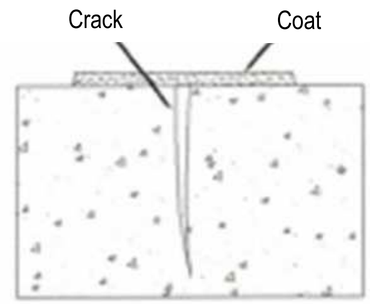
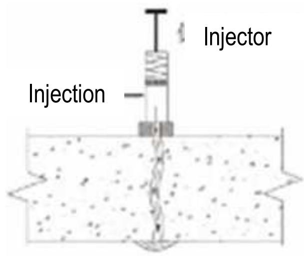
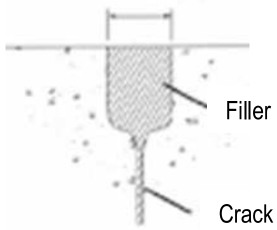
If the crack is with it width from more than 0.2mm to 1.0mm, injecting material, such as micro particle cement epoxy/acrylic resin and etc., shall be injected with pressure to fill the crack till the fond. It is called injecting method.

If the crack is with it width from more than 1.0mm, filling method shall be applied. The filling material is elastic epoxy resin, polymer cement mortar, or etc. It is called filling method.

If the crack has corroded rebar inside visible or water leaking with rust, there are rebar inside corroded and the rust on those rebar shall be removed before the repair methods of crack are executed. The cover concrete shall be removed and repair method would be the one for the damage that is peeling/rebar exposure, such as cross section recovery method. It would be explained in the next clause 2) 'Peeling/Rebar Exposure'.

Outline of 3 repair methods such as coating method, injected method, and filling method, are described in the table below.

Table 5.8 Outline of Repair Methods of Crack

Name	Coating method	Injecting method	Filling method
Image			
width	W<=0.2m	0.2mm<w<=1.0mm	1.0<w
Growth	Small/slow	Small/slow	Big/fast
Material	Inorganic cement, Epoxy putty	Micro particle cement, Epoxy/acrylic resin	Elastic epoxy resin, Polymer cement mortar

i) Coating method

Coating method is applied when the crack is still thin and the maximum width is up to 0.2mm and enlarging. It coats the set of cracks with coating materials and prevents water and moisture from infiltrating inside RCC member. If the thin cracks like this are left as it is and ignored, it would accelerates the corrosion of the rebar inside and grow of the crack of RCC member.

The area of the coating method applied shall cover all the visible cracks from the surface and it shall have margin of 30 to 50cm from the end of the cracks.

For selecting the main material of coating method, the characteristics of the material shall be studied to fit the external environment of the bridge and the member. Factors such as water, moisture, temperature, physical contact, animal excrement, and etc. which could affect the surface shall be checked and resist capacity shall be higher than to resist the environment with specific factors.

ii) Injecting method

Injecting method is applied for the crack with its maximum width from more than 0.2mm to 1.0mm. The injection shall cover the set of the cracks because the injection material is injected with pressure. The crack requires sealing before the injection.

The area of the coating method applied shall cover all the gap between the cracks continuously together inside the RCC member. It cannot be applied partially. Therefore, in applying this method, it shall cover all the crack of continuous section of concrete.

For selecting the material, the deflection of the member shall be studied. The injecting material shall follow the deflection of the member, otherwise it would not be adhered rapidly. For member with deflection, such as superstructure, pier column, cantilever pier head, and etc. material with high elasticity shall be applied.

iii) Filling method

Filling method is applied for the crack with its maximum width exceeding 1.0mm. Unlike the other methods, this method can be applied to partial section with large crack width. After executing the filling method, the remaining cracks of adjacent area could be repaired by injecting method or coating methods depending the maximum width.

The area of the filling method depends on the width of crack. It shall cover total stretch of cracks with its width more than 1.0mm. If there are 2 sections with its width more than 1.0mm in relatively near distance. The section of applying filling method shall be connected and the crack in between these 2 section shall be repaired by filling method.

If the cause of the crack is whether neutralization, ASR, or chloride, the specific repair method shall be done. For neutralization there is Re-alkalization Method, for ASR there is Lithium-ion Injection Method. For chloride there are Electric Rustproof Method and De-chlorination Method. All of these method requires specific equipment and trained skill workers.

2) Peeling/Rebar Exposure

Repair methods of concrete peeling/rebar exposure is selected by the area of damaged section which would be repaired. If the concrete surface is at the bottom surface, shotcrete is usually applied.

If the damaged area is up to $0.5m^2$ including the chipping section around the visible damaged area, the damage will be covered by mortar by plastering. It is called plastering method. Mortar would be plastered by hand and does not require special equipment.

If the damaged area is larger than $0.5m^2$ including the chipping section around the visible damaged area, the damage will be covered by mortar by grouting. It is called grouting method. Mortar would be grouted into the form by grout pump.

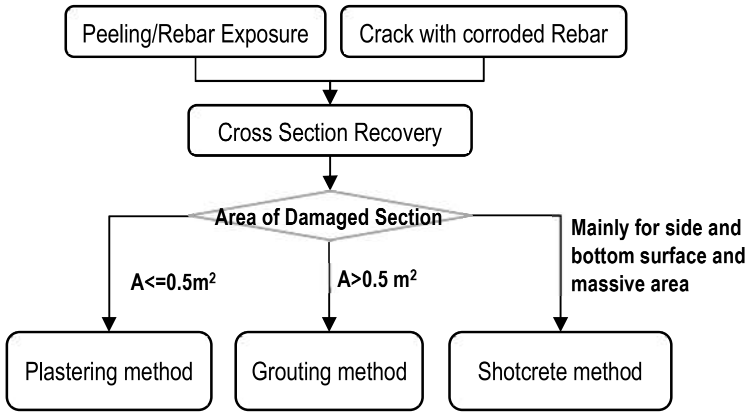
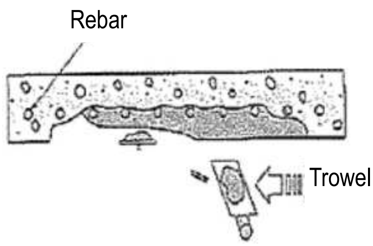
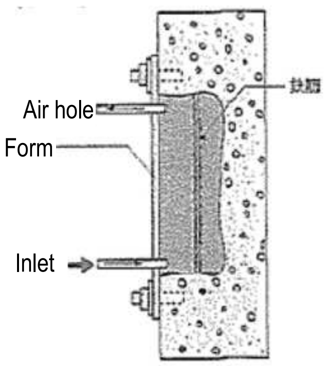
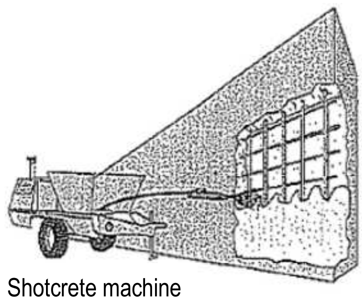


Figure 5.31 Flowchart of selecting Repair Method of Peeling/Rebar Exposure

If the surface is side or bottom surface, the cross section is recovered by spraying shotcrete. Shotcrete material is usually mortar. However, applying shotcrete allows easier handling in repair works because the form and support are not required.

Table 5.9 Outline of Repair Methods of Peeling/Rebar Exposure, Cross Section Recovery Method

Name	Plastering method	Grouting method	Shotcrete method
Image			
Area	A<=0.5m^2	A>0.5m^2	A>0.5m^2 and on the side and bottom surface
Materia l	Polymer Cement Mortar Resin Mortar	Polymer Cement Mortar Special Cement Mortar	Non-shrinkage Mortar

i) Plastering method

Plastering method is applied to the small peeling/rebar exposure which has smaller area than 0.5m^2 including the chipping area of deteriorated concrete or corroded rebar. Surrounding area of peeling/rebar exposure normally has deteriorated cover concrete or corroded rebar. These damaged material shall be removed before plastering method is executed. Including all the damaged material, the applied area shall be smaller than 0.5m^2.

Plastering would be execute manually using trowel. This work seems easy, however finishing with high quality requires experience. Unskilled workers leave air holes and would be the cause of deterioration after the completion of repair works. Stilled worker and experienced supervisor shall be assigned to secure the high quality.

ii) Grouting method

Grouting method is applied to the small peeling/rebar exposure which has larger area than $0.5m^2$ including the chipping area of deteriorated concrete or corroded rebar. Surrounding area of peeling/rebar exposure normally has deteriorated cover concrete or corroded rebar. These damaged material shall be removed before plastering method is executed. Including all the damaged material, if the applied area exceeds $0.5m^2$ this method is appropriate.

It requires rather large equipment, forms, grout pump and etc. Controlling the air discharge requires careful preparation and supervision.

iii) Shotcrete method

Shotcrete method is applied to the damage on side or bottom surface with large are of damage. It requires shotcrete machine but it does not require form and support. It has advantage for damages of members high off the ground level.

3) Water Leakage/Free Lime

Repair methods of concrete water leakage/Free lime is selected by the existence of free lime and rust fluid with the leaking water. If the water leakage is the only damage which is recognized in not only in periodic inspection but also in the detailed observation, the repair method would be crack repair method. If the leaking water contains free lime or rust fluid, the deteriorated concrete and corroded rebar shall be repaired simultaneously and it would be cross section recovery method.

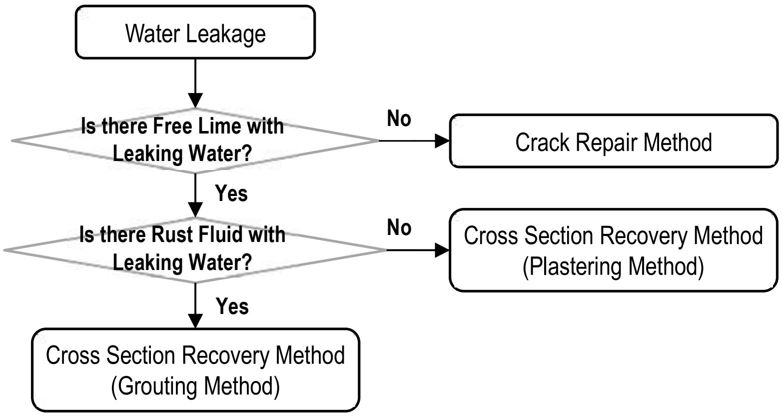


Figure 5.32 Flowchart of selecting Repair Method of Peeling/Rebar Exposure

If the damage inspected is only the crack with leaking water, it shall be repaired with crack repair method. However, the water supply shall be removed or sealed so that there would be no more water infiltrating into the damaged RCC member anymore. If the water supply is cut, the actual repair method is selected dependent on the width of the crack. Previous clause 1) 'Crack' shall be referred to for the details.

If the free lime is coming out of the crack, it indicates that the cement of RCC is running out from the member. It decreases the capacity against compression. Therefore, the area which the cement is washed away shall be defined and removed before the repair method is executed. It can be estimated that if there is only free lime and no rust fluid the damaged area is limited. In this case plastering method would be the most appropriate. However, if the amount of free lime is large and the wide area of concrete shall be removed, grouting method shall be applied. If the leakage is at the bottom surface of the superstructure with large amount of free lime, shotcrete method is an alternative as well. Refer to previous clause 2) 'Peeling/Rebar Exposure' for details. Moreover, the water supply shall be ceased before the execution of the repair method.

If there is rust fluid with leaking water, it indicates that there is corroded rebar inside the damaged RCC member. All rust shall be found and removed before the execution of the repair method. The method would be cross section recovery method. It is likely to be a repair works for large area in this case with existence of rust fluid. Therefore, grouting method is appropriate to by applied. If the leakage is at the bottom or side surface of the superstructure with large amount of chipping of the concrete, shotcrete method is an alternative as well. In designing the area of repair works in this case, not only the area of corroded rebar, but also the area of cement washed away shall be defined. Both shall be removed before the mortar is placed. Refer to previous clause 2) 'Peeling/Rebar Exposure' for details. Moreover, the water supply shall be ceased before the execution of the repair method.

4) Partial Loss of Concrete

Repair method of partial loss of concrete is cross section recovery method. Rebar of the RCC deck is usually exposed when the concrete is lost partially. And the depth of repair is equal to the thickness of the deck slab. Therefore, even the area is smaller than $0.5m^2$, grouting method shall be applied to repair the damage. Refer to previous clause 2) 'Peeling/Rebar Exposure' for details.

If the area is considerably large, recasting of RC deck shall be considered. In this case, cutting heavily corroded rebar and rearranging new rebar is necessary. In this case, the support, form, and scaffolding is necessary to be installed.

When the repair method is completed, the repaired RCC deck slab shall be waterproofed to prevent the re-deterioration. Waterproofing shall cover wider area than the repaired area. Extra 1m in 4 direction shall be added to prevent the infiltration of water into RCC deck slab again. Moreover, the repavement of wearing course shall be included in the design.

5) Honeycomb

Honeycomb is a damage which usually exists from initial construction period. It is basically due to malconstruction. However, it shall be repaired because it allows the water, moisture, and other deteriorating substance, such as chloride, chemical, and etc. infiltrate into the concrete and reach to rebar. It would accelerates the corrosion of rebar and enlarge crack width and length. It would end up the pilling of cover concrete, rebar exposure, and partial loss of RCC cross section.

Repair method is basically the cross section recovery method after removing the cement and aggregate which are left in the member. Therefore, if the area of honeycomb is small and shallow (area less than $0.5m^2$, depth less than 5cm), it can be repaired by plastering method. If the area is large and deep (area $0.5m^2$ and more, depth 5cm and more), grouting method shall be applied. If the honeycomb is shown on the bottom surface and the area is large, shotcrete method would be an alternative. Refer to previous clause 2) 'Peeling/Rebar Exposure' for details.

Table 5.10 Repair Method of Honeycomb by damage category

Category	Repair Method	Remarks
c	Plastering Method	A < $0.5m^2$ and d < 5cm
d, e	Grouting Method (or Shotcrete Method)	A >= $0.5m^2$ or d >= 5cm

=Preventive Repair Method=

REFERENCE: Surface Coating by Skelton Materials

Surface Coating of RCC concrete after the corrective repair works is completed would prevent re-deterioration of the RCC member. There are skeleton materials which covers the RCC member which secures the direct vision from outside and is able to observe the condition after the coating. These materials shuts down the cause substance including water and retard the deterioration. It would prolong the life span of the member and the entire bridge. It also contributes to reduce the life cycle cost of the bridge.

One of these coating materials have glassfibre sheet as a layer in the method. Not only prevents the re-deterioration, but it also prevents the peeling off and drop of concrete piece and strengthen the capacity against the bending moment and shear. It increases the strength of the member.

(Before Coating) (Glassfibre Sheet Adhered) (After Coating)

Figure 5.33 Examples of Skelton Coating of RCC Members

(Pier Coated after Repairing Crack) (Bottom Surface of Pier in Left Picture)

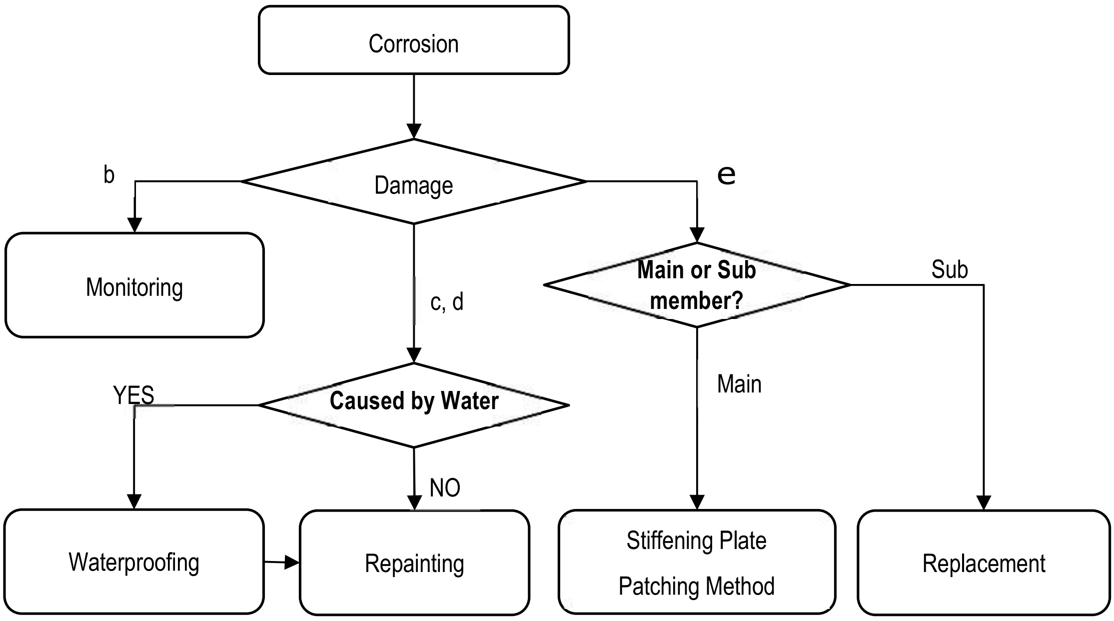
Figure 5.34 Examples of Bridge Members Coated by Skelton Coating Material

(2) Steel

Design of repair method of steel deck slab is divided into 5 types of damages, such as corrosion, crack, looseness/omission, fracture, and deterioration of painting. This clause focuses the steel plate deck for Bailey Bridges which are frequently applied in the rural area of Bhutan.

1) Corrosion

Repair method for corrosion is selected by how much of the steel member is corroded. If the reduction of thickness is scarce, it would be repaired. If it is reduced considerably, it shall be replaced by new steel members. The flowchart of selecting repair method of corrosion of steel members is shown on the figure below.



Note) "b, c, d, e" above represents the category of damage degree which are described in apeendix-2 of the 'Technical Manual on Inspection and Diagnosis of Bridge' prepared by CAMBRIDGE, JICA.

Figure 5.35 Flowchart of selecting Repair Method of Corrosion of Steel Members

If it is only on the surface without scarce reduction of the thickness and the corroded area is very limited (corresponds to Category 'b'), it shall be monitored in routine patrol that the corrosion is not developing. If the development of the corrosion is found in routine maintenance (Category turns to 'c'), it would be listed in the repair list. If the development is rapid, the cause shall be determined and rapidly removed, and the corrosion shall be repaired.

If the reduction of the steel member's thickness is scarce but in wide area (corresponds to Category 'c'), or the reduction of thickness is slightly recognized (corresponds to Category 'd'), the rust shall be removed carefully and newly covered by repainting. The details of repainting is described in the following clause 5) 'Deterioration of Painting'.

If the corrosion is widely spread and some area has recognizable reduction of the thickness (corresponds to Category 'e'), the member is considered that it no longer has initial strength anymore.

This member shall be replaced to new member partially or totally. If the corroded member is one of the main member of the deck, which sustain dead load of the bridge, it cannot be replaced by new member without installing large support beneath the superstructure. Therefore, additional stiffening plate would be patched on the corroded member after removing rust on it. If the corroded member is one of the sub members of the deck, it would be replaced by new member.

However, the steel plate deck of Bailey bridge is one of the main member but it can be replaced without much equipment and facilities. Therefore replacement could be an alternative of repair method of steel deck of Bailey bridge.

In calculating the quantity of the repair works, the area of the member to be repaired shall be wider than the actual area of corrosion. Scraping the old paint and rust on the member shall be done with margin. If the rust is continuing to different surface direction, it shall be all scraped.

Thickness of the stiffening plate shall be thicker than the initial steel plate. The dead load of additional stiffening plate shall be considered in stress calculation of the member.

The cause of the corrosion shall be removed totally before the repair works execution. There are organic waste left on the members of the bridge frequently in Bhutan due to religious practice. However, leaving organic waste on the steel member accelerates the corrosion progress. If the practice could not be banned for local people, it shall be removed immediately after it is found in routine patrol.

2) Crack

Unlike the crack on the RCC member, crack on the steel member is one of the critical damages which influence to the soundness of the member/bridge. Leaving even the one of the hair crack without any treatment could end up in fracture of the member, and moreover collapse of the superstructure. Crack on the steel members shall be treated immediately if the length of the crack exceeds 3mm. The width of the crack is not very important with steel member like with RCC members.

If the repair works cannot be execute immediately, emergency treatment of controlling the traffic, attaching supportive members shall be done immediately to secure the safety of the superstructure.

Any crack found in the inspection or in detailed observation shall not be left as it is. It is very difficult to predict when the member fractures apart. It could also grow any time, therefore, the growth shall be terminated by drilling stop hole at the ends of the crack.

If the length is less than 3mm, it shall be repaired by patching stiffening plate. Patching method is whether by welding or bolts. If the welding method is applied, the movement of the member shall be restricted as much as possible. The traffic shall be stopped during the welding and curing.

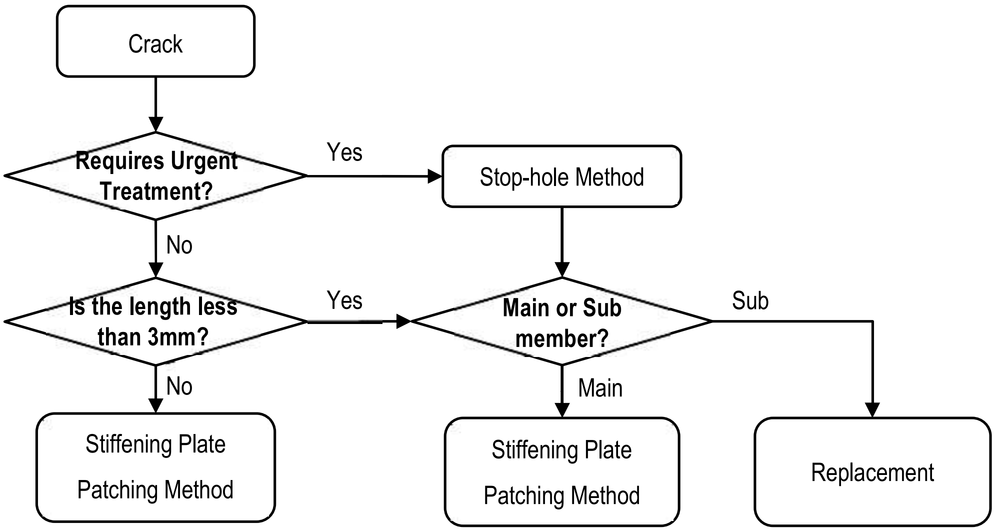


Figure 5.36 Flowchart of selecting Repair Method of Crack of Steel Members

If the length of the crack is 3mm or more and the member is one of the sub members of the deck, it would be replaced by new member. If the member with crack(s) is one of the main members of the deck, which sustain dead load of the bridge, it cannot be replaced by new member without installing large support beneath the superstructure. Therefore, additional stiffening plate would be patched on the cracked member after removing rust on it.

However, the steel plate deck of Bailey bridge is one of the main member but it can be replaced without much equipment and facilities. Therefore replacement could be an alternative of repair method of steel deck of Bailey bridge.

All rust shall be removed before patching the stiffening plate. Quantity of scraping and repainting shall be considered in designing the repair works of crack of steel members.

Thickness of the stiffening plate shall be thicker than the initial steel plate. The dead load of additional stiffening plate shall be considered in stress calculation of the member.

The cause of the corrosion shall be removed totally before the repair works execution. Organic waste shall be removed. Refer to the previous clause 1) 'Corrosion' for details.

3) Looseness/omission

They are three types of connecting steel members. One is by fastening bolts, second is by fastening by rivets, and the last is by welding. This clause explains the repair methods of looseness and omission of bolts mainly. The reason that the rivets are excluded is that rivets are not usually used in recent years due to its difficulty in replacing. If the looseness/omission of rivets are to be repaired, it shall be replaced by bolts.

Both loose bolts and omitted bolts shall be fastened by new bolts. Refastening loose bolts cannot secure the designed strength. All the loosen bolts shall be replaced by new bolts.

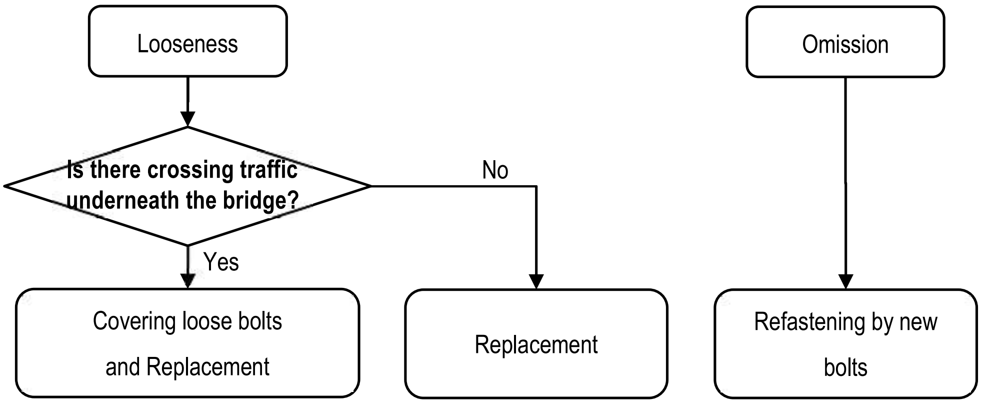


Figure 5.37 Flowchart of selecting Repair Method of Looseness/Omission of Steel Members

If the loosen bolts are fastened at the over bridge over crossing traffic, loosen bolts can drop and harm the traffic passing under the bridge. In this case, these loosen bolts shall be covered to prevent them from not falling off.

Most of the cases with loosen or omitted bolts are corroded together with spliced plates or the steel members. When the loosen bolts are replaced or before new bolts are set to fasten at the holes of omitted bolts, the rust of the steel members, including splice plates, shall be scraped and rust proof treatment shall be done. The area shall cover all the surface which 2 steel members have contact together.

4) Fracture

Fractured steel member does not have any strength and contribute to the structure system of the bridge at all. It shall be immediately treated and the traffic shall be stopped or at least regulated to pedestrians and light vehicles, such as motor cycles and bicycles. To open the traffic rapidly the temporary support structure shall be installed.

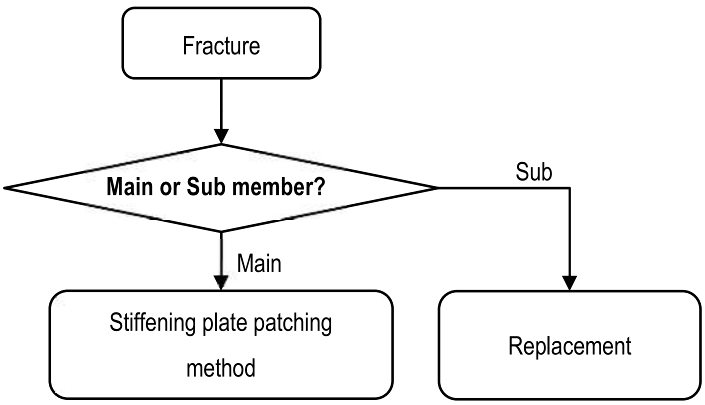


Figure 5.38 Flowchart of selecting Repair Method of Fracture of Steel Members

If the fractured member is one of the sub members of the deck, it would be replaced by new member. If the fractured member is one of the main member of the deck, which sustain dead load of the bridge, it cannot be replaced by new member without installing large support beneath the superstructure. Therefore, additional stiffening plate would be patched on the fractured member after removing rust on it.

Patching method is whether by welding or bolts. If the welding method is applied, the movement of the member shall be restricted as much as possible. The traffic shall be stopped during the welding and curing.

Thickness of the stiffening plate shall be thicker than the initial steel plate. The dead load of additional stiffening plate shall be considered in stress calculation of the member.

The cause of the fracture, it is usually the stress concentration, shall be removed totally before the repair works execution. Or the stiffening plate for the replacement of fractured member shall be capable to bear the stress concentration.

5) Deterioration of Painting

Before repainting the section of steel members with deterioration of painting, scraping the old paint and rust shall be executed. If the level of corrosion is heavy and spread to wide area, it shall be scraped by blasting method. Blasting is a method of scraping the old paint and rust by crushing tiny iron balls to the steel member by special equipment. Iron balls are very tiny that the diameter is 15 to 70 μm (micrometre).

If the level of corrosion is mild and not spread widely, scraping shall be done by scraping machine, such as disc sanding machine, bristle blaster and manual scraping tools, such as scraper and wire brush, etc.

These scraping works shall be included in design and calculation of cost estimates.

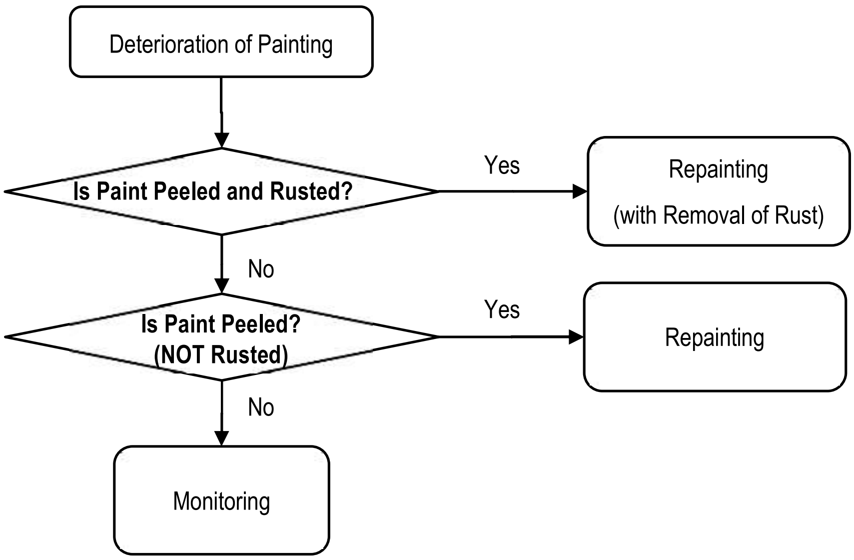


Figure 5.39 Flowchart of selecting Repair Method of Deterioration of Painting of Steel Members

If the old paint is peeled and the steel inside is rusted, the rust shall be scraped well and repainted. The scraping shall be done by blasting method ideally but careful work by handling scraping machine and manual scraping tools could be accepted for now until the facility and material supplying environment is prepared.

If the old paint is peeled and there is no recognizable rust on the steel member, old paint shall be scraped by handling scraping machine and manual scraping tools and repainted.

If the paint has colour change or short cracks of small numbers, it shall be monitored to recognize the worsening of the damage. If the deterioration of the paint progresses rapidly, it shall be scraped and repainted before it is corroded.

5.3.2.2. Main Girder

(1) Concrete

The design of repair works (specifically the selection of repair method) of concrete girders is basically the same with the design of RCC deck slab (Refer to clause 5.3.2.1. (1) ‘Concrete’). In case the PSC girder requires to be repaired, review of the stress would be different due to the existence of prestress force. Moreover, chipping could not be applied to the section where the compressive force is loaded by prestress force.

PC inner cable cannot be replaced. If the PC cable are found deteriorated and the prestress tension force doesn’t exist anymore, it shall be loaded by outer cable ore equivalent reinforcing method. Subchapter 6.3.1 shall be referred to for the details.

(2) Steel

The design or repair works of steel girders is basically the same with the design of steel deck slab (Refer to clause 5.3.2.1. (2) ‘Steel’).

5.3.3. Substructure

Design of repair works of the substructure is divided by its material. It is divided to 2 materials, such as Concrete (including RCC) and Masonry.

5.3.3.1. Concrete

The design of repair works (specifically the selection of repair method) of concrete girders is basically the same with the design of RCC deck slab (Refer to clause 5.3.2.1. (1) ‘Concrete’).

1) Crack

Detailed design of repair works (specifically the selection of repair method) of crack on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.3.2.1. (1) 1) ‘Crack’).

2) Peeling/Rebar Exposure

Detailed design of repair works (specifically the selection of repair method) of peeling/rebar exposure on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.3.2.1. (1) 2) ‘Peeling/Rebar Exposure’).

3) Water Leakage/Free Lime

Detailed design of repair works (specifically the selection of repair method) of water leakage/free lime on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.3.2.1. (1) 3) 'Water Leakage/Free Lime').

4) Honeycomb

Detailed design of repair works (specifically the selection of repair method) of honeycomb on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.3.2.1. (1) 5) 'Honeycomb').

5.3.3.2. Masonry

Masonry substructures shall be replaced by RCC substructures considering the flood discharge and earthquake of Bhutan as it is already mentioned in the detailed observation. However, the repair methods of masonry substructure shall be explained considering the numbers constructed along the national and Dzongkhag highways in Bhutan. In this subchapter, it is described how to select the repair method of masonry substructure. It shall be kept in mind that the result of the repair methods explained in this subchapter does not last for long period since masonry substructure does not have equivalent durability as RCC substructure.

1) Damage/Deformation

The repair methods of masonry substructure are basically 2 methods, one is partial replacement of RCC retaining wall and the other is re-patching of the masonry.

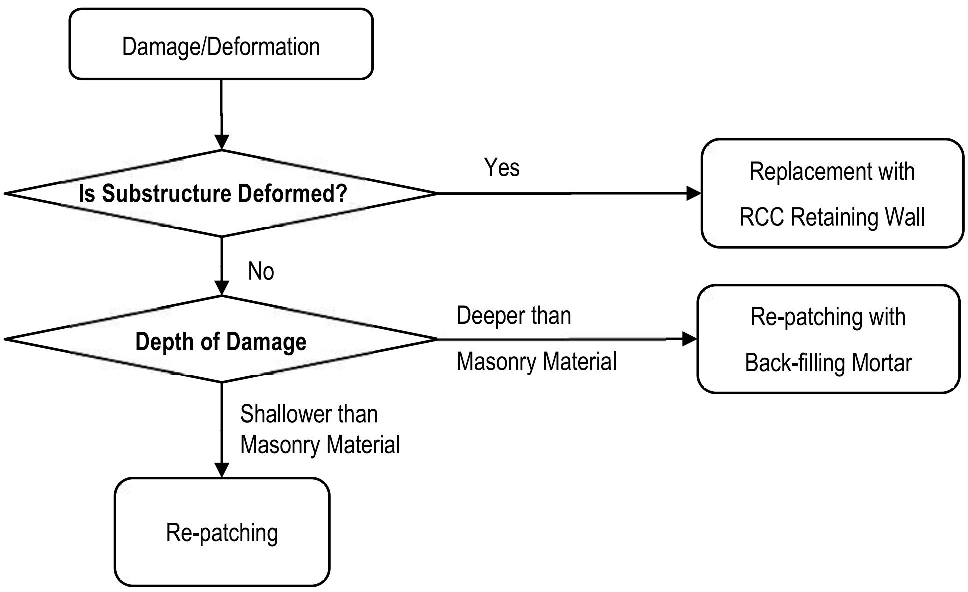


Figure 5.40 Flowchart of selecting Repair Method of Damage on Masonry Substructure

If the damage of masonry substructure is deformed, such as partial settlement, heaving, and inclination, it indicates that the backfill soil pressure is pushing the masonry structure, the foundation of the masonry structure is losing the bearing capacity, or exceeding the sustaining capacity of the masonry structure. Therefore, it shall be considered that the deformed section to be replaced by RCC retaining wall. The supporting capacity of substructure to support superstructure would increace significantly in replacing the masonry structure with RCC retaining wall. The temporary support structure is necessary to be installed and it shall be included in the design.

If the damage is only the crack or partial loss, masonry structure shall be re-patched by equivalent masonry material. It shall cover the all damaged section with surrounding sections. If the backfill is washed away and the loss is deeper than the depth of masonry material, back fill shall be refilled by mortar and then masonry material shall be re-patched. If the damage is only loss of the patching material of masonry substructure, only re-patching is required for the repair method.

5.3.4. Miscellaneous Members

Miscellaneous members which is explained in this subchapter are bearings, railings, wearing course, and expansion joint.

5.3.4.1. Bearing

Design of repair method of both rubber and steel bearing is explained in this subchapter.

(1) Bearing

1) Defect

If the defect of bearing is minor and is not effecting to other members of bridge, this damage could be monitored through routine patrol. If the defect is severe, replacement of the bearing by rubber bearing shall be considered. It is because that multi-layered rubber bearing has advantage in resisting against the 3-dimentional force which earthquake loads to bridge structure, specifically for bridges with long spans. Also even for the bridges with short span, the durability of the rubber has become high and reliable. It shall be more cost benefit than steel in recent years.

If the damage is mostly due to corrosion or deterioration by leaking water from bridge surface, waterproofing of deck slab and expansion joint shall be considered and executed with the bearing replacement.

2) Noise

If the noise of bearing is minor and is not effecting to other members of bridge, this damage could be monitored through routine patrol. If the noise is remarkably loud but the defect is not severe, it shall be observed in detail to find out the cause of the noise. Noise is often produced by crossing traffic and repeating movement of particular member of the bridge. Not only finding the member(s) making the noise, but the cause making the noise shall also be determined and removed.

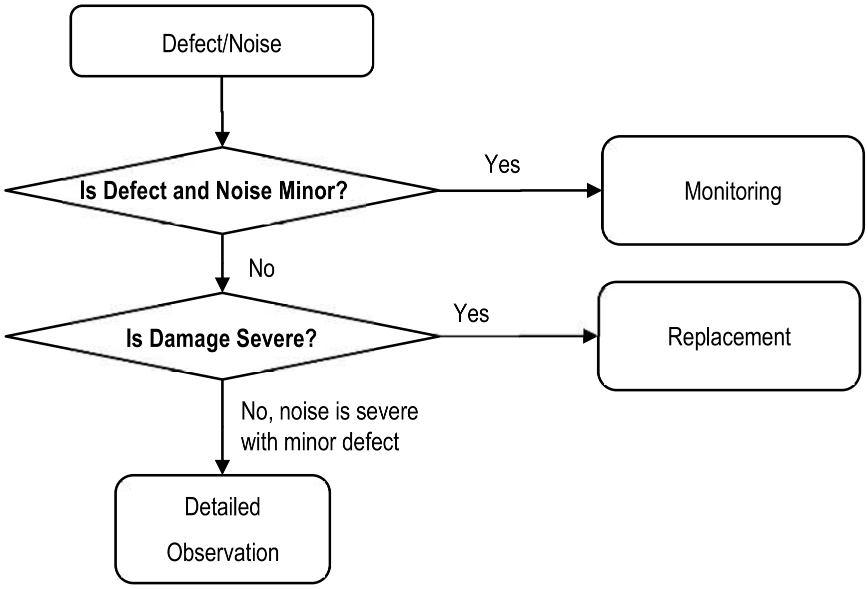


Figure 5.41 Flowchart of selecting Repair Method of Bearings

Replacing the bearings require jack-up and temporary support device for superstructure. The majority of cost is for this work item and requires high cost for temporary works.

(2) Base Mortar (Bearing Sheet)

Base mortar is cement based member, it requires repair works when the bearing is still usable. In case bearing is also damaged severely and requires replacement. Base mortar shall also be reinstalled adjusting new bearing which would be installed newly.

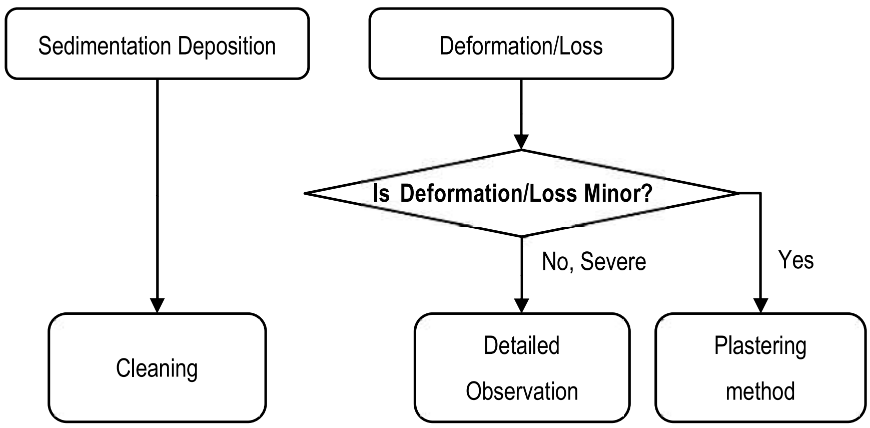


Figure 5.42 Flowchart of selecting Repair Method of Base Mortar of Bearings

1) Sediment Deposition

For sediment deposition, subchapter 4.3.2. Sediment Deposition shall be referred to for the details. Basic method is cleaning.

2) Deformation/Loss

If the deformation/loss is minor, it shall be repair by plastering method and recover the initial shape of the base mortar. Clause 5.3.2.1. (1) 2) 'Peeling/Rebar Exposure' shall be referred to for the details.

If the deformation/loss is severe, it shall be observed in detail to find out the cause of the damage. It could cause the settlement of the superstructure and produce big gap on the bridge surface. It often requires other repair work to be executed simultaneously with repair of the base mortar. Moreover, the bearing shall be damaged severely as well. Therefore, the basic repair method is reinstalling the new base mortar adjusting newly installed bearing. Designing the repair works shall be executed including repair works of other damaged members.

5.3.4.2. Ancillary Facilities

Design of repair method of ancillary facility, such as railing is explained in this subchapter.

(1) Railing

Railing shall have the strength to secure the safety of crossing traffic, such as vehicles and pedestrians, so as not to fall down from the bridge surface. It shall be installed in sound condition with sufficient strength. Although it is not the member of main structure of the bridge, it shall be kept in sound condition for the better service level of the bridge, specifically in the urban area.

If there is sufficient width of the bridge to have side walk(s), the guardrail for vehicle shall be installed at the border of side walk and carriageway. If the guardrail is installed, the railing at both edge of the bridge shall not have to resist the crash by vehicles.

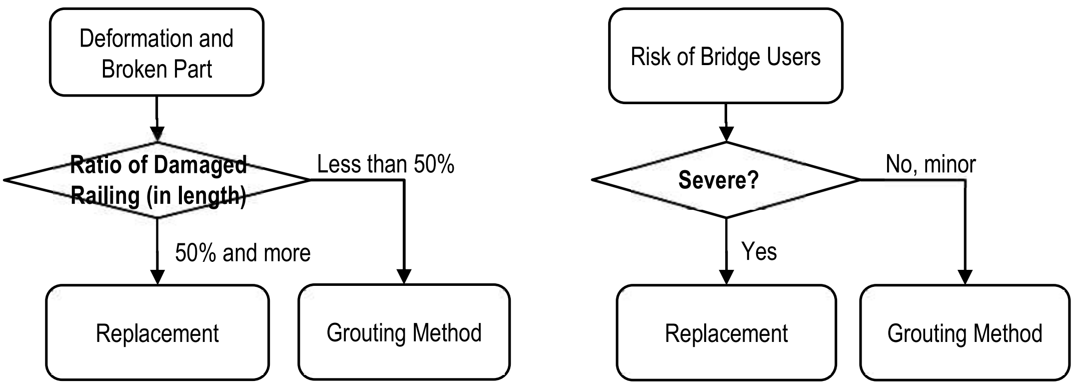


Figure 5.43 Flowchart of selecting Repair Method of Railing

1) Deformation or Broken Part

If the cross section of the railing is damaged more than 50%, the remaining railing shall be removed and the new railing shall be installed. It is better to install the standard type of railing so as not to design the details for every bridge which requires the new installation. Standard drawings and bill of quantity as well as unit cost for installation shall be prepared. It is cheaper to construct RCC railing in general, however standard of steel railing shall be considered for the bridges which cannot bear the dead load of RCC railing.

If the damage of cross section of the railing is less than 50%, it would be repaired by grouting method of cross section recovery method. Clause 5.3.2.1. (1) 2) 'Peeling/Rebar Exposure' shall be referred to for the details.

The special care is required to define the joint section of new railing and the existing superstructure. If it is necessary, new installation of curb shall be considered.

2) Risk of Bridge Users

If the railing loses its strength to secure the safety of bridge users, it shall be removed and replaced as well. It shall resist against the crash of vehicles so that the vehicles do not fall down off the bridge. If the column of railing is broken/deteriorated severely, the section with severe damage is dangerous for the bridge users, specifically for pedestrians. The existing railing of these sections shall be replaced by new railing.

If the damage is not severe and the strength could be recovered, it would be repaired by grouting method of cross section recovery method. Clause 5.3.2.1. (1) 2) 'Peeling/Rebar Exposure' shall be referred to for the details.

5.3.4.3. Deck Surface

Design of repair methods of deck surface, such as wearing course and expansion joint are explained in this subchapter.

(1) Wearing Course

Damage of wearing course could be found in routine patrol and as long as it is not severe, it could be repaired in maintenance works. The details shall be referred to subchapter 4.3.5 Wearing Course, Pavement for details.

(2) Expansion Joint

Expansion joint shall join parapet of abutment and deck or 2 decks next to each other and secure the gap in between because superstructure actually moves and the gap enlarges/shrinks due to earthquake, temperature change, and etc. If the gap is clogged by dirt or abutment is inclined, the gap will no longer exist and the movement of the superstructure pushes directly the abutment or superstructure next to it.

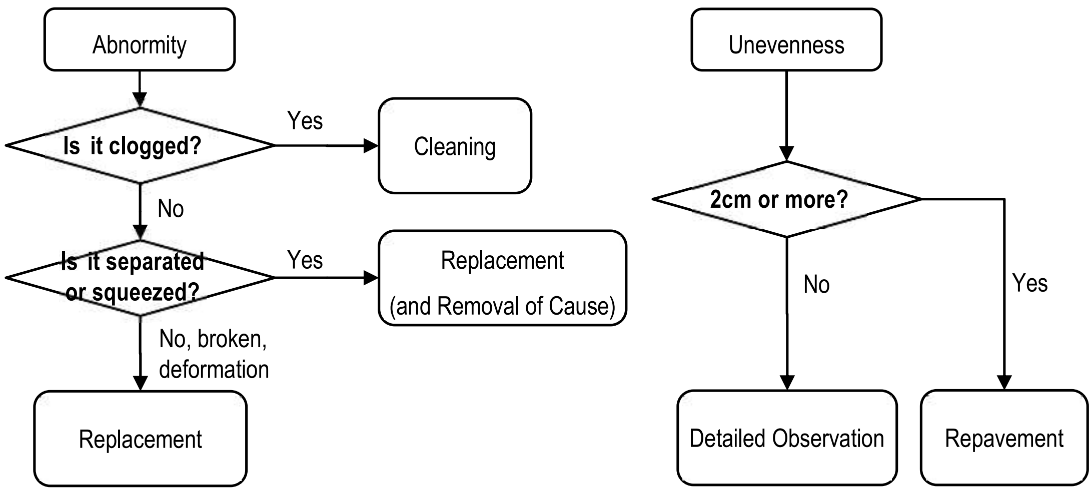


Figure 5.44 Flowchart of selecting Repair Method of Expansion Joint

On the contrary, the gap can be enlarged in some cases. This damage would put the traffic into dangerous condition, specifically the pedestrians and bicycle users. Also it would enlarge the impact to the bridge by heavy vehicles and be the cause of damage of other members.

In replacing the expansion joint, waterproofing function shall be included in new sets of the expansion joint. It stop the surface water at the expansion joint and let it drain to the side edge of the bridge and into the drainage basin and pipes. It does not let the surface water drain down to the bridge seat through the gap of expansion joint. It also does not wet the bearing nor let the dirt deposit on the bridge seat. It prevents rapid deterioration of bearings, bridge seat, and substructure. This type of expansion joint is often called expansion joint with waterproofing structure. This could retard the time period of replacing or repair of bearings or substructure and save the maintenance cost.

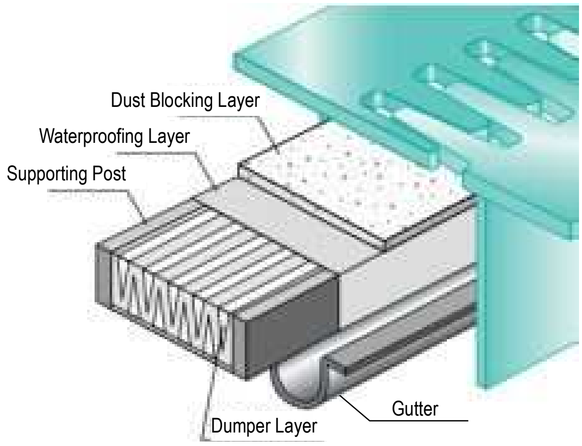


Figure 5.45 Example of Expansion Joint with waterproofing Structure

Moreover, uneven settlement of superstructure mainly caused by damages of bearings, severe deterioration of slab under the expansion joint, or fracture of the expansion joint itself could be a cause of vertical gap between parapet of abutment and deck or 2 decks next to each other. Bridge surface would be in the same situation with gap enlarged. It would put the traffic into dangerous condition, specifically the pedestrians and bicycle users. Also it would enlarge the impact to the bridge by heavy vehicles and be the cause of damage of other members.

1) Abnormity

If the gap is clogged, it shall be cleaned as early as possible. If it could be cleaned manually without special equipment, it shall be cleaned immediately when it is found. However, most of the time it is compacted and difficult to remove all the dirt out of the gap. Therefore, water jet shall be used for cleaning it sufficiently.

If the gap is enlarged (separated) or shrunken (squeezed), the expansion joint shall be replaced by new set. However, the movement of superstructure or parapet of abutment shall be repaired before the replacement. The initial distance of gap shall be secured in replacement.

If the damage is only on the expansion joint itself, such as bent, crack, missing parts, shall also be replaced.

Expansion joint is usually made by single member for the entire width of bridge. However, selecting units of expansion joint narrower, such as 1m or 2m for instance, could reduce the quantity of the repair work since the damage is often limited to small section.

2) Unevenness

If the gap of expansion joint have 2cm or more of vertical gap, it shall be replaced by new set as early as possible. However, the cause of gap shall be removed before the replacement. If the cause is damage of bearings, emergency treatment shall be executed, such as stop of traffic or limited to light vehicle such as motorcycles and bicycles.

If the vertical gap is less than 2cm, it shall be observed in detail to find out why the gap is caused. If it is due to the damage of bearing, same treatment shall be done for the gap 2cm or more, that is explained in the previous paragraph. If it is due to other reason and the bridge is sound, it could be monitored in routine patrol that the gap is not enlarging.

5.3.4.4. Construction Planning, Cost Estimate

(1) Result of Detailed Design

Whatever the damage or material is, the following items shall be included in the result of detailed design of repair works.

- Repair works (Drawing, Bill of quantity)
- Removal Works of Cause of Damage (Drawing, Bill of quantity, Specification)
- Temporary Structure (Drawing, Bill of quantity)
- General Equipment (Quantity)
- Special Equipment (Specification, Quantity)
- Construction Planning (General view)
- Construction Schedule
- Disposal (Quantity)
- Traffic Control (Specification)
- Labour Cost
- Overhead of Contractor

1) Construction Planning

Construction planning of repair works shall be designed considering the condition of each bridge and member. Not only the drawings and quantity of the materials, but also other items related to actual construction shall be included in the result of design. The items are listed in the previous clause, such as temporary structure, (support, scaffolding, form, and etc.), special and general equipment, traffic control equipment, disposal, traffic control, and construction schedule. Types, specification, quantity, and timing of these items shall be calculated based on the construction planning.

(2) Cost Estimate

Cost estimate of repair works shall include all the cost of the design results listed in the previous clause. To execute the repair works it also requires labour cost with overhead of contractor.

5.4. Repair Works

Actual construction of repair works shall be executed based on the results of detailed design explained in the previous subchapter 5.3 Detailed Design. Typical procedure and points which close attention shall be given are demonstrated in this subchapter.

However, repair works is a kind of works that every details cannot be defined in designing stage because many of the damage is invisible. The many of the actual details are disclosed during the construction stage. Therefore, every related member of repair works, such as road operator, supervision engineer, contractor, and even actual workers at site shall be reminded that there would be amendments of the design, quantity, and specification anytime during construction stage. Anyone finds the new findings of the damage which are revealed for the first time shall report to responsible personnel of the repair works immediately. Responsible engineer and managers of road operator shall not be reluctant of amendment if the new findings which change the condition of the design if they are found during the construction stage.

To secure the designed strength of the member which are repaired, there shall be 3 main items that shall be controlled in the construction stage, which are quality of the works, accuracy of shape in completion, and quality control of materials.

5.4.1. Whole Bridge

Typical procedure and the points which require close attention of repair works to repair the damage of whole bridge are demonstrated below.

(1) Extraordinary Deflection

If the cause of the damage is superstructure, there shall be scaffolding to access the damaged member from under the superstructure. After installing the scaffoldings, damage shall be observed by appropriate methods dependent on the materials and damages which are explained in previous subchapter 5.2. Detailed Observation, and then judge whether to repair or replace the superstructure. If the substructure is not in sound condition, the entire bridge shall be replaced. If it is judged to be repaired, the design would follow. Previous subchapter of 5.3 Detailed Design shall be referred to for the details.

If the cause is bearings, scaffolding shall be installed on the side of substructure. The rest of the procedure is as same as the previous paragraph (in case of damage of superstructure)

If the cause is settlement, movement, or inclination of the substructure, the condition of the foundation and soil underneath the footing shall be observed in detail. If the substructure is in the river flow, there shall be coffer dam to remove river flow around the substructure. The rest of the procedure is as same as the previous paragraph (in case of damage of superstructure)

(2) Settlement, Movement, Inclination

This damage requires replacement of bridge in most of the cases. However, if either of these damage is scarce and has possibility to be repaired, the condition of the foundation and soil underneath the footing shall be observed in detail. In case of the soil under the footing is washed away, not only the physical scale of scour but also the condition of remaining soil shall be observed. There could be sediments of flood which are very soft and shall be removed in repair works. However, even the repair of small level of these damages of substructure, it require massive temporary structure to repair the damage. There shall be a consultation from well-experienced engineer in judging to execute the repair works, detailed observation, designing the detailed repair method. Relevant subchapters in 5.2 Detailed Observation and 5.3 Detailed Design shall be referred to for details.

(3) Scouring

Repair methods of scouring explained in clause 5.3.1 (3) 'Scouring' are riprap, gabion, concrete block, RCC retaining wall, and refill of soil with soil improvement. All methods except refill of soil with soil improvement, require similar preparation procedure as follows,

Install Coffer Dam	・ Coffer dam to secure dry and safe condition at the site ・ Embankment or steel sheet pile
Dry up the Site	・ Dry up the site by using pumps
Excavation	・ Excavate the riverbed till bearing layer
Cleaning	・ Clean the dirt, mad, waist at the surface of excavation
Leveling	・ Level the surface of excavation ・ Casting of leveling concrete for RCC retaining wall for revetment.
Placing	・ Place the appropriate materials ・ Casting concrete for RCC retaining wall for revetment.
Finishing	・ Curing for RCC retaining wall for revetment. ・ Accuracy checking of shape in completion.

Figure 5.46 Workflow of Repair Works for Scouring

(Riverbed Protection by Gabion)

(RCC Retaining Wall)

Figure 5.47 Example of Construction of Coating Method

5.4.2. Superstructure

Typical procedure and the points which require close attention of repair works to repair the damage of superstructure are demonstrated below.

5.4.2.1. Deck Slab

Actual repair works of deck slab is explained following the structure of clauses of clause 5.2.3.1. and 5.3.3.1. 'Deck Slab'. It is divided by materials, such as concrete and steel. Both material is divided into smaller clauses by the types of damages.

(1) Concrete

Actual repair works of concrete deck slab is divided into 5 types of damages, such as crack, peeling/rebar exposure, water leakage/free lime, partial loss of concrete, and honeycomb

1) Crack

Repair works explained in the previous clause 5.3.2.1. (1) 1) 'Crack' are three methods, such as coating method, injecting method, and filling method. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses.

i) Coating Method

The workflow is shown in the figure below.

Inspection of Crack	・ Inspection of condition, width, length, depth ・ Plan the work flow/procedure
Removal of Cause	・ Waterproofing or water sealing (at the upstream of member) ・ Remove other cause indicated by the diagnosis of inspection data
Cleaning	・ Brush and clean the crack and surrounding area, better done by water jet cleaner. Test before using water jet cleaner not to worsen the crack. ・ Test the adhesiveness after cleaning
Primer Coating	・ Paint the primer coat which is specified by the coating product
Intermediate Coating	・ Coat the intermediate layer coating material specified by the coating product ・ Number of the layer is normally 1 or 2.
Finishing Layer Coating	・ Coat the finishing layer with coating material specified by the coating product
Finishing	・ Coating shall be cured till it is dried to prevent the crack ・ Temperature control is necessary in winter and summer.

Figure 5.48 Workflow of Coating Method

Before commencing the repair works, the contractor shall inspect the damage (crack in this case) in detail and check whether the condition (category and quantity of damage) has not been changed (worsened, increased) from the last inspection data. If the category of the damage has worsened or the quantity has increased considerably, contractor shall discuss with project owner the solution for it. If there is no change at the crack which would be repaired, the plan/schedule of the repair works shall be prepared by the contractor.

Repair of damage (crack in this case) is not enough just by repairing the damage by selected repair method (coating method in this case). The cause shall be removed to ensure the result of the repair works. The contractor shall remove the cause indicated by the diagnosis of the inspection. If the cause is the water infiltrating into the concrete, the member shall be waterproofed or the water stream shall be drained to other flow for instance.

Most of the time, cracks are dirty with mud, dust, oil, or other materials. These shall be completely cleaned before the coating work is executed. It shall be done by water-jet cleaner, since it cleans inside of the crack as well. After cleaning and drying, the adhesiveness with the repairing material shall be tested before the coating works.

There shall be multiple layers of coating to protect the concrete cracks from external environment. This manual shows primer, intermediate, and final layer. Material shall be procured by set for all the layers.

Each coating layer shall be cured so that any substances shall not be adhered and dried properly so that is would adhere with the next coating material. While curing the coating material, the temperature shall be controlled within the range identified in the specification of the material.

(Test after cleaning the surface)

(Finishing Layer Coating)

Figure 5.49 Example of Construction of Coating Method

ii) Injecting Method

The work flow is shown in the figure below.

Inspection of Crack	· Inspection of condition, width, length, depth · Plan the work flow/procedure
Removal of Cause	· Waterproofing or water sealing (at the upstream of member) · Special methods are required for sever damage by neutralization, Chloride and ASR
Cleaning	· Brush and clean the damage which is to be treated · Get rid of adhered substances including oil
Installing Washers	· Coat the injecting washers with sealing material · Set the injecting washers vertically at the center of the crack.
Sealing	· Seal the crack firmly so that the injecting resin does not flow out
Injection of Resin	· Confirm the hardness of sealing material · Set injectors to injecting washers and inject the injecting resin
Removal of Washers and Sealing	· Confirm the hardness of injecting resin · Remove washers and sealing.

Figure 5.50 Workflow of Injecting Method

Up to the stage of 'cleaning', the details shall be referred to the previous 'clause 5.4.2.1. (1) 1) i) 'Coating Method' to avoid the duplication.

Washers demonstrated in the table below shall be installed complying the technical specification of the procured equipment and materials. Injecting resin and the injecting washers shall be procured as a set to secure the quality of the repair method. Distance shall be set according the volume of the crack and washer. The volume of the washer shall exceed the volume of the crack to avoid the gap from remaining in the crack.

After installing the washers, the crack shall be sealed on the surface so that the injected resin is not pressed out. This sealing work shall be done without a fault because pressed out injected resin significates that it was not injected into the fond of the crack and left the gap inside.

Next step is the actual injection of the resin. The pressure shall follow the technical specification of the product. It shall not be higher or lower. Both error leaves gap in the crack and cannot secure the quality. If the resin is pressed out from the sealing, the section shall be inspected in detail after the injection is completed.

After curing the resin in certain temperature and period indicated in the technical specification of the product, the hardness of the resin shall be checked whether it is sufficiently harder than the specification of the product. The washers are removed after checking of the hardness.

Table 5.11 Examples of Equipment of Injecting Method

Cylinder Method	BICS Method	Micro Capsule
		

(Bottom Surface of Voided Slab) (Bottom Surface of RCC Slab)

Figure 5.51 Example of Construction of Injecting Method

iii) Filling Method

The work flow is shown in the figure below.

Inspection of Crack	· Inspection of condition, width, length, depth · Plan the work flow/procedure
Removal of Cause	· Waterproofing or water sealing (at the upstream of member) · Special methods are required for sever damage by neutralization, Chloride and ASR
Cutting the Ditch	· Cut the ditch for filling with electric concrete cutter · Ditch shall be with width 10mm and depth 10-15mm along crack
Cleaning	· Clean the surface of the ditch by wire brush or brush · Remove dust and powder left by cutting the ditch
Primer Coating	· Paint the ditch with primer coat which is specified by the coating product
Filling the ditch	· Fill the ditch with filling material using appropriate equipment. · Surface shall be flattened by trowel
Finishing	· Filled material shall be cured till it is dried · Rain and dust shall be avoided to touch the filled material in curing

Figure 5.52 Workflow of Filling Method

Up to the stage of ‘removal of cause’, the details shall be referred to the previous ‘clause 5.4.2.1. (1) 1) i) ‘Coating Method’ to avoid the duplication.

In this method, the crack is cut to make small ditch by electric cutter. The ditch shall follow the alignment of the crack (See the Figure below). The ditch shall have its width of 10mm and depth from 10 to 15mm. This size of the ditch is to secure the quality of the repair works, therefore it shall not be smaller size. If the size is bigger than it shall be, it would be waste of the material.

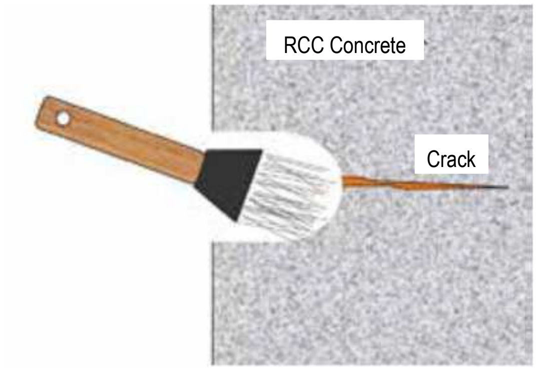
After cutting the ditch, the surface of the ditch shall be cleaned. There are powder dust from cutting works, and it shall be removed to secure the adhesiveness of the primer coating.

Primer coating shall be done to the ditch before filling the ditch with the filling material.

Filling material shall fill the ditch using appropriate equipment, such as caulking guns and etc. The surface shall be flattened by trowel manually. It shall be made sure that the filling material, usually epoxy resin or non-shrinkage mortar, are sufficiently filled in the ditch.

Filling material shall be covered and cured until it is dried and hardened so that water and dust, or other adhesive substances would not touch the surface. The length of the period shall be according to the technical specification of the product.

(Cutting the Ditch with Electric Cutter)



(Cleaning the Ditch)

Figure 5.53 Example of Construction of Filling Method

2) Peeling/Rebar Exposure

Repair works explained in the previous clause 5.3.2.1. (1) 2) 'Peeling/Rebar Exposure' are three methods, such as plastering method, grouting method, and shotcrete method. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses.

i) Plastering Method

The work flow is shown in the figure below.

Inspection of Peeling/Rebar Exposure	· Inspection of condition, width, length, depth · Plan the work flow/procedure
Removal of Cause	· Waterproofing or water sealing (at the upstream of member) · Special methods are required for sever damage by neutralization, Chloride and ASR
Removing Deteriorated Materials	· Removing the deteriorated concrete of damaged section · Using Electric concrete cutter/chipper and secure the depth more than 10mm
Scraping the rust of rebar	· Scrape the rust of rebar by wired brush/disk sander
Rust Prevention	· Coat the rebar with rust preventive material
Primer Coating	· Coat the cut/chipped surface with Primer Coat · This is to improve the adhesive strength with recovery material
Plastering	· Recover the cross section with recovery material by trowel manually
Finishing	· Filled material shall be cured till it is dried · Rain and dust shall be avoided to touch the filled material in curing

Figure 5.54 Workflow of Plastering Method

Up to the stage of 'removal of cause', the details shall be referred to the previous 'clause 5.4.2.1. (1) 1) i) 'Coating Method' to avoid the duplication.

The existing concrete around the damage, peeling/rebar exposure are deteriorated and has lost its strength. Therefore, surrounding section of the concrete shall be removed before the repair method is executed. Removal shall be done by chipping the existing concrete on the entire surface of the damage. The depth of the chipping shall be greater than 10mm. This depth is set adding additional depth to the cover of the RCC concrete.

After the deteriorated concrete is removed, there would be considerable amount of rebar exposed. This rebar shall be cleaned, especially when it is rusted. The section which rebar is already exposed before the removal of the deteriorated concrete, there shall be rust covering the surface. Rust shall be removed by using electric cleaner, such as disk sander and etc.

Cleaned rebar shall be rust prevented by coating the rebar by rust preventive material, such as epoxy resin, polymer cement paste, and etc.

Chipped surface of the concrete shall be coated by primer coating material to secure the adhesiveness between the existing concrete and plastering material. It shall be made sure that all the surface are coated by the primer coating material. It also shall be dried without adhesive substances attached on the surface of coating material.

Next step is recovering the cross section by plastering using trowel manually. It shall be made sure that the recovering material is filling all the cross section firmly. However, the plastering thickness shall not exceed 7mm. If the thickness of the recovering cross section exceed 7mm, plastering procedure shall be done several times to fill the entire cross section. This skill require training for quite long period. Unskilled worker shall not execute even it looks easy to avoid air holes in the plastering material.

Recovering material is usually polymer cement mortar which have sufficient strength and low shrinkage specification. It also has high workability due to less water-cement ratio because of the containment of polymer. It also adhere very well to the existing concrete.

Filling material shall be covered and cured until it is dried and hardened so that water and dust, or other adhesive substances would not touch the surface. The length of the period shall be according to the technical specification of the product.

(Rustproofing of Rebar, Primer Coating)

(Plastering)

Figure 5.55 Example of Construction of Plastering Method

ii) Grouting Method

The work flow is shown in the figure below.

Inspection of Peeling/Rebar Exposure	· Inspection of condition, width, length, depth · Plan the work flow/procedure
Removal of Cause	· Waterproofing or water sealing (at the upstream of member) · Special methods are required for sever damage by neutralization, Chloride and ASR
Removing Deteriorated Materials	· Removing the deteriorated concrete of damaged section · Using Electric concrete cutter/chipper and secure the depth more than 10mm
Scraping the rust of rebar	· Scrape the rust of rebar by wired brush/disk sander
Rust Prevention	· Coat the rebar with rust preventive material
Primer Coating	· Coat the cut/chipped surface with Primer Coat · This is to improve the adhesive strength with recovery material
Setting Form	· Set the form for grouting mortar · Seal the gap between the form and existing concrete
Grouting	· Grouting mortar by grouting equipment.
Finishing	· Grouted material shall be cured till it is dried · Remove the form and check the finishing condition

Figure 5.56 Workflow of Grouting Method

Up to the stage of 'primer coating', the details shall be referred to the previous clause 5.4.2.1. (1) 2) i) 'Plastering Method' to avoid the duplication.

After primer coating, the form for grouting shall be set firmly which resist the grouting pressure from inside. Form shall be supported by stiff material such as steel pipe for instance (See the Figure below). The gap between form and the surface of existing concrete shall be sealed so that the grouted material would not be pressed out.

Grouting shall be done by appropriate grouting equipment which are specified by the manufacturer of the grouting material. The pressure, diameter of the grouting tube and other specification are specified by the manufacturer to secure the quality. Matching of the grouting material and grouting equipment shall be kept as it is specified in the technical specification.

Substituting the equipment from other project is not permitted unless same grouting material is selected.

Grouting material is usually polymer cement mortar or non-shrinkage mortar. However, both chemical and physical specification differs by the product. The product shall be selected by the site condition. It shall be consulted by experienced engineer.

Grouting material shall be cured until it is dried and hardened according to the technical specification of the product. The length of the period shall follow the technical specification of the product. After it is hardened the form shall be removed.

(Grouting Non-shrinkage Mortar) (Curing)

Figure 5.57 Example of Construction of Grouting Method

iii) Shotcrete Method

The work flow is shown in the figure below.

Inspection of Peeling/Rebar Exposure	· Inspection of condition, width, length, depth · Plan the work flow/procedure
Removal of Cause	· Waterproofing or water sealing (at the upstream of member) · Special methods are required for sever damage by neutralization, Chloride and ASR
Removing Deteriorated Materials	· Removing the deteriorated concrete of damaged section · Using Electric concrete cutter/chipper and secure the depth more than 10mm
Scraping the rust of rebar	· Scrape the rust of rebar by wired brush/disk sander
Rust Prevention	· Coat the rebar with rust preventive material
Primer Coating	· Coat the cut/chipped surface with Primer Coat · This is to improve the adhesive strength with recovery material
Shotcreting	· Recover the cross section by shotcreting the recovery material using shotcreting equipment.
Finishing	· Placed material shall be cured till it is dried · Level the surface by plastering mortar manually, if necessary.

Figure 5.58 Workflow of Shotcrete Method

Up to the stage of ‘primer coating’, the details shall be referred to the previous clause 5.4.2.1. (1) 2) i) ‘Plastering Method’ to avoid the duplication.

Shotcreting material and equipment shall be procured as a set and the method of the shotcreting depend on the equipment. There are 2 main streams of the shotcreting methods which are dry-shot type and wet-shot type. The difference is when to mix water before shotcreting. Dry-shot mixes the water just before the shotcreting at the very end of the nozzle of the equipment. Wet-shot mixes before inserting material to the nozzle. Dry-shot type exceeds in transferring capacity due to the viscosity of the transferred material. However, the quality of dry-shot type depends on the skill of the worker who executes the shotcreting work. In other hand, wet-shot type does not require so much skilled worker as dry-shot type.

The special care shall be taken in shotcreting the cross section behind the rebar. It often leaves the gaps due to the existence of rebar. Shotcreting shall be done from multiple direction to avoid leaving these gaps.

Shotcreting shall be divided to several times if the thickness of recovering cross section is thick. Shotcreting to the rebar for first stage, shotcreting to near of the surface, and finishing by shotcrete for instance (see Figure below).

Material is rapid hardening cement mortar for dry-shot type and polymer cement mortar for wet-shot type. The admixture differs by product and shall be selected depend on the site condition and shotcrete method. It shall be consulted by experienced engineer.

Shotcrete material shall be cured until it is dried and hardened according to the technical specification of the product. The length of the period shall follow the technical specification of the product. After it is hardened, the surface could be smoothened for better external appearance.

(Beginning Stage) (Intermediate Stage) (Finishing Stage)

Figure 5.59 Example of Construction of Shotcrete Method

3) Water Leakage/Free Lime

Repair works explained in the previous clause 5.3.2.1. (1) 3) ‘Water Leakage/Free Lime’ are three methods, such as crack repair method, plastering method, and grouting method. Typical procedure and the points which require close attention of these methods are demonstrated in previous clauses, such as 5.4.2.1. (1) 1) ‘Crack’ and 5.4.2.1. (1) 2) ‘Peeling/Rebar Exposure’.

4) Partial Loss of Concrete

Repair works explained in the previous clause 5.3.2.1. (1) 4) ‘Partial Loss of Concrete’ is cross section recovery method. Typical procedure and the points which require close attention of these methods are demonstrated in previous clause 5.4.2.1. (1) 2) ‘Peeling/Rebar Exposure’.

5) Honeycomb

Repair works explained in the previous clause 5.3.2.1. (1) 5) ‘Honeycomb’ is cross section recovery method. Typical procedure and the points which require close attention of these methods are demonstrated in previous clause 5.4.2.1. (1) 2) ‘Peeling/Rebar Exposure’.

(2) Steel

Actual repair works of steel deck slab is divided into 5 types of damages, such as corrosion, crack, looseness/omission, fracture, and deterioration of painting

1) Corrosion

Repair works explained in the previous clause 5.3.2.1. (2) 1) 'Corrosion' are three methods, such as stiffening plate patching method, replacement, and repainting. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses. Patching stiffening plate shall be done by tightening bolts, and not by welding. It is because the welding would be executed at the site, so the existing members would deform/vibrate during the welding works are executed. Therefore, it is very difficult to secure the quality of welding.

i) Stiffening Plate Patching Method

The workflow is shown in the figure below.

Inspection of Corrosion	・ Inspection of condition, width, height, thickness of the steel member ・ Plan the work flow/procedure
Removal of Cause	・ Waterproofing or water sealing (at the upstream of member) ・ Remove other cause indicated by the diagnosis of inspection data
Removing Existing Paint	・ Clean the stain on the paint ・ Scrape the existing paint using handy scraping machine
Drilling Holes	・ Drilling Holes on the Exiting Plate to Patch the Stiffening Plate as is shown in the shop drawings
Place the Stiffening Plate	・ Place the stiffening plate at the right location and fix it temporarily ・ Stiffening plate shall be fabricated as the shop drawings previously in the factory
Fasten Bolts	・ Fasten Bolts to patch the Stiffening Plate
Painting	・ Paint the stiffening plate and exiting plate including bolts in layers in the manner specified in specification

Figure 5.60 Workflow of Stiffening Plate Patching Method

Up to the stage of 'removal of cause', the details shall be referred to the previous clause 5.4.2.1. (1) 1) i) 'Coating Method' to avoid the duplication.

Removing the existing paint shall be executed in good quality which removes deteriorated paints totally. Only the inner layers, such as primer coating layer, in good condition could be left on the steel members after this scraping works. The area of scraping shall cover the entire stiffening plate. The details of works in removing the existing paint shall be referred to the following clause 5.4.2.1. (2) 1) iii) 'Repainting'.

After the scraping works is finished, the hole to bind the stiffening plate shall be drill to the steel members of the existing bridge. It shall be carefully scaled at the site to fit the stiffening plate which is fabricated at the factory separately. If the holes are not drilled in the proper location, stiffening plated could not be bind firmly to the existing members.

The edge of the drilled holes shall be trimmed so that the entire surface of the stiffening plate is attached to the existing plate. It secures the friction resistance after the fastening of bolts.

Welding at the site is the other option to bind the stiffening plate with the existing members. However, welding at site and high of the ground on the scaffolding is very difficult work to secure the quality. It often end up with unevenness of the quality is the welding section, which could be the cause of the repeated damage at the same section even the original cause of the damage is removed. Welding shall be avoided unless it is impossible to patch the stiffening plate with bolts.

After the holes on the existing steel member is drilled and trimmed, the stiffening plate shall be placed temporarily at the place of installation. Even the stiffening plate is not a big size member, it weighs very heavy. The support structure and transferring method shall be carefully planned so that the stiffening plate would not deform before attaching to the existing members.

Stiffening plate shall be examined whether it is fabricated exactly as it is shown in the shop drawings. A few millimetres of difference with the shop drawing could end up that the bolts would not enter for fastening. Lack of bolts could not secure binding force between the existing member and stiffening plate. The examination shall be executed very strictly since modifying the fabrication of stiffening plate at site is hardly impossible.

Bolts to bind the stiffening plate shall be HTB (High Tensile Bolts) and fastened firmly in a method shown in the specification. Every bolts shall be fastened more than it is designed. There are 'Torshear Type High Strength Bolt' which are easier in quality control. If the torque is sufficient, the pin-tail would come off from the bolt.

After the bolts are fasten firmly and the splice plate is bound properly, the entire splice plate, all the bolts with surrounding existing members shall be repainted. The details of the repainting shall be referred to the following clause 5.4.2.1. (2) 1) iii) 'Repainting'.

Figure 5.61 Example of Construction of Stiffening Plate Patching Method

High Tensile Bolts Torshear Type High Strength Bolt

Figure 5.62 Example of HTB (High Tensile Bolts)

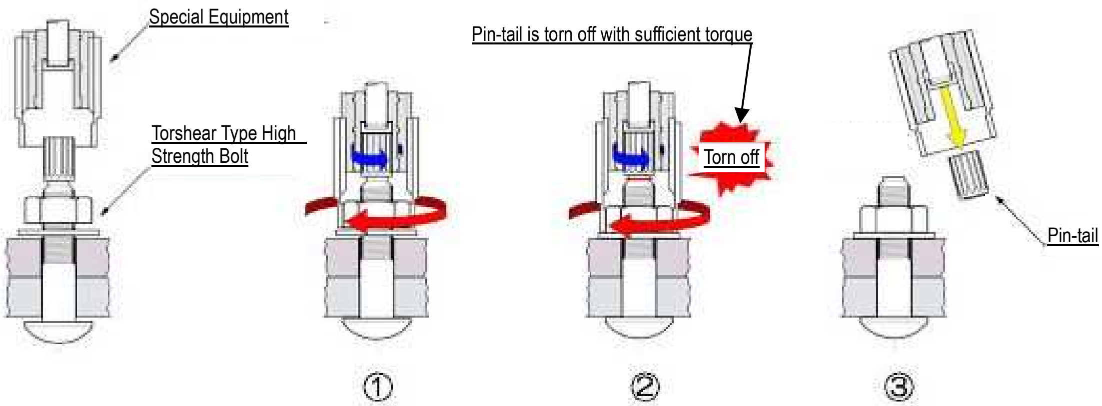


Figure 5.63 Mechanism of Torshear Type High Strength Bolt

ii) Replacement

The workflow is shown in the figure below.

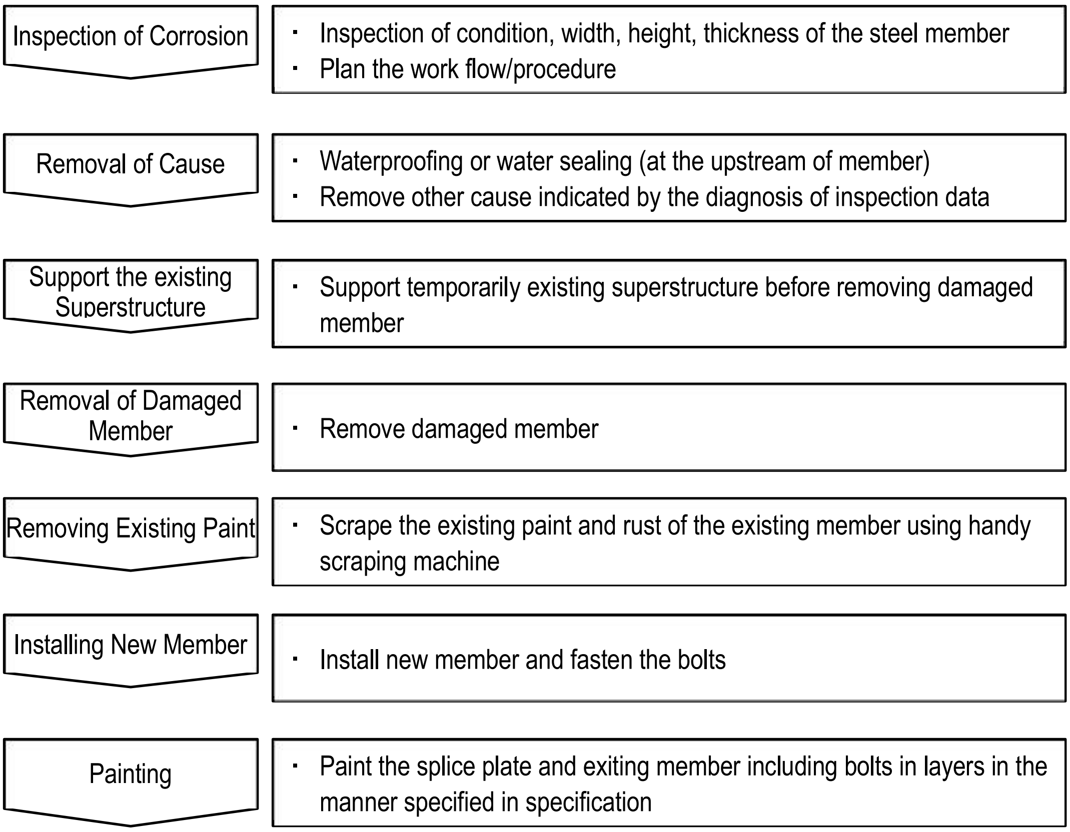


Figure 5.64 Workflow of Replacement of Damaged Member

Up to the stage of 'removal of cause', the details shall be referred to the previous clause 5.4.2.1. (2) 1) i) 'Stiffening Plate Patching Method' to avoid the duplication.

When replacing a member(s) of existing steel bridge, the other surrounding members could lost their support from the member which would be replaced. Therefore, temporary support structure shall be installed prior to removing the exiting damaged member. After installing the temporary support structure, it shall be examined strictly that the existing member would be supported after removing the damaged member.

Removal of the damaged member shall be done in a step confirming that it is not affecting the other existing structure. It is better to replace entire member by removing the existing bolts. However, if it is not possible or not feasible to replace entire member, some section shall be cut and replaced. In this case, new member shall be bound with the existing members firmly by stiffening plates. The details of the works shall be referred to the previous clause 5.4.2.1. (2) 1) i) 'Stiffening Plate Patching Method'.

After the stage of 'removal of damaged member', the details of the works shall be referred to the previous clause 5.4.2.1. (2) 1) i) 'Stiffening Plate Patching Method' to avoid the duplication.

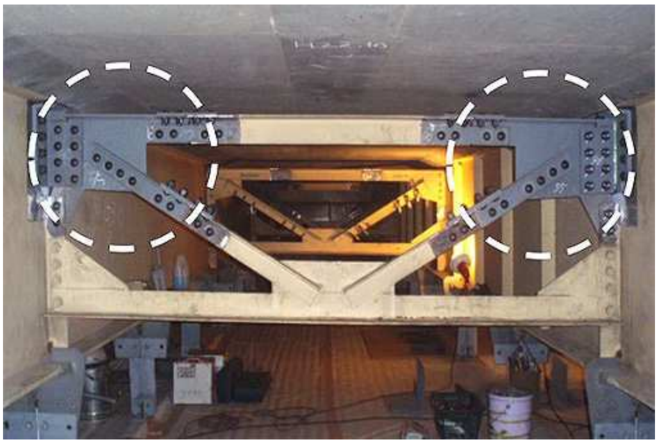


Figure 5.65 Example of Construction of Replacement of Damaged Member

iii) Repainting

The workflow is shown in the figure below.

Inspection of Corrosion	· Inspection of condition, width, height, thickness of the steel member · Plan the work flow/procedure
Removal of Cause	· Waterproofing or water sealing (at the upstream of member)
Removing Existing Paint	· Clean the stain on the paint · Scrape the existing paint using handy scraping machine
Painting	· Paint the stiffening plate and exiting member including bolts in layers in the manner specified in specification
Finishing	· Paint shall be dried without getting adhered substances.

Figure 5.66 Workflow of Repainting

(Scraping the existing Paint)

(Primer Coating)

(Intermediate Coating)

(Final Coating)

Figure 5.67 Example of Construction of Repainting

Up to the stage of 'removal of cause', the details shall be referred to the previous clause 5.4.2.1. (2) 1) i) 'Stiffening Plate Patching Method' to avoid the duplication.

Removing the existing paint shall be done manually using handy scraping machines such as disk sander and bristle blaster. The rust of the existing member shall be removed completely as well. For the bumpy surface, such as bolts or the corner of joints shall be done with different handy machine with smaller brush, such as cup wire wheel. Wherever the brush of the machine cannot reach, it shall be scraped by hand using scraping stick or etc. (See Figures below)

(Disk Sander)

(Bristle Blaster)

(Cup Wire Wheel)

(Scraping Stick)

Figure 5.68 Example of Scraping Works

There is blasting method to remove the existing paint and rust. It utilizes tiny metal balls and metal balls are crushed to the existing members. Special equipment to crush the metal balls is required and the workspace shall be covered so that the iron ball does not spread away in the air. It also shall be collected not to pollute the drainage.

The surface after removing the exiting layer and scraping would have completely different colour from the condition before the treatment. The example is shown as the Figure below.

before

after

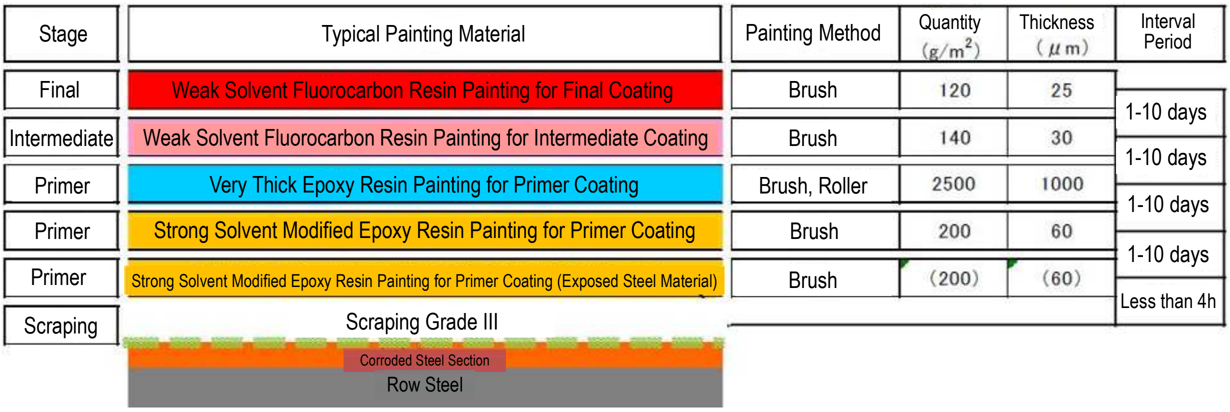
Figure 5.69 Example of Steel Surface after Scraping Grade III

Painting shall be with multiple layers to protect the steel member from corrosion. Corrosion is the most basic damage of the steel member which shall be avoided. The structure of the multiple layers of painting differ by member, location. Bolts, the edge of the flange, lapping section between the existing paint and newly paint for instance, shall be painted with thicker layers (See Figures below). It is recommended to procure painting materials of all the layers from same paint manufacture. It secures more firm adhesiveness between layers next each other.

Paints shall be dried for certain period without adhered substance. The period shall be set according to the technical specification of the product.

Stage	Typical Painting Material	Painting Method	Quantity (g/m^2)	Thickness (μm)	Interval Period
Final	Weak Solvent Fluorocarbon Resin Painting for Final Coating	Brush, Roller	120	25	
					1-10 days
Intermediate	Weak Solvent Fluorocarbon Resin Painting for Intermediate Coating	Brush, Roller	140	30	
					1-10 days
Primer	Weak Solvent Modified Epoxy Resin Painting for Primer Coating	Brush, Roller	200 × 2	60 × 2	
					1-10 days
Primer	Weak Solvent Modified Epoxy Resin Painting for Primer Coating (Exposed Steel Material)	Brush, Roller	(200)	(60)	
					Less than 4h
Scraping	Scraping Grade III				
	Corroded Steel Section				
	Row Steel				

Figure 5.70 Example of Coating Layers of Repainting after Scraping (Main Section)



Stage	Typical Painting Material	Painting Method	Quantity (g/m²)	Thickness (μm)	Interval Period
Final	Weak Solvent Fluorocarbon Resin Painting for Final Coating	Brush	120	25	
Intermediate	Weak Solvent Fluorocarbon Resin Painting for Intermediate Coating	Brush	140	30	1-10 days
Primer	Very Thick Epoxy Resin Painting for Primer Coating	Brush, Roller	2500	1000	1-10 days
Primer	Strong Solvent Modified Epoxy Resin Painting for Primer Coating	Brush	200	60	1-10 days
Primer	Strong Solvent Modified Epoxy Resin Painting for Primer Coating (Exposed Steel Material)	Brush	(200)	(60)	1-10 days
Scraping	Scraping Grade III				Less than 4h

Figure 5.71 Example of Coating Layers of Repainting after Scraping (Splice Plate)

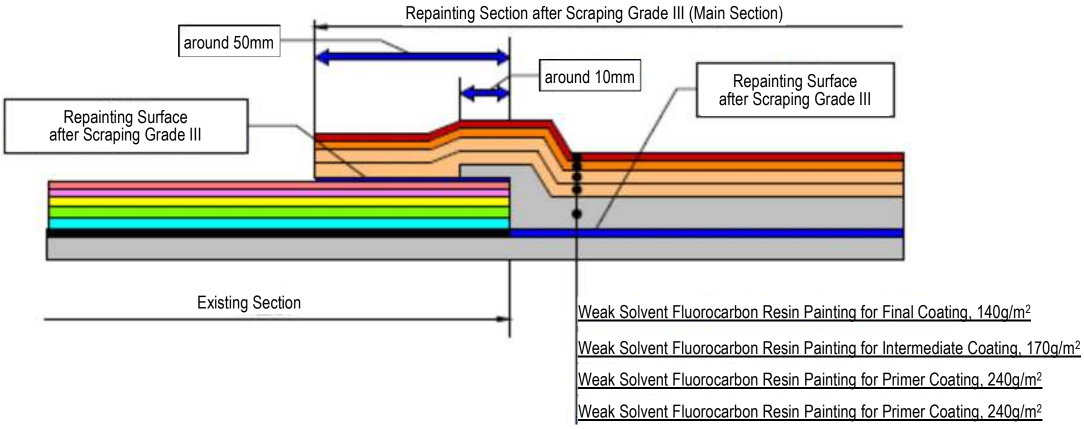


Figure 5.72 Example of Coating Layers of Repainting at the Border of Sections

2) Crack

Repair works explained in the previous clause 5.3.2.1. (2) 2) ‘Crack are three methods’, such as stop hole method, stiffening plate patching method, and replacement. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses.

i) Stop Hole Method

The workflow is shown in the figure below.

Inspection of Crack	· Inspection of crack, location, length of the steel member · Plan the work flow/procedure
Scraping Crack	· Scrape rust and paint around the crack
Drilling	· Drill the stop hole at the ends of the crack
Primer Coating	· Primer coating to prevent corrosion till further repair is executed.

Figure 5.73 Workflow of Stop Hole Method

Up to the stage of ‘inspection of crack’, the details shall be referred to the previous clause 5.4.2.1. (2) 1) i) ‘Stiffening Plate Patching Method’ to avoid the duplication.

The details of ‘scraping’ shall be referred to the previous clause 5.4.2.1. (2) 1) iii) ‘Repainting’.

The edge of the crack shall be drilled with diameter 8 to 10mm. This is to prevent the rapid progress of the crack. It is emergency treatment and shall be repaired completely in near future. (See figure below)

The crack and the surface of drilled hole shall be coated with primer coating material to prevent the corrosion until the addition repair works is executed. (See figure below)

(Stop Hole) (Crack before Emergency Treatment) (After Drilling Stop Hole)

Figure 5.74 Example of Construction of Stop Hole

ii) Stiffening Plate Patching Method

Typical procedure and the points which require close attention of the stiffening plate patching method are demonstrated in previous clause, such as 5.4.2.1. (2) 1) 'Corrosion'.

iii) Replacement

Typical procedure and the points of require close attention of the replacement are demonstrated in previous clause, such as 5.4.2.1. (2) 1) 'Corrosion'.

3) Looseness/omission

Repair works explained in the previous clause 5.3.2.1. (2) 3) 'Looseness/omission' are three methods, such as replacement, covering, and refastening by new bolts. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses.

i) Replacing

The workflow is shown in the figure below.

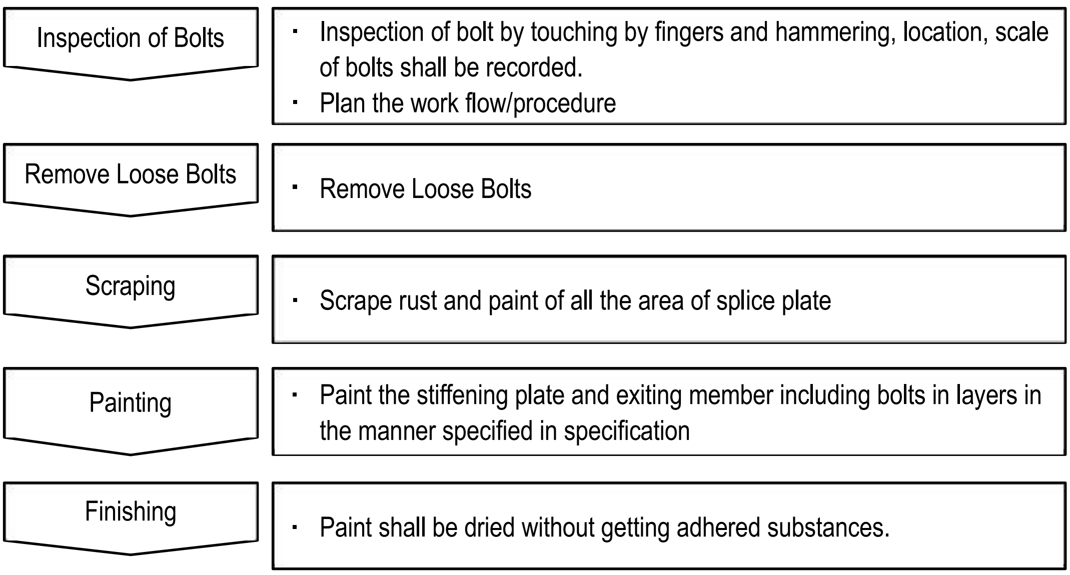
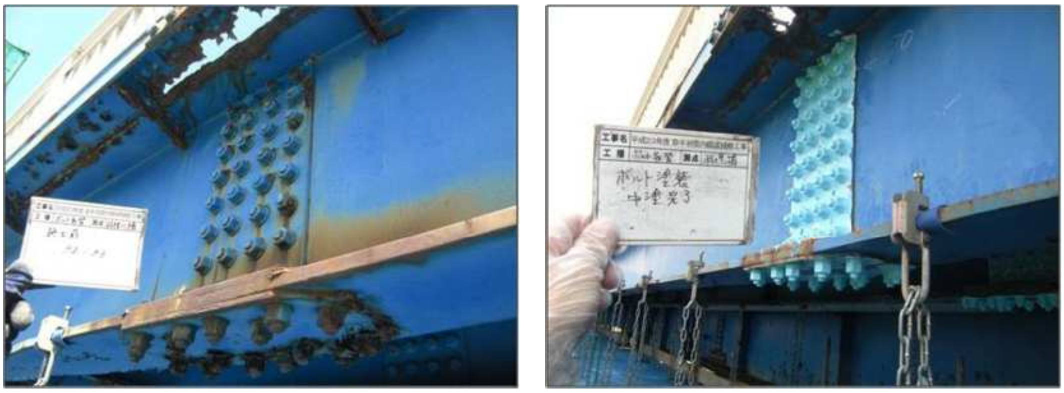


Figure 5.75 Workflow of Replacement of Loose Bolts

Up to the stage of 'inspection of bolts', the details shall be referred to the previous clause 5.4.2.1. (2) 1) i) 'Stiffening Plate Patching Method' to avoid the duplication.

It is better to remove the loose bolts by loosening them by torque. However, rusted bolts are not able to turn the nuts. In this case it shall be removed by cutting the bolts. Special attention is required not to damage the existing steel member.

The details of the stages after 'scraping' shall be referred to the previous clause 5.4.2.1. (2) 1) iii) 'Repainting'.



(before Replacing Bolts) (After Replacing Bolts with Repainting Splice Plate)

Figure 5.76 Example of Construction of Replacement of Loose Bolts

ii) Covering

The workflow is shown in the figure below.

Inspection of Bolts	· Inspection of bolt by touching by fingers and hammering, location, scale of bolts shall be recorded. · Plan the work flow/procedure
Remove Loose Bolts	· Remove Loose Bolts which can be replaced by hand
Installing the Cover	· Install the cover to both bolts and nuts. · Better to cover all the bolts on the splice plate · Replacing shall be planned and executed as early as possible

Figure 5.77 Workflow of Covering Loose Bolts

Up to the stage of 'inspection of bolts', the details shall be referred to the previous clause 5.4.2.1. (2) 1) i) 'Stiffening Plate Patching Method' to avoid the duplication.

In this method, loose bolts which can be replaced by hand are the only bolts to be removed.

Cover shall be procured from the manufacture and installed to every loosen bolts on the splice plate, or joint section. (See figure below)

(Cover for Nuts) (Cover for Bolts) (Actual Installation)

Figure 5.78 Example of Construction of Fall Prevention Cover for Bolts

iii) Refastening by new bolts

The workflow is shown in the figure below.

Inspection of Bolts	· Inspection of omission of bolts. Location, and scale of bolts shall be recorded. · Plan the work flow/procedure
Scraping	· Scrape rust and paint around the refastening area
Refastening	· Refasten the omission of the bolts by new bolts
Repainting	· Paint the stiffening plate and exiting member including bolts in layers in the manner specified in specification
Finishing	· Paint shall be dried without getting adhered substances.

Figure 5.79 Workflow of Refastening by New Bolts

Up to the stage of 'inspection of bolts', the details shall be referred to the previous clause 5.4.2.1. (2) 1) i) 'Stiffening Plate Patching Method' to avoid the duplication.

The details of the stages after 'scraping' shall be referred to the previous clause 5.4.2.1. (2) 1) iii) 'Repainting'. The inner surface of the holes shall be scraped as well.

New bolts which has equivalent strength with the existing bots are installed to the holes of missing bolts and refastened firmly following the technical specification of the bolts.

4) Fracture

Repair works explained in the previous clause 5.3.2.1. (2) 4) 'Fracture' are stiffening plate patching method and replacement. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses.

i) Stiffening Plate Patching Method

Typical procedure and the points which require close attention of the stiffening plate patching method are demonstrated in previous clause, such as 5.4.2.1. (2) 1) 'Corrosion'.

ii) Replacement.

Typical procedure and the points which require close attention of the stiffening plate patching method are demonstrated in previous clause, such as 5.4.2.1. (2) 1) i) 'Stiffening Plate Patching Method'.

5) Deterioration of Painting

Repair works explained in the previous clause 5.3.2.1. (2) 5) 'Deterioration of Painting' is Repainting. Typical procedure and the points which require close attention of the method is demonstrated as following clause.

i) Repainting

Typical procedure and the points which require close attention of the repainting are demonstrated in previous clause, such as 5.4.2.1. (2) 1) i) 'Stiffening Plate Patching Method'

5.4.2.2. Main Girder

(1) Concrete

The repair works of concrete girders is basically the same with the repair works of RCC deck slab (Refer to clause 5.4.2.1. (1) 'Concrete'). In case the PSC girder requires to be repaired, special attention is required not to damage PC cable and sheath during the actual construction.

(2) Steel

The repair works of steel girders is basically the same with the repair of steel deck slab (Refer to clause 5.4.2.1. (2) 'Steel'). However, the flange of the main girder shall be taken special care in repainting. The edge of the bottom flange shall be trimmed with curved surface. The edge with angle tends to have less thickness of paints and end up being the first points of corrosion.

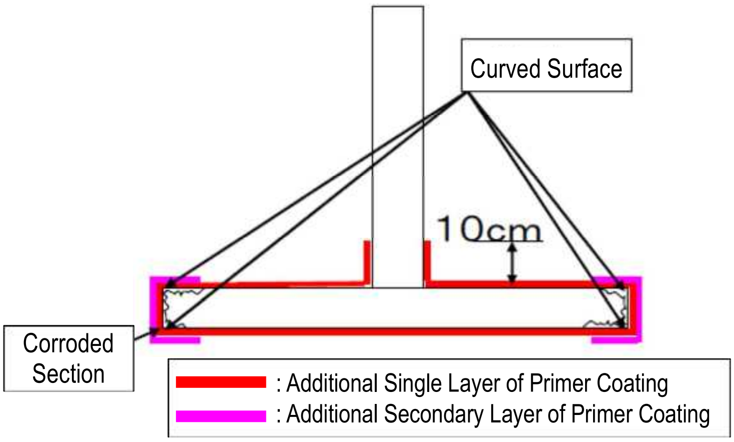


Figure 5.80 Additional Paining on the Bottom Flange

5.4.3. Substructure

Actual construction of repair works of the substructure is divided by its material. It is divided to 2 materials, such as Concrete (including RCC) and Masonry.

5.4.3.1. Concrete

Actual construction of repair works of concrete girders is basically the same with the design of RCC deck slab (Refer to clause 5.4.2.1. (1) 'Concrete').

1) Crack

Actual construction of repair works of crack on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.4.2.1. (1) 1) 'Crack').

2) Peeling/Rebar Exposure

Actual construction of repair works of crack on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.4.2.1. (1) 2) 'Peeling/Rebar Exposure').

3) Water Leakage/Free Lime

Actual construction of repair works of crack on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.4.2.1. (1) 3) 'Water Leakage/Free Lime').

4) Honeycomb

Actual construction of repair works of crack on concrete substructure is basically same with the methods of crack on concrete deck slab (Refer to clause 5.4.2.1. (1) 5) 'Honeycomb').

5.4.3.2. Masonry

Repair works explained in the previous clause 5.3.3.2. 'Masonry' are replacement with RCC retaining wall and re-patching. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses.

1) Replacement with RCC Retaining Wall

Replacement of the masonry substructure shall only be for some section and not for the entire section. Replacement of the entire section requires jack-up or replacement of the existing superstructure. It would require massive temporary structures and heavy machineries. Reimplementation of the new bridge is much cheaper than replacement of the entire masonry substructure.

The workflow is shown in the figure below.

Step	Description
Preparation	· Regulate the traffic during the construction · Confirm the latest status of the damage
Install Temporary Support for Superstructure	· Install temporary support structure for superstructure to release the load from superstructure, steel truss support · Regulate the traffic during the construction
Install Coffer Dam	· Coffer dam to secure dry and safe condition at the site · Embankment or steel sheet pile
Dry up the Site	· Dry up the site by using pumps
Remove the Cause	· Remove the cause of the damage · Regulation of heavy vehicle, reduce water behind the masonry, etc.
Remove Damaged Masonry	· Remove damaged area and its surrounding of masonry structure
Cast Lining Concrete for RCC Retaining Wall	· Cast lining concrete for the foundation of RCC retaining wall · Make sure the subsoil under the new RCC retaining wall has sufficient bearing capacity
Rebar arrangement	· Rebar arrangement of new RCC retaining wall
Casting Concrete	· Casting of concrete for new RCC retaining wall · Vibrating shall be done properly to secure the quality of cast-in-situ concrete
Finishing	· Curing for new RCC retaining wall · Accuracy checking of shape and quality in completion. · Remove the temporary support structure for superstructure and coffer dam

Figure 5.81 Workflow of Replacement with RCC Retaining Wall

As is stated in all the repair methods already mentioned above, the first thing you shall do for repair works of masonry substructure is also confirmation of the damage which is to be repaired. If the category of the damage has worsened or the quantity has increased considerably, contractor shall discuss with project owner the solution for it. If there is no change at the damage which would be repaired, the plan/schedule of the repair works shall be prepared by the contractor.

The traffic shall be regulated during the execution of this repair method because the bearing capacity of the substructure would be reduced during the construction. Heavy vehicles shall not pass the bridge during the construction period.

If the area/volume of replacement is large, there are high possibility of collapse of the backfill during the construction. Therefore, the superstructure shall be supported with the temporary support structure, such as steel truss support. In case if the construction is executed without temporary support of superstructure because the replacement are is small, the traffic shall be completely stopped during the construction, even the pedestrians. If there is no detour nearby, installation of temporary bridge shall be considered.

To secure the work place in front of the masonry substructure, coffer dam shall be installed and the river shall be dried up. If there are enough space in the river waterway, embankment could be installed for the cofferdam. If there is limited space, necessity of steel sheet pile shall be considered. In any case, the construction shall be done in dry season after the level of the river flow has decreased.

After drying up the riverbed in front of the masonry, the cause of the damage shall be removed. If the damage is due to the water flow behind the abutment, the drainage shall be improved.

The damaged masonry would be removed after removing the cause of the damage. Special care shall be taken in removing the members of masonry structure because small collapse of masonry members can derive massive collapse of the substructure due to its structure mechanism. This is one of the reason the temporary support of superstructure is recommended. Backfill of the masonry structure shall also be removed so that the RCC retaining wall can be casted.

Before casting the RCC retaining wall, the bearing layer of the retaining wall shall be checked to confirm that it has sufficient bearing capacity. Without confirming the bearing capacity, the casted RCC retaining wall could settle immediately or gradually after the casting of concrete. It would leave gap/crack between remaining masonry and new RCC retaining wall and induce the wash away of the backfill.

Rebar arrangement shall be done according to the shop drawing.

Vibrating the casted concrete shall be done properly. Vibrating by the vibrator is the best method, however it could be done by striking the form evenly if vibrator is difficult to procure. Proper vibration prevents honeycomb after the deforming. Workability (slump value, sufficient mixing, water-cement ratio, etc.) shall also be managed well for prevention of honeycomb. Joint shall not be made since the volume is limited in this repair method.

Casted concrete shall be cured until it is dried ad hardened. It is better to mix admixture for quick hardening so that the traffic regulation could be cancelled quickly. After curing the concrete, the form shall be removed, and the shape and quality of concrete shall be checked so that there are no gaps with the existing masonry substructure. If the RCC retaining wall is casted accurately, the temporary support for superstructure and coffer dam would be removed.

2) Re-patching

Re-patching includes repairing the cracks of the masonry structure.

The workflow is shown in the figure below.

Preparation	· Regulate the traffic during the construction · Confirm the latest status of the damage
Install Coffer Dam	· Coffer dam to secure dry and safe condition at the site · Embankment or steel sheet pile
Dry up the Site	· Dry up the site by using pumps
Remove the Cause	· Remove the cause of the damage · Regulation of heavy vehicle, reduce water behind the masonry, etc.
Remove Damaged Masonry	· Remove damaged area and its surrounding of masonry structure
Cleaning and Backfilling	· Clean the backfill soil and remove the loose soil · Backfill with mortar if necessary
Re-patching	· Re-patch the missing section by mortar or pre-cast blocks · Inject mortar to the gaps between pre-cast blocks
Finishing	· Curing for new mortar and injected materials · Accuracy checking of shape in completion. · Remove coffer dam

Figure 5.82 Workflow of Re-patching the Masonry Structure

Up to the stage of 'remove damaged masonry', the details shall be referred to the previous clause 5.4.3.2. 1) 'Replacement with RCC Retaining Wall' to avoid the duplication. However, the stage of 'Install Temporary Support for Superstructure' is not required for this repair method.

After removal of the damaged masonry member, the loose backfill shall be removed. If the considerable amount of backfill is loose, it shall be filled with mortar before re-patching.

Re-patching shall be done with mortar or pre-cast concrete blocks. It shall be made sure that there would not be gaps between backfill and re-patching materials. Mortar shall be injected sufficiently into the gaps between pre-cast concrete blocks.

Mortar shall be cured until it is dried. Coffer dam shall be removed after checking the construction quality at site.

(Repair of Cracks in front of Abutment)

(Re-patching of Masonry Structure)

Figure 5.83 Example of Construction of Repairing Masonry Revetment

5.4.4. Miscellaneous Members

Miscellaneous members which is explained in this subchapter are bearings, railings, wearing course, and expansion joint.

5.4.4.1. Bearing

Repair works of both rubber and steel bearing is explained in this subchapter.

(1) Bearing

Repair works explained in the previous clause 5.3.4.1. (1) 'Bearings' are replacement, detailed observation and monitoring. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses.

1) Replacement

Replacement of bearing requires jack up of the superstructure. It could not be done without jacking up the superstructure. The traffic has to be stopped or detoured during the construction. If there is not any detour bridge nearby, temporary bridge shall be installed to secure the local traffic.

The workflow is shown in the figure below.

Preparation	· Regulate the traffic during the construction · Install the temporary bridge if necessary
Jack up Superstructure	· Jack up superstructure from bridge seat · If the existing bearing is anchored firmly both superstructure and substructure, the anchor bolts shall be cut before jack up.
Remove Existing Bearings	· Remove the existing bearings · Anchor bolts shall be cut to remove steel bearings, it also require chipping concrete of bridge seat
Install New Bearings	· Install new bearings · Place it with anchor bolts or welding if necessary
Finishing Bridge Seat	· Filling chipped section with mortar · Cure the mortar till it harden sufficiently
Jack down Superstructure	· Jack down superstructure on the new bearings
Remove the Cause	· Remove the cause of the damage · Waterproofing the expansion joints, regulation of heavy vehicle, etc.

Figure 5.84 Workflow of Replacing the Existing Bearings

During the replacement of the bearings, traffic on the bridge shall be completely stopped including pedestrians. If there is not any detour nearby, installing the temporary bridge shall be considered.

Jacking up the superstructure shall be executed to replace the bearings. If the bearings are deeply anchored to both superstructure and substructure, it shall be separated with both superstructure and substructure by cutting the anchor before jacking up the superstructure. If it is difficult to cut the anchor bolts before jacking up due to space constraints, the existing bearing could be cut into 2 pieces, jack up the superstructure and cut the anchor bolts.

As soon as the superstructure is jacked up, the existing bearing shall be removed immediately.

As soon as the existing bearing is removed, the new bearing shall be installed and placed firmly by anchor bolts. It can also be welded to base plate, however it is not recommended to apply welding method due to the difficulty of quality control of welding at site.

As soon as the new bearing is firmly placed at the bridge seat, the superstructure shall be jacked down immediately. The total time length of jacking up the superstructure shall be minimized considering the safety of the construction site.

After the replacement of the bearing, the cause of previous damage shall be removed. If the cause is water flow from the surface of the bridge, applying waterproof expansion joint is very effective to shut down the water which wets bearing. If the cause is stress concentration, regulating the traffic shall be considered. However, it could also be solved by upgrading the specification of new bearing. It shall also be considered that the removing of the cause simultaneously with replacing the bearing while jacking up the superstructure. The timings of removing the cause shall be compared and the most effective and reasonable method shall be selected.

The end section of the superstructure is often damaged/deteriorated when the bearings require replacement. The repair of the end section shall be done together with the replacement of bearings. The specific repair method depends on the type and material of superstructure and relevant subchapter/clause shall be referred to for selecting the repair method.

(Jack Up) (Welding) (New Bearing)

Figure 5.85 Example of Construction of Replacement of Bearings (Steel Plate Girder)

(Damaged Bearing) (Placing Bottom Bearing) (New Bearing)

Figure 5.86 Example of Construction of Replacement of Bearings (PSC Girder)

2) Detailed Observation

There are common points of steel and rubber bearings to be observed and inspected for damaged bearings. There are also individual points to be observed in detailed observation. Table below shows the main observation points for the damaged bearing.

Table 5.12 Observation Points in Detailed Observation of Damaged Bearings

Types of Bearings	Observation Point	Cause
Common	· Dirt/rubbish Sedimentation · Crack · Deformation	· Non-waterproofed expansion joint, flood · Stress concentration · Stress concentration, corrosion, impact of debris
Steel	· Corrosion · Peeling of Paints	· Non-waterproofed expansion joint, antifreezing admixture, etc. · Corrosion inside the paint
Rubber	· Deterioration, hardening	· Non-waterproofed expansion joint

The scale and level shall be recorded as well as the information to determine the cause of the damage. Especially if the damage is caused by stress deformation, the structure and the location of the superstructure members near the damaged bearings shall be carefully recorded as the inspection drawings in detail.

The deterioration of the rubber can be observed by colour, touch, or hammering. It could be easily crumbled or lose elasticity.

Most of the cracks of the steel bearing is very difficult to be observed only by sight observation. For detailed observation, the clause 5.2.3.1 (2) 1) 'Corrosion' can be referred to for the details.

3) Monitoring

If the damage or noise of bearings are not severe, it can be monitored through the routine inspection. However, the damage of the bearings cannot be observed from the surface of the bridge. Therefore, if there are significant gap at the ends of the girders or settlement of the superstructure, it shall be suspected that the damage of the bearings has been progressed and the bearings under the damage of the surface shall be observed as soon as possible. The traffic shall be regulated if necessary.

(2) Base Mortar (Bearing Sheet)

Repair works explained in the previous clause 5.3.4.1. (2) 'Base Mortar (Bearing Sheet)' are detailed observation and monitoring, plastering, and cleaning. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses.

1) Detailed Observation

The points of base mortal of bearing shall be observed and inspected carefully. There are many cases that the bearing does not break considerably but the base mortar is extremely damaged. There are also individual points to be observed in detailed observation. Table below shows the main observation points for the damaged bearing.

In the detailed observation of base mortar, the scale and the category of the damage shall be inspected and recorded. If it is damaged severely and deep into the area underneath the bearings, it is suspected that the bearing capacity of the base mortar has been lost. Therefore the area of the damage is carefully inspected. If the damage is in small area, it could be repaired by plastering method (See the next clause for the details). If the damage is big and the bearing capacity of base mortar, superstructure and the existing bearing shall be temporarily removed.

Table 5.13 Observation Points in Detailed Observation of Damaged Base Mortar

Observation Point	Cause
· Dirt/rubbish Sedimentation · Crack · Peeling, Partial Loss	· Non-waterproofed expansion joint, flood · Stress concentration, impact of debris · Stress concentration, corrosion, impact of debris

2) Plastering Method

If the area of damaged of base mortar is small enough, it could be repaired by plastering method. The details are referred to the previous clause 5.4.2.1 (1) 2) i) ‘Plastering Method’.

3) Cleaning

If the damage is only sedimentation deposition, the existing bearing and its surrounding shall be cleaned to secure the movement which is defined in the original design. It is recommended to use water jet cleaner, however if it is difficult to procure, it could be cleaned without it manually using handy equipment. However, running water must be prepared to secure the removal of the sedimentation deposition completely.

5.4.4.2. Ancillary Facilities

Repair works of ancillary facilities such as railing is explained in this subchapter.

(1) Railing

Repair works explained in the previous clause 5.3.4.2. (1) ‘Railings’ are replacement, and grouting method. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses.

1) Replacement

Replacement of railing is selected when the ratio of damaged area is 50% and more of its cross section or the risk of the bridge users are severe.

The workflow is shown in the figure below.

Preparation	・ Regulate the traffic during the construction
Remove Existing Railing	・ Remove the existing Railing ・ Anchor bolts shall be cut or removed to remove steel railing
Drill Anchoring Holes	・ Drill anchoring holes to the existing curb ・ Place anchoring device prior to casting concrete if necessary
Rebar Arrangement and Forming	・ Rebar arrangement for RCC railing ・ Forming with necessary support for casting concrete at site
Casting and Curing Concrete or Place Steel Railing	・ Cast the concrete for new RCC railing ・ Cure the newly casted concrete ・ Place steel railing for steel railing
Deforming Anchoring	・ Deform and finish the surface of RCC railing ・ Anchor firmly and connect parts together by bolts for steel railing

Figure 5.87 Workflow of Replacing the Existing Railing

Traffic shall be regulated, such as 1 lane alternate traffic, to secure the work space on the surface of the bridge.

The existing railing shall be removed completely including the anchor bolts for steel railing anchored to the curb of the bridge or rebar anchored to the curb for RCC railing. Curb shall be chipped and the anchor bolts/rebar shall be cut.

Whichever material of the new railing, it shall be bound to the existing curb. To secure the firm bound, sufficient number and strength of new anchor bolts shall be installed to the existing curb.

In case of replacing with RCC railing, rebar shall be arranged and form shall be installed for casting concrete at site. Casted concrete shall have sufficient workability and shall be vibrated properly to avoid honeycomb. If there are joints of concrete member, it shall be casted subsequently to avoid cold joint. If it could not be casted subsequently, the surface of the old concrete shall be cleaned and chipped to prevent cold joint.

The casted concrete shall be cured until it is hardened and dried.

If it is replaced by steel railing. It shall be bound to the existing curb firmly by anchor bolts, the pieces of steel railing shall be connected by bolts firmly as well.

If the existing curb is chipped in this repair method, it shall be re-casted by grouting method. The details shall be referred to the previous clause 5.4.2.1 (1) 2) ii) 'Grouting Method'.

2) Grouting Method

Typical procedure and the points that require close attention of this grouting method are basically same with that are demonstrated in previous clause, such as 5.4.2.1 (1) 2) ii) 'Grouting Method'.

5.4.4.3. Deck Surface

Repair works of deck surface such as wearing course and expansion joint are explained in this subchapter.

(1) Wearing Course

The basic points that require close attention in repairing the wearing course is mentioned in the previous subchapter 4.3.5 Wearing Course, Pavement. If the wearing course is replaced by new wearing curse material, such as asphalt concrete, the existing RCC deck shall be waterproofed. There are two types of waterproofing product, one is sheet type and the other is bitumen type (See the figure below). However, the rapping section of sheet type shall be sealed by bitumen type as is shown in the figure below. Sheet type has advantage of quality control and rapid construction, on the other hand bitumen type exceeds in construction cost.

(Sheet type)

(Bitumen type)

Figure 5.88 Example of Construction of Waterproofing Existing RCC Deck

(2) Expansion Joint

Repair works explained in the previous clause 5.3.4.3. (2) 'Expansion Joint' are cleaning, replacement, detailed observation, and repaving. Typical procedure and the points which require close attention of these methods are demonstrated as following clauses.

1) Cleaning

If the expansion joint is clogged by dirt or other waste, it cannot secure the movement of the superstructure defined by original design caused by temperature, earthquake, brake of the vehicle, etc. Therefore, it shall be cleaned as early as possible. There are two methods of cleaning, one is by water jet and the other is manually using cleaning equipment. It is recommended to apply water jet considering the quality of the cleaning. However, if the clogged section is small and it can be removed easily, manual cleaning shall also be applied. Running water shall be prepared to improve the quality of cleaning in manual cleaning.

(Cleaning by Waterjet)

(Cleaning Manually)

Figure 5.89 Example of Cleaning Expansion Joint

2) Replacement

If the existing gap of expansion joint is separated or squeezed, or the existing expansion joint is partially broken, it shall be replaced by new expansion joint.

The workflow is shown in the figure below.

Step	Description
Preparation	· Regulate the traffic during the construction · Install the temporary bridge if necessary
Remove the Cause	· Remove the cause of the damage · Waterproofing the expansion joints, regulation of heavy vehicle, etc.
Remove Existing Bearings	· Remove the existing bearings · Cutting and chipping concrete of parapet of abutment and RCC deck slab. Wearing course is also to be removed
Smoothing the RCC surface	· Smoothing the RCC surface after removing the existing expansion joint · Primer coating
Setting New Expansion Joint	· Setting new expansion joint · Fixing before casting concrete, by welding or anchor bolts
Casting Concrete	· Cast concrete to fill the gap and fix new expansion joint · Cure the casted concrete until it is dried and hardened
Repavement	· Repave the surface to secure the smoothness of the bridge surface

Figure 5.90 Workflow of Replacing the Existing Expansion Joint

Traffic shall be regulated, such as 1 lane alternate traffic, to secure the work space on the surface of the bridge.

If the existing gap of expansion joint is separated or squeezed there shall be displacement of either abutment of superstructure or both. If the displacement has not stopped, there is not any justification of replacing with new expansion joint. The displacement of substructure/superstructure shall be stopped before the replacement.

If the cause of broken expansion joint is unevenness of the road surface next each other connected by the existing expansion joint, the unevenness shall be flattened before the replacement. The cause of the unevenness could be broken bearings, settlement/inclination of abutment, or etc.

In removing the existing expansion joint, anchor bolts shall be cut at site.

New anchor holes shall be drilled to bind the expansion joint with abutment/deck. It shall be taken care that rebar shall not be cut in drilling anchor holes. Location of rebar shall be confirmed using Electromagnetic Wave Radar (See details in previous clause 5.2.3.1 (1) 1) iv) 'Actual Rebar Arrangement Survey').

The exiting concrete surface shall be cleaned, levelled and primer coated to secure adhesiveness with newly casted concrete.

New expansion joint is set before casting concrete, by anchor bolts. Welding can be done to regulate the movement in casting concrete. Water proof type shall be applied so the surface water does not drain to bridge seat and prevent bearings, deck slab, and girder from deterioration.

Casted concrete shall have sufficient workability and shall be vibrated properly to avoid honeycomb. The size of the aggregate shall be limited to improve the workability.

The casted concrete shall be cured until it is hardened and dried.

To secure evenness of the bridge surface, repavement by asphalt concrete shall be executed around the newly installed expansion joint.

(Removing) (Anchor Bar, Rebar Arrangement) (Casting Rapid Hardening Concrete)

Figure 5.91 Example of Construction of Replacement of Expansion Joint

3) Detailed Observation

If there is unevenness of the road surface next each other connected by the existing expansion joint, the unevenness shall be observed in detail to define the reason of the unevenness. The cause of the unevenness could by broken bearings, settlement/inclination of abutment, or etc. If the gap is less than 2cm, warning sign to vehicle drivers shall be installed and the damage shall be monitored by routine inspection.

4) Repavement

If thee unevenness of the road surface next each other connected by the existing expansion joint is greater than 2cm, repavement to fill the gap shall be done to secure the safety to the traffic temporarily. This repair method is emergency maintenance. Therefore, the cause of the gap shall be defined by detailed observation and removed to repair the gap. In repairing the gap, the existing expansion joint shall be replaced by new expansion joint. The details of replacing expansion joint is explained in the previous clause 5.4.4.3. (2) 2) ‘Replacement’.

6. Strengthening Works

6.1. Planning

6.1.1. Mid-term Strengthening Plan

Strengthening shall be executed to the bridges/members which requires stronger strength than original design. To plan the mid-term strengthening plan of bridges in the highway network, the necessity of the strengthening of each bridge shall be judged based on the inventory information.

Generally speaking, necessity of strengthening raises when the design code of the bridge is upgraded, such as increase of live load or seismic load, decrease of bearing capacity of the soil strata, and etc. Superstructure shall have to resist to the bending moment caused by heavy vehicles which are not considered until the upgrade of the design code. Substructure shall have to resist to the seismic force caused by the earthquake which are not considered until the upgrade of the design code as well. Basically, all the bridges has possibility of having necessity of strengthening after the upgrade of the design code. Every bridge shall be reviewed to judge the necessity of the strengthening. Therefore, if the upgrade of the design code is severe, there would be more bridges which requires the strengthening.

Figure 6.1 Procedure of Mid-term Strengthening Plan

After the review of the existing bridges, the list of bridges which requires the strengthening shall be prepared for the further preparation of mid-term strengthening plan (Long list of strengthening Plan). To plan the mid-term plan, the priority of each bridges in the list shall be prepared. It would be obvious and easy to understand the procedure if the priority of the listed bridges are evaluated by points. Factors could be the importance of the route, traffic volume, existence of the detour bridge, ratio of the commercial vehicles, etc. Cost for strengthening works is indeed very important factor for the prioritization. However, it shall not be taken into account in this stage to realize the priority by the importance of the bridge.

After giving the priority to the bridges on the list, those bridges shall be divided into 3 to 5 groups according to the result of prioritization. 1st group with top priority, 2nd with high priority and so on. Rough cost estimation shall be done to the 1st group (2nd in some cases) to schedule the strengthening works in each bridges considering the budget procurement availability of the highway operation agency (DOR in case of Bhutan). Bridges in the long list of strengthening plan would be in order after this procedure. It can be divided into annual strengthening plan by considering annual budget of the highway operation agency.

6.1.2. Strengthening Plan of Individual Bridges

Planning the strengthening project of an individual bridge requires the original condition of the bridge. Therefore, design document, shop drawings, as-built drawing, and construction record shall be reviewed to define the original condition. Original condition would be the base of strengthening of the bridge/member.

The original design and condition shall be reviewed by updated design code to estimate roughly the scale of the strengthening works, such as strengthening method and the quantity of the works. This would be the basic information of strengthening project if the existing bridge remains as the original condition. The outline of the strengthening project could be planned by this information.

However, the bridge member deteriorates gradually during the operation. Therefore, many bridges are not in the original condition any more. The level of the deterioration shall be recognized to judge the technical feasibility of the strengthening. If the deterioration is severe, the bridge/member is no longer capable for the strengthening work. These bridges/members shall be replaced rather than strengthened.

Moreover, it shall have some damages which influence the strength of the bridge/member. Those members are weakened from the original condition just after the completion of construction. These damages shall be repaired before the strengthening work. It also shall be judged whether the repaired section could bear the increase of the stress by the strengthening work or not. If there is scarce possibility that the repair section could bear it, the members shall be replaced by new member which could bear the load of upgraded design code rather than being repaired.

To define and judge the technical feasibility of the strengthening, the current condition of the bridge shall be inspected in detail to evaluate and define the level of deterioration and the category of the damage. If the inspection results ensures the technical feasibility with reasonable cost, the damage shall be repaired before the strengthening works. The details shall be referred to Chapter 5. ‘Repair Works’.

While the damage is being repaired, the strengthening work shall be designed. Appropriate strengthening methods shall be selected technically and economically. It shall never exceed the cost of replacement of the member.

After the detailed design is executed, the construction contractor of the strengthening work shall be selected by bid and the actual execution of the strengthening work shall be commenced.

The procedure of planning strengthening project of individual bridge is described in the following figure.

Figure 6.2 Procedure of Strengthening Works (Individual Bridge)

In planning the strengthening project, the following item shall be assumed additional to the results of the periodic inspection. i) to iii) shall be done in detail with accuracy and iv) to viii) could be in tentative level. The details of ii) to iv) shall referred to the Chapter 5. ‘Repair Works’.

i) Scale of Members which would be strengthened
ii) Method of Detailed Observation
iii) Quantity and Cost of Detailed Observation
iv) Repair Project (if necessary)
v) Quantity and Cost of Detailed Design
vi) Alternatives of Strengthening Method
vii) Quantity and Cost of Strengthening works
viii) Overall Schedule of Strengthening Project

The contents mentioned above are all applied to the bridges which are properly designed by design code of the time that the bridge was implemented. However, there are number of bridges that does not satisfy the latest design code because of the implementation year, inappropriate design & construction. These bridges/members shall be strengthened when the design code is upgraded. There are 4 cases of strengthening which is explained in this manual as is described as follows,

Case (1) shows the strengthening of members which are constructed by the latest design code. It would be strengthened so that it would have the strength defined by updated design code. This case would be applied to the bridge which is rather new and properly constructed as the design result (see the figure below).

Case (2) shows the case of strengthening of member which is older than case (1). The member which would be strengthened are deteriorated and has lost the strength from the original condition. In this case the member shall be repaired to the original condition and strengthened to have the strength by upgraded design code (see the figure below).

Case (3) shows the case of strengthening of member which is very old and only has the strength of the previous design code. These members are surely deteriorated but it could be sound to be strengthened, such as main body of RCC substructure. The damage shall be repaired to the original condition and then strengthened to meet the upgraded design code (see the figure below).

Case (4) shows the case of rather new member but does not satisfy the required strength. It can be happened mainly by bad design or malconstruction. In this case, the member shall be STRENGTHENED to have originally required strength and also to have the strength by upgraded design code. These two step of strengthening could be done at once if the member can bear the stress due to the strengthening (see the figure below).

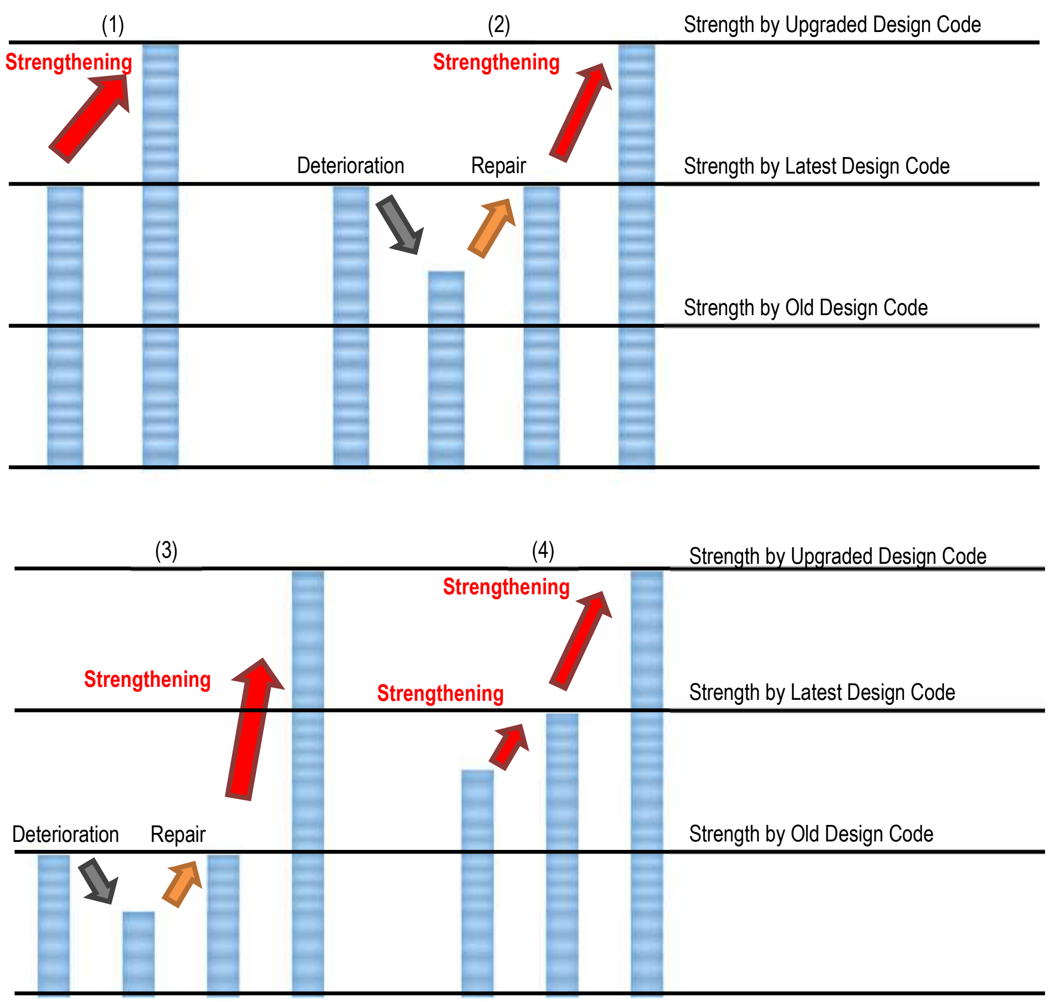


Figure 6.3 Cases of Strengthening treated in This Manual

6.2. Design

This manual explains 3 strengthening measures, such as ‘Strengthening against Live Load Increase’, ‘Strengthening against Seismic Load Increase’, and ‘Strengthening against Flood Discharge Increase’. Bridges constitutes section of the road network and closure of the bridge disconnects the communication among the regions. Sustainability of the soundness of the bridge is very indispensable for inhabitants’ everyday life and also for the development of the regional economy along the route. Collapse of the bridge is the most critical accident in the maintenance of the bridges.

There are mainly 3 causes of collapse of bridge, which are over loaded vehicle(s) passing, strong earthquakes, and violent flood flow. Bhutan as a whole country is suffering from closure of the bridge caused by these social/natural phenomenon and numerous number of the bridges shall be strengthened so that they could bear the accident/disaster.

In addition to the 3 strengthening measures, ‘waterproofing’ is explained in this manual. There are many damages due to water leaking and infiltration. The bridge member shall be kept dry at the section where there could be a cause of damages by water, such as crack of concrete, corrosion of steel members, deterioration of bearings, and etc. Considerable number of damages could be reduced if the water is drained properly.

6.2.1. Strengthening against Live Load Increase

If the technology and economy develops, the carrying capacity of goods by freight/cargo transportation vehicle increases and simultaneously the size/weight of the freight vehicle increases. It means that the axel/live load by heavy vehicles would increase in proportion to the increase of weight and carrying capacity of the freight vehicles. The bridge’s capacity against live load shall also be increased at the same time to enjoy the fruit of the increase of efficient cargo transportation for the regional economic development.

Methodology to resist against live load is basically to increase bearing capacity of bending moment of superstructure. If the superstructure is sustained by the bearings and not connected to substructure rigidly, this would be the case. If the superstructure is rigidly connected with substructure, the increase of bending moment could be occurred in substructure. This manual treats the former case which the superstructure is sustained by bearings that is the structure of the majority of the bridges in Bhutan, which are managed by DOR especially.

There are mainly 2 members to be strengthened, one is main girder and the other is deck slab.

6.2.1.1. Strengthening of Main Girders

There are 'Outer Cable Method' and 'CFRP Plate Bonding (Pre-tension) Method' for RCC/PSC main girders. Steel main girders could also be strengthened by 2 methods which could be applied to RCC/PSC main girders, and also 'Additional Plate Girder Method' could be applied. The outline and advantage/disadvantage, is summarized in the table below.

Table 6.1 Strengthening Method of Main Girders

	Outer Cable Method	CFRP Plate Bonding (Pre-tension) Method	Additional Plate Girder Method
Applied to	RCC/PSC main girders, Steel girders	RCC/PSC main girders, Steel girders	Steel plate girders
Outline	Install outer cable longitudinally and load tension force to the cable. It loads compressive force to the girders to resist against Bending Moment	Set CFRP Plate longitudinally, load tension force to the CFRP Plate, and bond the CFRP Plate to the girder. It loads compressive force to the girders to resist against Bending Moment	Install additional steel plate girders between/outside of the exiting steel plate girders and jointed with cross and stiffening girders. Increased bending moment would be distributed to additional girders.
Image			
Advantage	- Cheapest construction cost for RCC/PSC girders	- Smallest dead load increase - Less anchor bolts to the existing girder than outer cable method	- Cheapest construction cost - No additional compressive stress to the existing girders
Disadvantage	- Considerable additional compressive stress to the existing girders - Dead load increase is larger than CFRP Plate	- Construction cost is high - Considerable additional compressive stress to the existing girders - Require trained skills	- Biggest dead load increase - Longest construction period - Complicated construction procedure
Important Points in Design	- Soundness of the existing concrete - Increase of compressive stress to the existing concrete - Location of anchorage and deviator of outer cable - Details of anchor bolts to anchorage and deviator	- Soundness of the existing concrete - Increase of compressive stress to the existing concrete - Location of anchorage of outer cable - Details of anchor bolts to anchorage	- Location of additional girder - How to connect with existing girder - How to bind with existing RCC slab - Construction planning

6.2.1.2. Strengthening of RCC Deck Slab

For deck slab, RCC deck slab could be strengthened by various methods. There are ‘RCC Thickening Method (Lower side and Upper side)’, ‘Steel Plate Bonding Method’, and ‘CFRP Bonding Method’. The outline and advantage/disadvantage, is summarized in the table below.

Table 6.2 Strengthening Method of RCC Slab Deck

	RCC Thickening Method (Lower side and Upper side)	Steel Plate Bonding Method	CFRP Bonding Method
Applied to	RCC deck slab	RCC deck slab	RCC deck slab
Outline	Increase the thickness of the deck slab by casing additional RCC deck slab. It can be done both from lower and upper side.	Bond steel plate at the bottom surface of the RCC deck slab.	Bond CFRP plate in grid shape at the bottom surface of the RCC deck slab.
Image	 (Bottom side)		
Advantage	- Upper side thickening is the cheapest and bottom side thickening is the second cheapest in construction cost - Easiest quality control (upper side)	- Rapid construction period - Cheaper construction cost than CFRP - Small increase of dead load	- Rapid construction period - Smallest increase of dead load - Grid shape bonding ensures the inspection availability of the existing RCC deck slab after the strengthening construction is completed.
Disadvantage	- Existing RCC deck slab cannot be inspected directly after the strengthening construction is completed. (bottom side) - Longest closure of the bridge (upper side) - Large increase of dead load	- Existing RCC deck slab cannot be inspected directly after the strengthening construction is completed. (It is not applied very much anymore due to this reason in Japan)	- High construction cost - Bonding requires trained skill - There is a method bonding the entire bottom surface but it cannot inspect the existing slab directly. Therefore it is not applied much anymore in Japan.
Important Points in Design	- The details of connecting with existing RCC slab	- The details of connecting with existing RCC slab - Measuring exact length of bottom surface for fabrication of steel plate	- Measuring exact length of bottom surface for fabrication of CFRP sheets

The RCC deck slab can be replaced by new RCC deck slab or precast PSC deck slab. Both methods require long period of closure of the bridge. However, the quality of the strengthening is very high. Precast PSC deck slab has stronger durability than RCC deck slab and it would decrease the maintenance cost for the future. It is one of the preventive maintenance.

6.2.2. Strengthening against Seismic Load Increase

Severe damages occurred by strong earthquake could be divided into 4 groups, such as collapse of spread foundation, collapse of substructure (column of pier, wall of abutment), collapse of bearing, and fall of superstructure. The outline of the strengthening to prevent these damages is described as follows,

6.2.2.1. Strengthening of Foundation

(1) Spread foundation

Collapse of spread foundation could be prevented by increasing the cross section of the footing and area of bottom surface of the footing. The details of connecting device of additional section and the existing section and surface treatment of the existing footing shall be studied and designed in detail. It shall secure the rigidity of connection.

(2) Pile/Caisson foundation

The collapse of pile foundation and well foundation could be happened by the earthquake as well. Method of reinforcing pile foundation is to increase numbers of piles.

Reinforcing caisson foundation would be very difficult and massive construction work. It can be done by driving steel pile sheet pile around the existing caisson and connect each other firmly. The soundness of exiting caisson foundation shall be sufficient to execute this strengthening method. However, it is very difficult to inspect and confirm the soundness of the existing caisson foundation. Therefore, applying this method is very limited to special occasions. Realistic solution for strengthening caisson foundation is to replace the entire bridge.

6.2.2.2. Strengthening of Substructure

(1) Pier Column

There are two types of collapse of pier column, one is by bending moment and one is by sheer. Both are obviously recognized by sight. Collapse section runs horizontally when it is collapsed by bending moment and diagonally by sheer. Strengthening method against bending moment is to increase the cross section of the column, therefore it is basically by wrapping the column with additional materials, such as RCC, steel plate, and CFRP. Strengthening method against sheer is to regulate the relative displacement of sections within single column. It could be strengthened by rapping new materials as same as method against bending moment and it could be wrapped around by cables as well.

(Bending Moment)

(Sheer)

Figure 6.4 Example of Collapse of Pier Column

(2) Abutment wall

Abutment wall could be strengthened by thickening the wall on front side. This would increase the dead load of the abutment which the existing foundation shall bear. If the abutment is spread foundation. The foundation could be strengthened simultaneously. If the abutment has pile foundation, the pile has to be added to strengthen the foundation and requires considerable amount of construction cost. There is another method to strengthen abutment wall by setting the ground anchor and distribute the seismic load to the bearing soil of the ground anchor. The existence of the firm soil layer nearby is essential to apply this method.

6.2.2.3. Strengthening of Bearings

Superstructures are sustained by bearings if it is not rigidly connected to substructure. Majority of the bridge has its superstructure and substructure separated and superstructure sustained by bearings. Bearings are often damaged severely by earthquake and leave big gaps on bridge surface. Even the other members of the bridge are sound after the struck of the earthquake, vehicles cannot pass the bridge because of these gaps produced by earthquake. Strengthening method of the bearing is replacement of the bearing with higher specification.

If the superstructure is continuous single span structure, superstructures of spans adjacent to others could be rigidly connected together, the bearing could be replaced by horizontal force dispersing bearings or seismic isolation bearings. These bearings control the horizontal force loaded to substructure by superstructure and reduce the scale of strengthening of substructure/foundation. It could be more economical and effective than reinforcing only substructure/foundation in total.

6.2.2.4. Strengthening to Prevent Fall of Superstructure

Simple span superstructure is the most fragile structure for fall of superstructure. It can be fallen by collapse of foundation, column, and abutment wall, and also by displacement of superstructure. The strengthening method of preventing superstructure from falling is to limit the relative displacement of superstructure with substructure by compressive or tension force. The former is installing steel/RCC brackets to the superstructure so that the displacement of the superstructure would be limited to the location of the bracket. The latter is to connect the superstructure with substructure by cable or chain.

Table 6.3 Strengthening Method to Prevent Fall of Superstructure

	Compressive Force	Tension Force (Cable)	Tension Force (Chain)
Outline	Steel/RCC bracket attached to superstructure	Connect superstructure with substructure by cable	Connect superstructure with substructure by chain
Image			

There is another simple method to prevent superstructure from falling is to widen the width of bridge seat both on abutment and pier. This method is often applied together with the fall prevention devices mentioned in the table below. It can be applied alone for short span bridges with small possibility of massive displacement. Images of widening of bridge seat are shown below.

(Combination with Other Device)

(Widening Alone)

Figure 6.5 Example of Widening of Bridge Seat

6.2.3. Strengthening against Flood Discharge Increase

River in Bhutan increases flood discharge dramatically in rainy season and the substructure of the bridge are facing very severe risk of scouring. However, not all of the substructure is protected from the risk of it. Even it is protected, it is covered by riprap or gabion and it could be washed away in the following rainy season due to its poor durability. There are some locations that has RCC retailing wall covering the substructure, but the size is small and not protecting the substructure sufficiently.

Covering these substructures which are facing the risk of scouring caused by very violent flood discharge is one of the easiest and cheapest method of strengthening against flood discharge increase. The recommended area of protection is shown in the previous clause 5.3.1. (3) ‘Scouring’.

Backfill of abutments are also facing the risk of washed away by the flood discharge. The method of reinforcing to reduce this risk is widening the cross section of flood flow by extending the bridge length. Additional span behind the abutment is one option. However, it would require long period of closure of the existing bridge and requires temporally bridge for detour. Constructing new bridge aside/nearby is likely to be applied instead of constructing additional span behind the abutment.

Whichever method (additional span to the existing bridge or replacement by new bridge) is taken, the new cross section of flood shall have sufficient area to discharge the design flood discharge of 50-year return period for the bridge on arterial routes and of 20-years return period for the other highways.

Table 6.4 Strengthening Method against Flood Flow

Damage	Countermeasure	Strengthening Method	Remarks
Scouring and Wash-away of river bank/bed	Install stronger protection of river bank/bed	Install sufficient size of RCC retaining wall	Top of RCC retaining wall shall be higher than HWL (at least 1m for big rivers, 50cm for minor rivers)
Backfill Wash-away	Increase cross section of food discharge	- Additional span behind abutment - Replace entire bridge	Constructing additional span requires temporary bridge and long period of bridge closure.

6.2.4. Waterproofing

Most of damages of RCC members is fully or partially by water infiltrating into the member. It accelerate the corrosion of rebar inside and growth of cracks. RCC deck are easily wetted by rainfall and the water would infiltrate to the deck slab. This is one of the most critical cause of the damage of the RCC deck slab equivalently severe with overloaded freight/cargo transportation vehicles. Waterproofing the top surface of the RCC deck is mandatory regulation in most of the countries in the world because it could prevent the damages of RCC deck slab significantly.

When the wearing course (base course and surface course) of the bridge is repaved for the entire surface of a span/bridge, the waterproofing of the corner shall be executed in specific method. Multiple layers of waterproofing material shall be added to the corner waterproofing. If the corner is down stream of the surface drainage, drain pipe shall be installed to collect the water and drain to drainage basin. The example of the waterproofing of corner at the curb of side walk is demonstrated in the following figure.

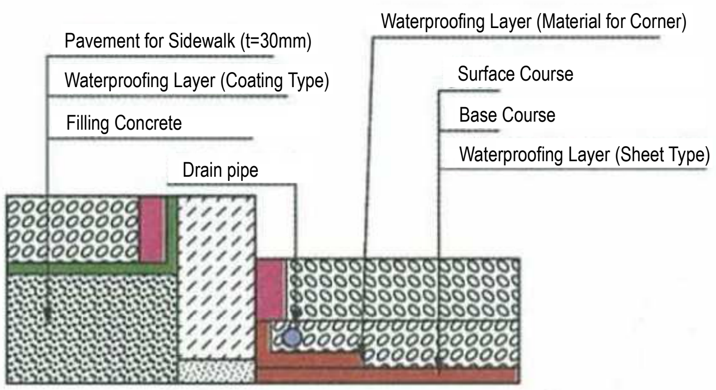


Figure 6.6 Example of Drainage Structure at the Corner of Curb

The following figure shows an example of drainage plan of a bridge. Drain pipes are set at the corners of slope end attached to curb or expansion joint. Drain duct shall be installed if the surface water cannot be drained directly to drainage basin. Interval of the drainage basin and drain duct shall be design by drainage design based on the design precipitation and slope and scale (length/width) of the bridge.

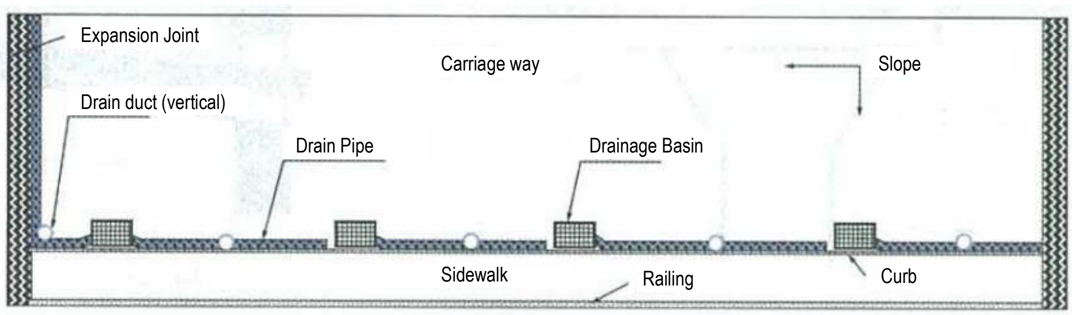


Figure 6.7 Example of Drainage Plan for Bridge

One more member of bridge which shall be waterproofed is expansion joints. Ordinary expansion joint does not have drainage gutter under the expansion joint structure. Therefore, the surface water drain through the expansion joint and wet the bearings and bridge seat. Debris and dirt go through with the water. Therefore, debris and dirt would be left on the bridge seat as sedimentation deposition and corrode steel bearings, deteriorate rubber bearings, or/and damages the bridge seat. Replacing the expansion joint with expansion joint with waterproof function can retard the corrosion/deterioration of bearing and bridge seats. It is one of the preventive maintenance method which is easily executed.

6.3. Strengthening Works

As is explained in the previous subchapter 6.2 ‘Design’, there are 4 subchapters of strengthening measures. Procedures and points to be taken care of in actual construction works explained in the previous subchapter 6.2 ‘Design’ are explained in this subchapter.

6.3.1. Strengthening against Live Load Increase

There are 2 main bridge member that shall be strengthened against live load increase, one is main girder and the other is RCC deck slab.

6.3.1.1. Strengthening of Main Girders

3 strengthening method is explained in the previous subchapter 6.2.1.1 ‘Strengthening of Main Girders’. Procedures and points to be taken care of in actual construction works of each methods are described as follows,

(1) Outer Cable Method

The workflow for concrete main girder is shown in the figure below.

Preparation	・ Inspection of condition of main girder (damage, compressive strength) ・ Control the condition of stocks of materials ・ Regulate the traffic and set the scaffoldings for the site works
Identifying Location of Rebar/PC cable	・ Identify the location of rebar/PC cable by electromagnetic wave radar. ・ Make sure not to drill where there are rebar/PC cables
Drilling Anchoring Holes	・ Drill the holes for anchor bolts and clean inside by vacuum and brush
Installing Anchorage	・ Anchor and cure the anchor bolts following the procedure written in the technical specification of the product ・ Install steel anchorage device to the anchor bolts
Installing Deviator	・ Anchor and cure the anchor bolts following the procedure written in the technical specification of the product ・ Install steel deviator to the anchor bolts
Installing PC Cable and Prestressing	・ Set the PC cable at anchorage and deviator without damaging the cable ・ Load the tension to the PC cable from the both side simultaneously
Rust Prevention Works of PC-Cable	・ Coat the PC cable, anchorage device, and deviator
Finishing	・ Remove the scaffoldings and open the bridge to traffic

Figure 6.8 Workflow of Outer Cable Method

(Drilling Anchoring Holes)

(Installing Anchorage)

(Prestressing)

Figure 6.9 Example of Construction of Outer Cable Method

The anchorage could be RCC structure. Forming and casting as it is required in the case. However, there would be strong force concentrated to the anchorage. Quality control requires extensive experience as well as actual works at the site.

The workflow for the steel main girder is similar to that for concrete main girder. It connects the anchorage and deviator with bolts and drilling hole to the web member. The sheer force produced to the main girder by the outer cable shall be reviewed and main girder shall be strengthened to resist it if necessary.

Construction of outer cable method requires trained skill and experience of both engineer and workers. The existence of these personnel shall be mandatory to apply and execute this method. It is better to procure labour with the product recommended by the manufacture.

Outer cable method is one of the strengthening method to strengthen cantilever girders. Intermediate girder would be sustained by the outer cable and strengthened against the live load increase. However, cantilever girder cannot resist increase of compressive force. Therefore, the anchorage shall not be installed at the girder. It shall be separately installed to other structure independently stable.

(2) CFRP Plate Bonding (Pre-tension) Method

The workflow for concrete main girder is shown in the figure below.

Step	Description
Preparation	・ Inspection of condition of main girder (damage, compressive strength) ・ Control the condition of stocks of materials ・ Regulate the traffic and set the scaffoldings for the site works
Identifying Location of Rebar/PC cable	・ Identify the location of rebar/PC cable by electromagnetic wave radar. ・ Make sure not to drill where there are rebar/PC cables
Drilling Anchoring Holes	・ Drill the holes for anchor bolts and clean inside by vacuum and brush
Installing Anchorage	・ Anchor and cure the anchor bolts following the procedure written in the technical specification of the product ・ Install steel anchorage device to the anchor bolts
Primer Coating	・ Clean and chip the surface of the main girder to secure the adhesiveness with the CFRP plate ・ Coat the surface of the main girder with primer painting material
Installing CFRP Plate	・ Set the CFRP plate at anchorage ・ Set intermediate fixing device with equal intervals
Prestressing and Adhering CFRP Plate	・ Load the tension to the CFRP plate from the both side simultaneously ・ Adhere the CFRP plate to the main girder by adhesive specified in the technical specification
Final Coating	・ Coat the CFRP plate and main girder's surface with final coating material
Rust Prevention Works of Anchorage	・ Coat anchorage by rust prevention coating material
Finishing	・ Remove the scaffoldings and open the bridge to traffic

Figure 6.10 Workflow of CFRP Plate Bonding (Pre-tension) Method

(Drilling Anchoring Holes) (Installing CFRP Plate) (Prestressing)

Figure 6.11 Example of Construction of CFRP Plate Bonding (Pre-tension) Method

Construction of CFRP plate method requires trained skill and experience of both engineer and workers. The existence of these personnel shall be mandatory to apply and execute this method. It is better to procure labour with the product recommended by the manufacture.

(3) Additional Plate Girder Method

To plan the procedure of additional plate girder method requires the great deal of steel superstructure because it requires separating jointed plate girders and install the new plated girder in between, or outside of, the existing girder. Unexpected force could be produced in disjointing the cross beams and stiffening girder. The order of disjointing and re-jointing is tailor maid so it is difficult to generalize.

Construction of additional plate girder method requires trained skill and experience of both engineer and workers much more than other 2 methods of strengthening against live load increase to main girder. The existence of these personnel shall be mandatory to apply and execute this method. It is better to procure labour from overseas with rich experience of similar strengthening projects.

6.3.1.2. Strengthening of RCC Deck Slab

3 strengthening method is explained in the previous subchapter 6.2.1.2 ‘Strengthening of RCC Deck Slab’. Procedures and points to be taken care of in actual construction works of each methods are described as follows,

(1) RCC Deck Slab Thickening Method

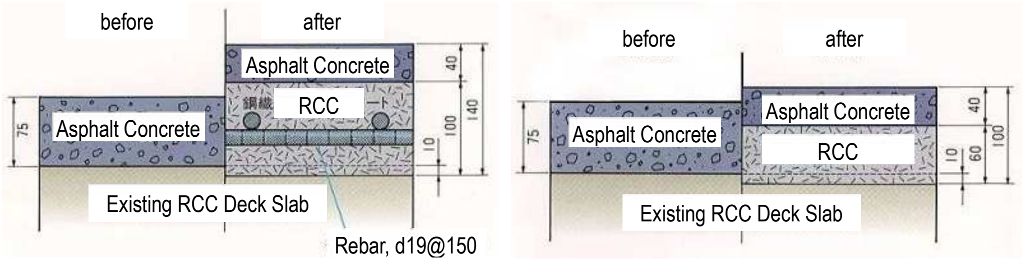
There are 2 method of RCC deck slab thickening method, such as upper side thickening method and bottom side thickening method.

1) Upper Side

The workflow is shown in the figure below.

Preparation	・ Inspection of condition of RCC deck slab (damage, compressive strength) ・ Regulate the traffic
Remove the wearing course, waterproofing layer	・ Remove wearing course, waterproofing layer and expose the top surface of the RCC deck slab
Surface Preparation	・ Blast or chip the surface of RCC deck slab about 10mm to secure the adhesiveness with additional RCC slab
Primer Coating	・ Coat the prepared RCC deck slab with primer coating materials to secure the adhesiveness with additional RCC slab
Rebar Arrangement	・ Rebar arrangement for additional RCC slab
Casting Concrete	・ Cast concrete on the existing RCC slab ・ Cure the casted concrete until it is hardened and dried
Waterproofing the RCC Deck Slab	・ Waterproof the top surface of the additional RCC slab, thicker layer at the corner with the curb ・ Set drain pipe at the corner with curb at the downstream end.
Wearing Course	・ Pave the bridge surface with base course and surface course ・ Cure the wearing course until it is dried
Finishing	・ Mark the road marking ・ Open bridge to the traffic

Figure 6.12 Workflow of RCC Deck Slab Thickening Method (Upper Side)



(Layer Structure with Rebar) (Layer Structure without Rebar)

Figure 6.13 Typical Layer Structure of RCC Deck Slab Thickening Method

(Casting Concrete w/o rebar)

(Casting Concrete with rebar)

(Levelling Concrete)

(Levelling Concrete)

Figure 6.14 Example of Construction of RCC Deck Slab Thickening Method

It requires special casing machine for casting the concrete. Therefore, it has advantage in long viaducts. RCC could be replaced to FRC (fibre strengthened concrete). It can reduce the amount of rebar and shorten the construction period.

If RCC could be replaced by SFRC (Steel Fibre Reinforced Concrete), it can reduce additional rebar amount, specifically the strengthening without rebar. Due to increase of the thickness of the slab, the existing rebar could not bear the stress in some case. Applying SFRC could avoid tensile stress induced to the rebar from exceeding the limit.

2) Lower Side

The workflow is shown in the figure below.

Preparation	· Inspection of condition of RCC deck slab (damage, compressive strength) · Regulate the traffic · Install scaffolding to secure the working space
Waterproofing	· Waterproof RCC deck slab from top surface to remove the cause of the damage or its possibility
Surface Preparation	· Clean the surface of the bottom surface · Blast or chip the surface of RCC deck slab to secure the adhesiveness with additional RCC slab
Primer Coating	· Coat the prepared RCC deck slab with primer coating materials to secure the adhesiveness with additional RCC slab
Rebar Arrangement	· Rebar arrangement for additional RCC slab
Casting Concrete by Shotcrete	· Cast concrete to the existing RCC slab by shotcrete
Plastering	· Plaster and level the surface of the shotcrete
Curing	· Placed material shall be cured till it is dried
Finishing	· Remove Scaffolding · Open bridge to the traffic

Figure 6.15 Workflow of RCC Deck Slab Thickening Method (Bottom Side)

(Rebar arrangement) (Casting Shotcrete) (Finishing)

Figure 6.16 Example of Construction of RCC Deck Slab Thickening Method (Bottom Side)

Actual construction works of RCC Deck Slab Thickening Method (Bottom Side) is very similar to the construction works of shotcreting method of repair of peeling/rebar expose. See the details of the previous clause 5.4.2.1 (1) 2) iii) ‘Shotcrete Method’

(2) Steel Plate Bonding Method

Up to the stage of 'surface preparation', the details shall be referred to the previous clause 6.3.1.2. (1) 2) 'RCC Deck Slab Thickening Method (Bottom Side)' to avoid the duplication.

After the surface preparation is done, the holes of anchor bolts to bound the steel plate to the bottom surface of the RCC deck is drilled. The gap between steel plate and the bottom surface of the RCC deck is grouted by adhesive material.

The plate shall be fabricated specifically for the grouting work and the actual construction requires trained skill. It cover up totally the existing RCC deck slab and would not be observed directly by sight any more. Due to this reason, it shall be applied to the location where the other methods are difficult to apply.

The crack is generally caused by infiltration of water from deck surface. Therefore, waterproofing from top surface shall be executed

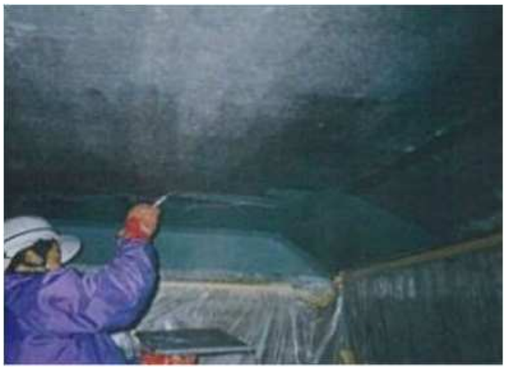
(3) CFRP Sheet Bonding Method

The workflow is shown in the figure below.

Preparation	· Inspection of condition of RCC deck slab (damage, compressive strength) · Regulate the traffic · Install scaffolding to secure the working space
Waterproofing	· Waterproof RCC deck slab from top surface to remove the cause of the damage or its possibility
Surface Preparation	· Clean the surface of the bottom surface · Blast or chip the surface of RCC deck slab to secure the adhesiveness with CFRP sheet
Primer Coating	· Coat the prepared RCC deck slab with primer coating materials to secure the adhesiveness with additional RCC slab
Unevenness Adjusting	· Coat the RCC deck slab surface with unevenness adjusting material, such as putty
Adhering CFRP sheet	· Adhere the CFRP sheet in grid shape · Adhere multiple layers according to the design result · The procedure and direction of adhering shall follow the technical specification of the product.
Final Coating	· Coat the CFRP sheet with final coating materials
Finishing	· Remove Scaffolding · Open bridge to the traffic

Figure 6.17 Workflow of CFRP Bonding Method

(Primer Coating)



(Unevenness Adjusting)

(Adhering CFRP Sheet)

(Finishing)

Figure 6.18 Example of Construction of CFRP Bonding Method

The crack is generally caused by infiltration of water from deck surface. Therefore, waterproofing from top surface shall be executed

The grid shape of adhering the CFRP sheet is to secure the visibility of the existing slab after the strengthening works are completed. It could easily observe if the existing slab is deteriorated/damaged again in the future. There are a method adhering CFRP sheet to the entire surface of the existing slab. However, it would lose the visibility of the existing slab to observe the condition of the existing slab. Even the strengthening efficiency is high covering the entire surface, it shall be applied to the location where the other methods are difficult to apply.

Construction of CFRP bonding method requires trained skill and experience of both engineer and workers. The existence of these personnel shall be mandatory to apply and execute this method. It is better to procure labour with the product recommended by the manufacture.

6.3.2. Strengthening against Seismic Load Increase

There are 4 main bridge members that shall be strengthened against seismic load increase, 1st is foundation, 2nd is substructure, 3rd is bearings, and the last is to prevent superstructure from falling down to the ground.

6.3.2.1. Strengthening of Foundation

(1) Spread foundation

To strengthen the foundation, there are 2 purposes of strengthening. One is to increase the bearing capacity, and the other is to increase capacity to resist against the sectional force, such as bending moment and shear.

To increase bearing capacity, the bottom surface of the footing shall be enlarged. Sufficient anchorage rebar shall be penetrated to the existing footing to secure the rigid connectivity between the existing footing and the newly casted footing. This strengthening is to increase the size in plan. It is recommended that the direction of enlargement shall be equal in all directions.

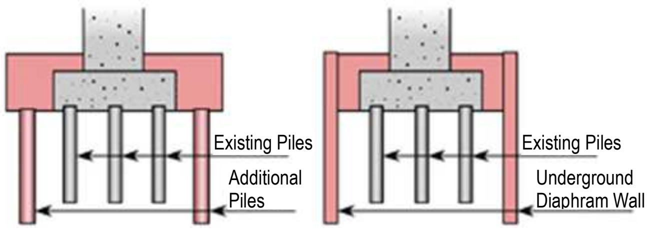
Due to the increase of the size in plan, cross sectional force would also increase. If the existing footing cannot bear the cross sectional force produced by the new footing. It shall be strengthened by thickening the footing and adding shear strengthening.

To realize this method, the entire footing shall be opened by excavating the cover soil. It means that the bridge would be closed for the entire construction period. Temporary bridge shall be installed if there is no detour bridges nearby.

(2) Pile/Caisson foundation

Reinforcing pile foundation, adding the piles and connect to the existing structure by connecting the footing is common method to applied. Additional piles could be replaced by underground diaphragm walls. Securing the connectedness between the existing footing and the newly casted footing is very important in increasing the bearing capacity of the pile foundation.

Both method usually requires thickening of the footing and shear strengthening. It means that the bridge would be closed for the entire construction period. Temporary bridge shall be installed if there is no detour bridges nearby.



(Additional piles) (Underground diaphragm walls)

Figure 6.19 Example of Strengthening Method of Pile Foundation

Reinforcing the caisson (well) foundation could be done by addition steel pile sheet pile foundation and connect to the existing caisson cup. It requires machinery for driving steel pile sheet piles and it could not be executed at the location where large size gravel exist in the soil.

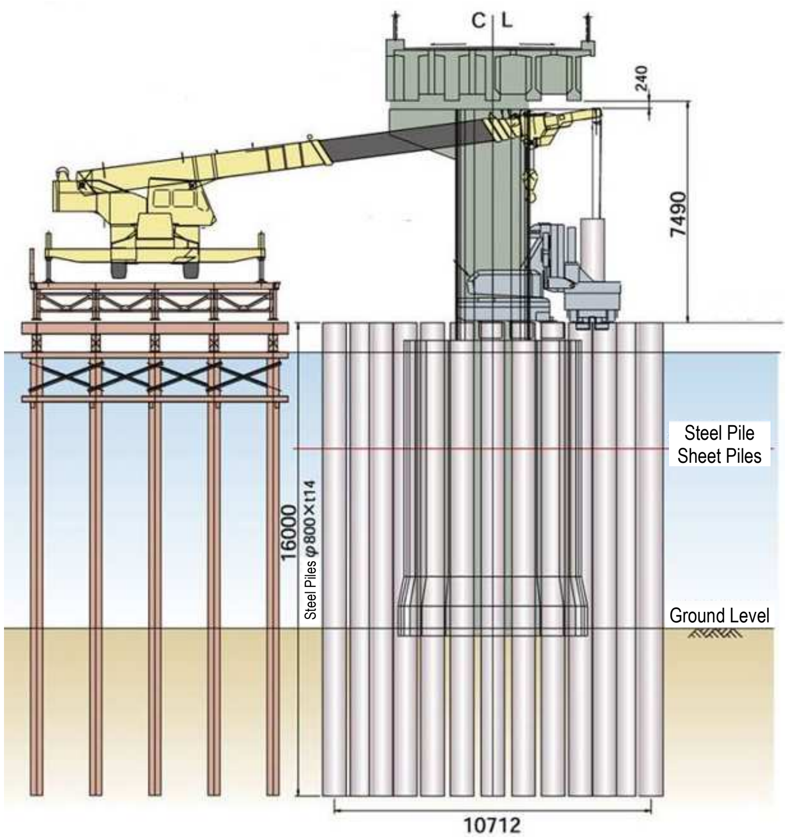


Figure 6.20 Example of Strengthening Method of Caisson Foundation

6.3.2.2. Strengthening of Substructure

(1) Pier Column

Reinforcing the pier column is to increase capacity to resist against bending moment and shear produced by earthquake. This manual introduce 4 methods, RCC lining method, steel plate lining method, CFRP sheet lining method, and Precast-blocks and Additional Tendons.

1) RCC Lining Method

The workflow is shown in the figure below.

Preparation	・ Inspection of condition of RCC pier column (damage, compressive strength) ・ Install scaffolding to secure the working space if necessary
Surface Preparation	・ Clean the surface of the column ・ Blast or chip the surface of column to secure the adhesiveness with newly casted concrete
Penetrating Errection Bars to Column	・ Penetrate the errection bars to the column for rebar arrangement
Anchoring Rebar to Footing	・ Anchoring the vertical rebar to the existing footing.
Rebar Arrangement	・ Rebar arrangement for newly casted lining wall ・ Mechanical joints to connect rebar are recommended for quality control
Forming	・ Install forms for the new lining wall
Casting Concrete	・ Cast concrete around the pier
Curing	・ Cure the concrete until it is hardened and dried
Finishing	・ Remove forms and Scaffolding

Figure 6.21 Workflow of RCC Lining Method

(Rebar Arrangement)

(Finishing)

(Rebar Arrangement)

(Finishing)

Figure 6.22 Example of Construction of RCC Lining Method

Casting concrete for this method could be replaced by shotcrete method. In this case, there would be no forming and deforming procedure.

This RCC Lining method is the most simple and principal method to strengthen the pier column. However, dead load increase is the largest among 4 methods

2) Steel Plate Lining Method

The workflow is shown in the figure below.

Preparation	· Inspection of condition of RCC pier column (damage, compressive strength) · Install scaffolding to secure the working space if necessary
Surface Preparation	· Clean the surface of the column · Blast or chip the surface of column to secure the adhesiveness with newly casted concrete, chamfer the corners
Drilling Anchor Holes to the Footing	· Drill anchor holes to footing to anchor the anchor bolts which will be connected to lining steel plate
Setting the Steel Plate	· Set the lining steel plate around the column
Welding	· Weld the lining steel plate together to rap around the column · Fix the lining plate to footing with anchor bolts and seal the gap
Grouting	· Grout grouting material to the gap between column and lining steel plate · Grouting material is non-shrinkage mortar or epoxy resin
Painting	· Paint the steel lining plate with proper layers (primer, intermediate and final)
Finishing	· Remove Scaffolding

Figure 6.23 Workflow of Steel Plate Lining Method

(Welding) (Grouting) (Painting)

Figure 6.24 Example of Construction of Steel Plate Lining Method

This method could be done quicker than RCC lining method due to unnecesity of rebar arrangement. However, it would cover the entire surface of concrete of the pier column. Soundness of the existing pier column shall be confirmed before applying this method.

Quality control of the welding at sight is very important to secure the quality of the strengthening, specifically against shear force.

3) CFRP Sheet Lining Method

The workflow is shown in the figure below.

Preparation	・ Inspection of condition of RCC pier column (damage, compressive strength) ・ Install scaffolding to secure the working space if necessary
Surface Preparation	・ Clean the surface of the column ・ Blast or chip the surface of column to secure the adhesiveness with newly casted concrete, chamfer the corners
Primer Coating	・ Coat the prepared RCC column surface with primer coating materials to secure the adhesiveness with CFRP sheet
Unevenness Adjusting	・ Coat the RCC column surface with unevenness adjusting material, such as putty
Adhering CFRP sheet	・ Adhere the CFRP sheet around the pier ・ Adhere multiple layers according to the design result ・ The procedure and direction of adhering shall follow the technical specification of the product.
Final Coating	・ Coat the CFRP sheet with final coating materials
Finishing	・ Remove Scaffolding

Figure 6.25 Workflow of CFRP Sheet Lining Method

(Unevenness Adjusting)

(Coating Adhesive)

(Adhering CFRP Sheet)

(Final Coating)

Figure 6.26 Example of Construction of CFRP Sheet Lining Method

This method could be done quicker than RCC lining method and steel plate lining method due to simple procedure. However, it would cover the entire surface of concrete of the pier column. Soundness of the existing pier column shall be confirmed before applying this method.

The procedure introduced in this manual only resist against shear produced by earthquake. Anchoring with footing shall be firmly done to resist the bending moment to resist against bending moment. Just wrapping around the CFRP sheet leave the very bottom cross-section unstrengthened. The details of anchoring to the footing firmly is still under research and not yet applied to the substructure of bridges in Japan.

Construction of CFRP sheet lining method requires trained skill and experience of both engineer and workers. The existence of these personnel shall be mandatory to apply and execute this method. It is better to procure labour with the product recommended by the manufacture.

4) Precast-blocks and Spiral Tendons Method

The workflow is shown in the figure below.

Preparation	・ Inspection of condition of RCC pier column (damage, compressive strength) ・ Install scaffolding to secure the working space if necessary
Surface Preparation	・ Clean the surface of the column ・ Blast the surface of column to secure the adhesiveness with PSC precast-blocks
Set PSC Precast-blocks	・ Set PSC precast-blocks ・ Adhere the PSC precast-blocks with existing pier by non-shrinkage mortar
Set Spiral Tendons	・ Set spiral tendons with equal interval
Connect Spiral Tendons	・ Connect spiral tendons with mechanical joint
Load Tension to Spiral Tendon	・ Load tensile force to spiral tendon to specified strength
Finishing	・ Remove Scaffolding

Figure 6.27 Workflow of Precast-blocks and Spiral Tendons Method

(Surface Preparation)

(Set PSC Precast-blocks)

(Set Spiral Tendons)

(Connect Spiral Tendons)

(Load Tension to Spiral Tendon)

(Completion)

Figure 6.28 Example of Construction of Precast-blocks and Spiral Tendons Method

Materials of this method are precast and fabricated, therefore it is very easy to control the quality of the materials. The most important part of the quality control is to control the tensile load loaded to spiral tendon. If it fails or loses after the completion, the design effect of the strengthening could not be realized.

This method is to resist against shear only. There shall be another strengthening method executed to resist against bending moment.

It also does not require craning equipment because all the particles are small and could be carried manually. Therefore the temporary structure would be only scaffoldings.

The existing column could be observed directly from the gaps of the PSC precast-blocks at the corners. If the existing column are deteriorated or damaged by massive earthquake, it could be quickly checked preliminarily from the corners.

(2) Abutment Wall

If the abutment wall is thickened, the sufficient amount of the rebar of newly casted wall shall be anchored to the existing footing and wall. The surface of the existing wall shall be cleaned and basted to secure the adhesiveness with the newly casted concrete. It shall be primer coated before casting the concrete.

If the foundation shall be strengthened because of the increase of the dead load, similar method shall be applied to the method mentioned in the previous clause 6.2.2.1 ''Strengthening of foundation'.

If there exists stable bearing layer nearby behind the abutment, abutment wall could be anchored to the layer by ground anchorage. To apply this method, countermeasure is required to prevent the abutment wall to collapse by punching-shear.

It requires cutting the rebar of abutment wall in executing this strengthening method. The number of the rebar, specifically the vertical rebar, which would be cut shall be minimized. The capacity to resist against bending moment and shear of abutment wall shall be reviewed despite the reduction of the amount of rebar.

Construction of ground anchor to existing structure requires trained skill and experience of both engineer and workers. The existence of these personnel shall be mandatory to apply and execute this method. It is better to procure labour with the product recommended by the manufacture.

(Casing of Ground Anchor) (Anchoring) (Completion)

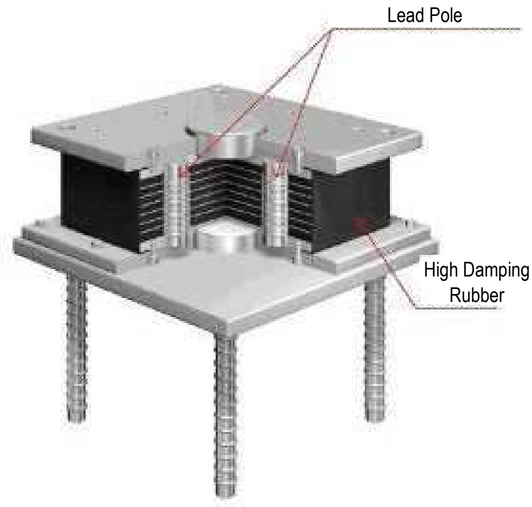
Figure 6.29 Example of Construction of Anchoring Abutment Wall

6.3.2.3. Strengthening of Bearings

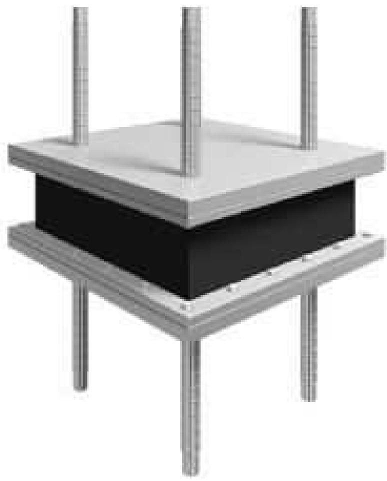
There are 2 types of aseismic bearing to sustain continuous superstructure. One is seismic isolation bearing and another is horizontal force dispersing bearing. Seismic isolation bearing has more capacity to resist against the seismic force.

Both types is made of multi-layer of high elastic rubbers. Seismic isolation bearing has fat lead pole that lengthen the movement of the superstructure and damps the force. Horizontal force dispersing bearing controls the horizontal force produced by earthquake and transferred from superstructure to substructure. If the bearing capacity of a pier is weak, the force would be reduced by softer/low elastic rubber. If a pier has stronger bearing capacity, the force it distributed more with harder/high elastic rubber.

The work flow of this strengthening works are similar to that of the bearing replacement. The details shall be referred to the previous clause 5.4.4.1 (1) 1) ‘Replacement’. However, aseismic bearings have higher height than the original bearings. Therefore, securing the space to install the aseismic bearings is an important factor to select the type of the bearings.



(Seismic Isolation Bearing)



(Horizontal Force Dispersing Bearing)

Figure 6.30 Example of Aseismic Bearings

Figure 6.31 Example of Deformation of Aseismic Bearings

6.3.2.4. Strengthening to Prevent Fall of Superstructure

Construction of bridge fall prevention device (Compression Force) are basically adding additional member to the existing member. Attaching the steel bracket to steel girder is similar to the previous clause 5.4.2.1. (2) 1) i) ‘Stiffening Plate Patching Method’. Attaching the steel bracket to RCC bridge seat is anchoring steel member to RCC member. Adding RCC bracket on bridge seat is casting the additional RCC member to RCC member. The details could be referred to the previous clause 5.4.2.1. (1) 2) ii) ‘Grouting Method’.

Construction of bridge seat widening is also similar to the details described in the previous clause 5.4.2.1. (1) 2) ii) ‘Grouting Method’.

(Steel Bracket to Steel Girder) (RCC Bracket to PSC Girder) (Bridge Seat Widening)

Figure 6.32 Example of Bridge Fall Prevention Device (Compression Force) and Bridge Seat Widening

Installing the fall prevention device is whether connecting chain or cable both to the exiting substructure and superstructure. If the member which will be connected by fall prevention devise is RCC, it shall be connected by anchor bolts, if it is steel, it shall be connected by bolts. The procedure and points to be taken care of connecting the devise to the existing member are similar to that of previous clauses, such as 6.3.1.1. (1) Outer Cable Method for RCC.

Construction of bridge fall prevention device (tension force) to existing structure requires trained skill and experience of both engineer and workers. The existence of these personnel shall be mandatory to apply and execute this method. It is better to procure labour with the product recommended by the manufacture.

(Chain Type Device) (Cable Type Device)

Figure 6.33 Example of Bridge Fall Prevention Device (Tension Force)

6.3.3. Strengthening against Flood Discharge

Actual works of strengthening method to prevent scouring of substructures and wash away of the backfill behind the abutment is explained in this subchapter. Protection of river bank/bed is selected for scouring and increase of cross section of flood discharge is selected for wash away as is described in the previous subchapter 6.2.3. ‘Strengthening against Flood Discharge’.

(1) Protection of River Bank/Bed

River bank (revetment) of the river with large flood velocity & discharge shall be covered by RCC retaining wall, and river bed by concrete blocks. River bank (revetment) of the river with small flood velocity

& discharge could be covered by stone pitching/gabion, and river bed by riprap/gabion. The details of detail desing shall be referred to in the previous clause 5.3.1. (3) ‘Scouring’

The details of the construction works are explained in the previous clause 5.4.1. (3) ‘Scouring’

(2) Increase Cross Section of Flood Discharge

Cross section of flood discharge shall be designed with 50-year return period for the bridge on arterial routes and of 20-years return period for the other highways. However, this is not always satisfied by the bridges in Bhutan. Therefore, there are needs of increasing cross section of flood discharge in many bridges.

Recommended method is to replace the bridge including the revise of the bridge alignment, specifically the longitudinal alignment. And the bridge length shall be longer the width of the river from revetment of left band to right bank.

However, if this could not be realized easily due to budget procurement issue, RCC abutment could be modified to pier and extend the bridge length behind the abutment. Extended bridge length shall be longer than the width of the river cross section which can stream the design flood discharge. The followings are the works that is necessary to modify the abutment to pier.

- Remove parapet of abutment
- Widen the bridge seat
- Review the capacity of the wall and thicken if necessary
- Enlarge and thicken the footing if necessary (increase number of piles in case of pile foundation)
- Protect wall from debris by installing protection guard on the upstream side of the wall

6.3.4. Waterproofing

Actual works of strengthening method to prevent infiltration of the water to RCC deck slab and prevent wetting the bearing/bridge seat is described in the subchapter. Waterproofing top surface of RCC deck is selected for infiltration and waterproofing expansion joint is selected for wetting the bearing/bridge seat as is described in the previous subchapter 6.2.4. ‘Waterproofing’.

(1) RCC Deck Slab

The workflow of waterproofing with sheet type is shown in the figure below.

Step	Works
Preparation	· Regulate the traffic to secure the work space
Removing pavement	· Remove waring course (base course and surface course) · Inspect the condition of RCC deck slab and repair it if necessary · Remove the existing waterproofing layer if it exists.
Cleaning and Unevenness Adjusting	· Clean the surface of RCC deck slab, blast to remove stains · Plaster the surface to adjust the unevenness with primer coating
Primer Coating	· Coat the RCC deck slab with primer coating material (sufficient amount) · Scatter silica sand before drying if necessary
Adhesive Coating	· Coat the surface on the primer coating with adhesive coating material (sufficient amount)
Waterproof Sheet Pasting	· Set the waterproofing sheet taking care of wrapping section. (wrapping width shall be more than 10cm)
Top Coating	· Coat the wrapping section with waterproofing material (sufficient amount)
Waterproofing Corner Section	· Additional waterproofing treatment to the corner (curb, expansion joint) · Install drain pipe at the downstream corner of slope
Repaving	· Repave the waring course (base course and surface course) · Cure the waring course till it is hardened and cooled down
Finishing	· Mark the road marking · Open bridge to the traffic

Figure 6.34 Workflow of Waterproofing RCC Deck Slab (Sheet Type)

It is very important to prepare the surface of the RCC deck slab before starting the waterproofing works. It shall be cleaned and dried very well and the stains shall be removed by blasting the deck. Infiltrated asphalt material shall also be removed by blasting or chipping method. If the condition of RCC deck slab is not sound with crack, peeling off, rebar exposure, or deteriorated by leakage of cement, it shall be repaired before waterproofing works. All of these preparation is for securing the adhesiveness between the RCC deck slab and waterproofing materials.

Waterproofing sheets are usually sold with the other coating/adhesive materials by the sheet manufacturer. The manufacturer have their recommendation of layer structure with specific materials and quantity. It is recommended to procure as a set which the manufacturer recommends. It is not recommended to buy individually strongly. If it could not be procured as a set, it is very highly requested to confirm the quality to use the other materials with manufacturer's recommendation.

(Primer Coating) (Waterproof Sheet Pasting) (Top Coating)

Figure 6.35 Example of Construction of Waterproofing RCC Deck Slab (Sheet Type)

The details of the waterproofing corner explained with the figure below.

Waterproofing Deck Surface	· The details are explained in the figure above
Primer Coating	· Coat the corner with same primer coating material of the deck surface · Amount of the material per m^2 could be different with deck surface
Waterproof Coating	· Coat the surface on the primer coating with waterproof coating material with same material of deck surface (sheet/coating type) · Amount of the material per m^2 could be different with deck surface
Top Coating	· Coat the waterproofing material with top coating material · Amount of the material per m^2 could be different with deck surface · Cure the waterproofing material until it is dried
Install Drain Pipe	· Install the drain pipes at the downstream corner of slope attached to curb or expansion joint · Install the drain duct if necessary
Repaving	· Repave the waring course (base course and surface course) · Back to the procedure of the entire surface

Figure 6.36 Workflow of Waterproofing RCC Deck Slab (Corner Section)

Figure 6.37 Example of Drain Pipe and Drain Basin

Corner section shall be waterproofed separately to secure the quality of waterproof strengthening. One of the reason is that it could be damaged in repaving works. The other reason is that surface water infiltrated to wearing course would pool at the downstream corner of slope. If the waterproof layers are damaged it would infiltrate to the deck slab easily. The pooled water shall be collected by drain pipe and drained to drainage basin rapidly.

The workflow of waterproofing with coating type is shown in the figure below.

Preparation	· Regulate the traffic to secure the work space
Removing pavement	· Remove waring course (base course and surface course) · Inspect the condition of RCC deck slab and repair it if necessary · Remove the existing waterproofing layer if it exists.
Cleaning and Unevenness Adjusting	· Clean the surface of RCC deck slab, blast to remove stains · Plaster the surface to adjust the unevenness with primer coating
Primer Coating	· Coat the RCC deck slab with primer coating material
Waterproof Coating	· Coat the surface on the primer coating with waterproof coating material
Top Coating	· Cover the waterproofing material with top coating materials if necessary · Scatter silica sand before drying if necessary
Waterproofing Corner Section	· Additional waterproofing treatment to the corner (curb, expansion joint) · Install drain pipe at the downstream corner of slope
Repaving	· Repave the waring course (base course and surface course) · Cure the waring course till it is hardened and cooled down
Finishing	· Mark the road marking · Open bridge to the traffic

Figure 6.38 Workflow of Waterproofing RCC Deck Slab (Coating Type)

The difference from sheet type is the layer structure of the waterproofing. Also it is different whether to apply sheet material for waterproofing or not. Sheet material is manufactured material therefore it is easier to control the quality of site works. Therefore it is recommended to use when the area of waterproofing is large. Coating type shall be applied when the area is relatively small.

(Primer Coating) (Waterproof Coating) (Scatter Silica Sand)

Figure 6.39 Example of Construction of Waterproofing RCC Deck Slab (Coating Type)

Waterproofing coating materials are usually sold with the other primer/top coating materials by the manufacturer. The manufacturer have their recommendation of layer structure with specific materials and quantity. It is recommended to procure as a set which the manufacturer recommends. It is not recommended to buy individually strongly. If it could not be procured as a set, it is very highly requested to confirm the quality to use the other materials with manufacturer's recommendation.

(2) Expansion Joint

Waterproofing the expansion joint is executed by replacing the existing expansion joint with waterproof expansion joint which has drain gutter under the joint structure to drain surface water of the bridge aside. The details of waterproof expansion joint is described in the previous clause 5.3.4.3. (2) 'Expansion Joint'.

The details of the construction procedure is explained in the previous clause 5.4.4.3. (2) 'Expansion Joint'. However, the specific requirement of the product which is mentioned in the technical specification of the product shall be followed during the construction.

MANUAL 3 : Guideline for a field checklist on the basic items on quality control for Bridge Construction

CAMBRIDGE

Technical Cooperation Project for Capacity Developmen
in Construction and Maintenance of Bridges
in the Kingdom of Bhutan

Guideline for a field checklist on the basic items on quality control for Bridge Construction

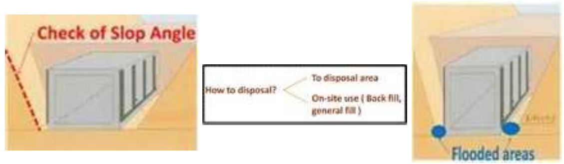
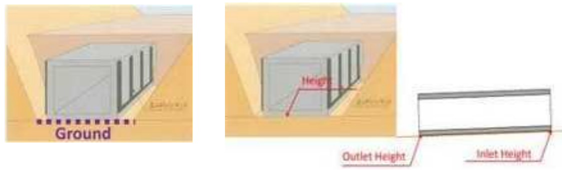
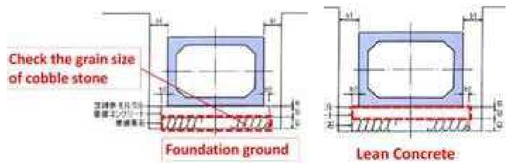
April 2022

Department of Road
Ministry of Works & Human Settlement
Royal Government of Bhutan

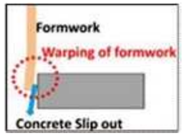
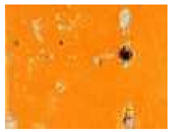
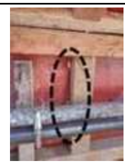
Japan International Cooperation Agency

Contents

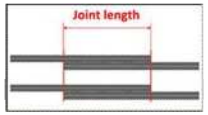
1. Common Edition

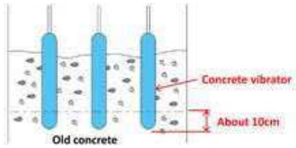
Items		Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
1-1	Preparatory Work	(1) Did you confirm the construction work plan?				Compare with the construction plan
		(2) Did you confirm the construction schedule?				Compare with the construction plan
		(3) Did you check the benchmark of survey?				Check on the site
1-2	Excavation	(1) Is the excavation slope appropriate?				Compare with the construction plan
		(2) Is the disposal of excavated soil appropriate?				Compare with the construction plan
		(3) Is the removal of water appropriate?				Check on the site
1-3	Foundation Ground	(1) Is the strength of bearing ground sufficient?				Check by plate loading tests
		(2) Did you check the ground height?				Check on the site Confirm with the survey report
1-4	Backfill	(1) Did you check the backfill material?				Compare with the construction plan
		(2) Is there any organic matter, such as plants, stumps, roots, mixed into the backfill material?				Check on the site
		(3) Did you confirm the soil density test results?				Check on the site Confirm with the test report
		(4) Did you confirm the compacted thickness?				Check on the site
1-5	Foundation	(1) Did you check the thickness of foundation ground?				Compare with the construction plan
		(2) Are the compaction and gradation of cobble stone sufficient?				Check on the site
		(3) Is the lean concrete surface finished flat?				Check on the site

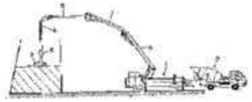
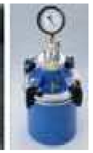
1. Common Edition (Concrete)

Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
1-6- 1	Preparatory Concrete Work	(1)	Did you confirm the concrete work plan?	 Concrete mix plan  Certificate of Cement			Compare with the construction plan
		(2)	Did you confirm the concrete mix plan?				Compare with the construction plan
		(3)	Did you confirm the quality control plan?				Compare with the construction plan
		(4)	Did you check the quality of cement?				Compare with the construction plan
1-6- 2	Supporting	(1)	Is the strength of bearing ground sufficient?	 Strength of bearing ground  Not damaged, deformed, corroded, etc.			Check by plate loading tests
		(2)	Are the materials being used not damaged, deformed, corroded, etc.?				Check on the site
		(3)	Did you check the timing, method and procedure for removal of the support?	Refer to the formwork for the rough judgment of the removal time.			Compare with the construction plan
1-6- 3	Formwork	(1)	Are the quality and thickness of the formwork material appropriate?	 No warping  No hole  Cleaning with the brush			Compare with the construction plan
		(2)	Are there no holes, rotting or warping in the formwork?				Check on the site
		(3)	Was the formwork completely cleaned, so that rust and concrete are not adhered to it?				Check on the site
		(4)	Is the release agent sufficiently applied to the inner surface of the formwork?	 Coating the release agent with the roller  Form clamping metal fitting  Gap			Check on the site
		(5)	Is the formwork clamping fitted appropriately?				Check on the site
		(6)	Are there no asperity or gap in the formwork?				Check on the site
		(7)	Has the frame been constructed so that the finished shape dimensions satisfy the dimensional accuracy?				Inspection of finished shape Check by inspection tape
		(8)	Did you check the timing, method and procedure for removal of the formwork?	Removal Timing of Formwork Source: Standard specifications for concrete structures in Japan			Check by concrete strength tests

Type of Structures		Compressive strength (N/mm2)
Vertical or vertically close surface of thick-walled parts	Side of Footing	3.5
Vertically close surface, Bottom surface with a slope steeper than 45°	Side of pile, wall and beam	5.0
Bottom surface with a gentle slope than 45°	Bottom of slab and beam, inside of arch	14.0

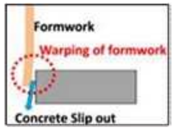
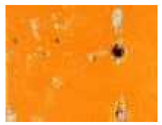
Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
1-6- 4	Transport	(1)	Is the supply of fresh concrete being carried out smoothly?				Check on the site
		(2)	Has the mixer drum been continuously rotated during transportation and standby?				Check on the site
1-6- 5	Preparation of Casting	(1)	Has the formwork, rebar and concrete surface been cleaned sufficiently and kept moist?	 Cleaning  Watering  Concrete casting on the foot board			Check on the site
		(2)	Have the foot boards been properly placed so that the workers do not stand directly on the reinforcing bars or formwork during concrete casting?				Check on the site
		(3)	Has the sheeting been prepared for when rain is expected?				Check on the site
		(4)	When night-time concrete casting is assumed, has night lighting equipment been prepared?				Check on the site
1-6- 6	Reinforcing Bar	(1)	Did you confirm the quality of rebar?	 Rebar Certificate  Mill Sheet  Rebar does not touch the ground			Confirm with the certificate of quality
		(2)	Has the rebar been stored properly?				Check on the site
		(3)	Has the rebar been thoroughly cleaned?				Check on the site
		(4)	Is the thickness of cover concrete been secured with an appropriate spacer?	 Clean the mortar attached to the rebar  Concrete Spacer  Joint length			Check on the site
		(5)	Has the rebar been fixed sufficiently with binding wire?				Check on the site
		(6)	Is the lap joint length appropriate?				Check with the shop drawing
		(7)	Are there any other fittings not shown in the shop drawing?				Check on the site
		(8)	Have joints/splices of rebar been point-welded?	 Check the number and diameter of rebar  Check the position and interval of rebar Rebar Inspection			Check on the site
		(9)	For future additions of rebar, is the protection of exposed rebar from the structure appropriate?				Check on the site
		(10)	Are the number and diameter of rebar correct?				Compare with the shop drawing
		(11)	Are the position and interval of rebar appropriate?				Compare with the shop drawing
		(12)	Are workers not standing directly on the rebar while working?				Check on the site

Items			Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
1-6- 7-1	Casting	(1)	Did you check the class of concrete before concrete casting?	 Certificate of delivery			Confirm with the shipping ticket
		(2)	Is the capacity and number of concrete casting machines appropriate?				Compare with the construction plan
		(3)	Is the chief engineer taking control of the whole work?				Check on the site
		(4)	Is the capacity and number of vibration compaction machines appropriate?				Compare with the construction plan Check on the site
		(5)	Are the number of workers appropriate?	As a general rule, the time from concrete mixing to the end of concrete casting must not exceed 1.5 hours when the outside temperature exceeds ℃ and not more than 2 hours when the outside temperature is below 25℃. Source: Standard specifications for concrete structures in Japan			Compare with the construction plan Check on the site
		(6)	Has concrete work been done in the proper time from complete of mixing to complete of concrete casting?				Check on the site
		(7)	Is the location of dropping for fresh concrete appropriate?	 Concrete vibrator inserted			Check on the site
		(8)	Has the concrete been caste in horizontal layers when casting concrete for tall structures?				Compare with the construction plan Check on the site
		(9)	Is the concrete vibrator inserted in the next layer inserted up to the old concrete?				Check on the site
		(10)	Is the falling height of fresh concrete appropriated?	 Casting by Hopper  Casting by Shoot  Casting by Hose Falling height of fresh concrete			Check on the site
		(11)	Has the casted concrete been sufficiently compacted with a vibrator?				Check on the site
1-6- 7-2	Casting by the Pump	(1)	Is the diameter of the concrete conveying pipe appropriate?				Compare with the construction plan Check on the site
		(2)	Is the type of the concrete conveying pipe appropriate?				Compare with the construction plan Check on the site
		(3)	Has the concrete conveying pipe not been placed on rebar or formwork?				Compare with the construction plan Check on the site

Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
		(4)	Before concrete casting, has the mortar that passed through the concrete conveying pipe been discarded?	 Concrete pump car  Do not place pipes on rebar			Check on the site
		(5)	If the transport pipe is blocked, has the fresh concrete of concrete conveying pipe been discarded?	 Do not use damaged pipes			Check on the site
1-6- 7-3	Casting by the Chute	(1)	When using the inclined chute, is the gradient uniform and appropriate?	 			Compare with the construction plan Check on the site
		(2)	Are the location and interval of the inclined chute appropriate?				Check on the site
1-6- 7-4	Horizontal Concrete Joint	(1)	Has the laitance been removed in the horizontal concrete joint face?	Laitance remove by wire brushing Laitance remove by high-pressure washing			Check on the site
		(2)	Is the position and direction of the concrete joint face appropriate?	 			Compare with the drawing and construction plan
1-6- 7-5	Vertical Concrete Joint	(1)	Was the concrete joint face pitching carried out?				Check on the site
		(2)	Is the position and direction of the concrete joint face appropriate?	Concrete joint face pitching			Compare with the drawing and construction plan
1-6- 7-6	Quality Control	(1)	Did you check the slump, air content and temperature at concrete casting site?	  			Compare with the construction plan Check on the site
		(2)	Did you take sample pieces for concrete strength testing?	Slump test Temperature check Air content test			Check on the site Confirm by the test result
		(3)	Does the concrete strength satisfy the reference value?	  			Check on the site Confirm by the test result
		(4)	Is the strength of the concrete properly managed?	Sample pieces for concrete strength testing Concrete compressive test			Check on the site Confirm by the test result

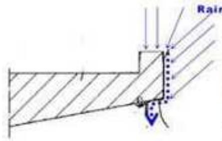
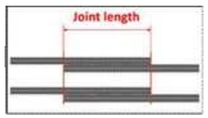
Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
1-6- 8	Curing	(1)	Has curing of concrete in moist conditions been carried out soon after concrete casting?	Average daily temperature / Curing time: More than 15℃ – More than 5 days More than 10℃ – More than 7 days More than 5℃ – More than 9 days Curing Time Source: Standard specifications for concrete structures in Japan  Sheet Cover Curing  Wet Sheet Curing  Water Curing			Check on the site
		(2)	Has a suitable method been used for curing of concrete in moist conditions?				Check on the site
1-6- 9	Winter Concreting	(1)	Has the concrete casting being properly constructed when constructing in the winter?				Compare with the construction plan Check on the site
		(2)	Has snow and ice adhered to rebar and formwork been removed before concrete casting?				Check on the site
		(3)	After casting concrete, are the method, period, temperature and management of curing appropriate?				Compare with the construction plan Check on the site
1-6- 10	Hot Weather Concreting	(1)	Is concrete casting of fresh concrete done within 1 hour after mixing?				Check on the site

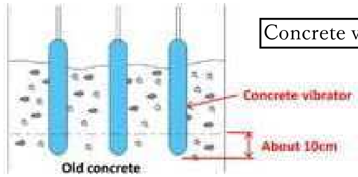
2. Concrete Bridge Edition

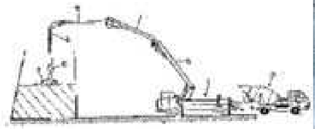
Items			Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
2-1	Preparatory Concrete Work	(1)	Did you confirm the concrete work plan?	 Concrete mix plan  Certificate of Cement			Compare with the construction plan
		(2)	Did you confirm the concrete job mix plan?				Compare with the construction plan
		(3)	Did you confirm the quality control plan?				Compare with the construction plan
		(4)	Did you confirm the quality of cement?				Confirm by the certificate of quality
2-2	Supporting	(1)	Is the strength of bearing ground sufficient?	 Strength of bearing ground   Not damaged, deformed, corroded, etc.			Check by plate loading tests
		(2)	Are the materials being used not damaged, deformed, corroded, etc.?				Check on the site
		(3)	Is the volume of camber allowance appropriate?	The camber amount is collated with calculated value and field survey value.			Compare with the over-raise calculate report
		(4)	Did you check the timing, method and procedure for removal of the support?	Refer to the formwork for the rough judgment of the removal time.			Compare with the construction plan
2-3- 1	Formwork	(1)	Are the material and thickness of the formwork material appropriate?	 No warping  No hole  Cleaning with the brush			Compare with the construction plan
		(2)	Are there no holes, rotting or warping in the formwork?				Check on the site
		(3)	Is the formwork completely cleaned, so that rust and concrete are not adhered to it?	 Coating the release agent with the roller  Form clamping metal fitting  Gap			Check on the site
		(4)	Is the release agent sufficiently applied to the inner surface of the formwork?				Check on the site
		(5)	Is the formwork clamping fitted appropriately?				Check on the site
		(6)	Is there an asperity and gap in the formwork?	(see table below) Removal Timing of Formwork Source: Standard specifications for concrete structures in Japan			Check on the site
		(7)	Did you check the timing, method and procedure for removal of the formwork?				Check by the concrete strength test

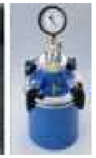
Type of Structures		Compressive strength (N/mm2)
Vertical or vertically close surface of thick-walled parts	Side of Footing	3.5
Vertically close surface, Bottom surface with a slope steeper than 45°	Side of pile, wall and beam	5.0
Bottom surface with a gentle slope than 45°	Bottom of slab and beam, inside of arch	14.0

Removal Timing of Formwork
Source: Standard specifications for concrete structures in Japan

Items			Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
2-3- 2	Slab Formwork	(1)	Has the frame been constructed so that the finished shape dimensions satisfy the dimensional accuracy?	  Structure for the dripping water			Compare with the shop drawing
		(2)	Does the undersides of the overhanging portion of the slab have a structure for the dripping water?				Check on the site
2-4	Transport	(1)	Is the supply of fresh concrete being carried out smoothly?				Check on the site
		(2)	Has the mixer drum been continuously rotated during transportation and standby?				Check on the site
2-5	Preparation of Casting	(1)	Has the formwork, rebar and concrete surface been cleaned sufficiently and kept moist?	 Cleaning  Watering  Concrete casting on the foot board			Check on the site
		(2)	Have the foot boards been properly placed so that the workers do not stand directly on the reinforcing bars or formwork during concrete casting?				Check on the site
		(3)	Has the sheeting been prepared for when rain is expected?				Check on the site
		(4)	When night-time concrete casting is assumed, has night lighting equipment been prepared?				Check on the site
2-6	Reinforcing Bar	(1)	Did you confirm the quality of rebar?	 Rebar Certificate  Mill Sheet  Rebar does not touch the ground			Confirm by the certificate of quality
		(2)	Has the rebar been stored properly?				Check on the site
		(3)	Has the rebar been thoroughly cleaned?				Check on the site
		(4)	Is the thickness of cover concrete been secured with an appropriate spacer?	 Clean the mortar attached to the rebar  Concrete Spacer  Joint length			Check on the site
		(5)	Has the rebar been fixed sufficiently with binding wire?				Check on the site
		(6)	Is the lap joint length appropriate?				Compare with the shop drawing
		(7)	Are there any other fittings not shown in the shop drawing?				Check on the site
		(8)	Have joints/splices of rebar been point-welded?				Check on the site

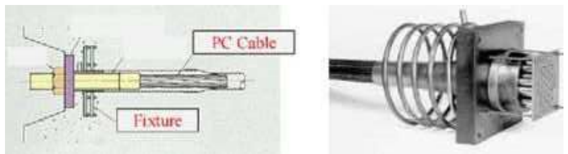
Items		Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
		(9) For future additions of rebar, is the protection of exposed rebar from the structure appropriate?	 Check the number and diameter of rebar  Check the position and interval of rebar Rebar Inspection			Check on the site
		(10) Are the number and diameter of rebar correct?				Compare with the shop drawing
		(11) Are the position and interval of rebar appropriate?				Compare with the shop drawing
		(12) Are workers not standing directly on the rebar while working?				Check on the site
2-7- 1	Casting	(1) Did you check the class of concrete before concrete casting?	 Certificate of delivery			Compare with the shipping ticket
		(2) Is the capacity and number of concrete casting machines appropriate?				Compare with the construction plan
		(3) Is the chief engineer taking control of the whole work?				Check on the site
		(4) Is the capacity and number of vibration compaction machines appropriate?				Compare with the construction plan Check on the site
		(5) Are the number of workers appropriate?	As a general rule, the time from concrete mixing to the end of concrete casting must not exceed 1.5 hours when the outside temperature exceeds ℃ and not more than 2 hours when the outside temperature is below 25℃. Source: Standard specifications for concrete structures in Japan			Compare with the construction plan Check on the site
		(6) Has concrete work been done in the proper time from complete of mixing to complete of concrete casting?				Check on the site
		(7) Is the location of dropping for fresh concrete appropriate?	 Concrete vibrator inserted			Check on the site
		(8) Has the concrete been caste in horizontal layers when casting concrete for tall structures?				Compare with the construction plan Check on the site
		(9) Has the vibrator been inserted to the previous layer when casting the next layer of concrete?				Check on the site
		(10) Is the falling height of fresh concrete appropriate?	 Casting by Hopper  Casting by Shoot  Casting by Hose Falling height of fresh concrete			Check on the site
		(11) Has the casted concrete been sufficiently compacted with a vibrator?				Check on the site

Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
2-7- 2	Casting by the Pump	(1)	Is the diameter of the concrete conveying pipe appropriate?	 Concrete pump car  Do not place pipes on rebar  Do not use damaged pipes			Compare with the construction plan Check on the site
		(2)	Is the type of the concrete conveying pipe appropriate?				Compare with the construction plan Check on the site
		(3)	Has the concrete conveying pipe not been placed on rebar or formwork?				Compare with the construction plan Check on the site
		(4)	Before concrete casting, has the mortar that passed through the concrete conveying pipe been discarded?				Check on the site
		(5)	If the transport pipe is blocked, has the fresh concrete of concrete conveying pipe been discarded?				Check on the site
2-7- 3	Casting by the Chute	(1)	When using the inclined chute, is the gradient uniform and appropriate?	 Laitance remove by wire brushing  Laitance remove by high-pressure washing  Concrete joint face pitching			Compare with the construction plan Check on the site
		(2)	Are the location and interval of the inclined chute appropriate?				Check on the site
2-7- 4	Horizontal Concrete Joint	(1)	Has the laitance been removed in the horizontal concrete joint face?				Check on the site
		(2)	Is the position and direction of the horizontal concrete joint face appropriate?				Compare with the shop drawing and construction plan
2-7- 5	Vertical Concrete Joint	(1)	Is the vertical concrete joint face pitching carried out?				Check on the site
		(2)	Is the position and direction of the vertical concrete joint face appropriate?				Compare with the shop drawing and construction plan
2-7- 6	Quality Control	(1)	Did you check the slump, air content and temperature at concrete casting site?				Compare with the construction plan Check on the site
		(2)	Did you take sample pieces for concrete strength testing?				Check on the site Confirm by the test result

Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
		(3)	Does the concrete strength satisfy the reference value?	 Slump test  Temperature check  Air content test			Check on the site Confirm by the test result
		(4)	Is the strength of the concrete properly managed?	 Sample pieces for concrete strength testing  Concrete compressive test			Check on the site Confirm by the test result
2-8	Curing	(1)	Has curing of concrete in moist conditions been carried out soon after concrete casting?	Average daily temperature / Curing time: More than 15℃ – More than 5 days; More than 10℃ – More than 7 days; More than 5℃ – More than 9 days Curing Time Source: Standard specifications for concrete structures in Japan			Check on the site
		(2)	Has a suitable method been used for curing of concrete in moist conditions?	 Sheet Cover Curing  Wet Sheet Curing  Water Curing			Check on the site
2-9	Winter Concreting	(1)	Has the concrete casting being properly constructed when constructing in the winter?				Compare with the construction plan Check on the site
		(2)	Has snow and ice adhered to rebar and formwork been removed before concrete casting?				Check on the site
		(3)	After casting concrete, are the method, period, temperature and management of curing appropriate?				Compare with the construction plan Check on the site
2-10	Hot Weather Concreting	(1)	Is concrete casting of fresh concrete done within 1 hour after mixing?				Check on the site

3. Prestressed Concrete Bridge Edition

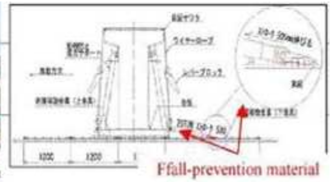
Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
3-1	Supporting	(1)	Is the structure not constraining the elastic modulus of concrete when prestressed?	 Supporting			Compare with the construction plan Check on the site
		(2)	When introducing prestressing, is it structured to withstand the change of the load state sufficiently?				Compare with the construction plan Check on the site
		(3)	When using a support with a large potential for elastic deformation, can it be adjusted with a wedge?				Compare with the construction plan Check on the site
		(4)	Is the volume of sinking allowance appropriate?	The camber amount is collated with calculated value and field survey value.			Compare with the construction plan
3-2	Girder Production Table	(1)	Is the girder production table sufficiently solid? Has the structure been constructed such that unequal settlement does not occur due to concrete placement and the ground does not loosen due to curing water or rain?	 Girder production table			Check on the site
		(2)	Is the girder production table in accordance with the construction plan?				Compare with the construction plan Check on the site
3-3	Formwork	(1)	Is the bottomed form a structure that does not constrain the elastic deformation of concrete during prestressing?	 Bottomed Form			Compare with the construction plan Check on the site
		(2)	Is the volume of sinking allowance appropriate?	The camber amount is collated with calculated value and field survey value.			Confirm by the construction plan
		(3)	Does the formwork have a structure that prevents mortar from leaking from joints and holes?	 Be careful of concrete leaking form the gap			Check on the site
		(4)	Is the fixing form firmly attached to the formwork?	 The fixing from should be firmly attached to the formwork			Check on the site
		(5)	Are the time of removal of the bottomed form and inner form of box girder appropriate?				Check on the site

Items			Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
		(6)	Is the cleaning of cross beam and/or slab concrete and girder joints appropriate?				Check on the site
		(7)	Is the girder clearance appropriate?				Compare with the shop drawing
		(8)	Has the frame been constructed so that the finished shape dimensions satisfy the dimensional accuracy?				Compare with the shop drawing
3-4	PC Steel Work				–	–	
3-4- 1	Material	(1)	Is the material as per the standard?	The quality of material should be confirmed by certificate.			Compare with the certificate of quality and material test result
		(2)	Is the storage of PC cable materials, fixtures and sheaths appropriate?	 Storage of PC steel materials			Check on the site
		(3)	Are there significant rust and harmful scratches on the PC cable?				Check on the site
		(4)	Is stacking pattern for the PC cable wire in storage area appropriate?				Check on the site
		(5)	Is the structure of sheath such that it is hardly being damaged during concrete casting?				Compare with the construction plan
		(6)	Is the structure of the sheath water-tight during concrete casting?	 Fixture should be fixed a right angle to the axis of the PC cable			Check on the site
		(7)	Is the structure of the sheath flexible during concrete casting?				Check on the site
3-4- 2	Bending	(1)	Is the bending radius appropriate?				Check on the site
3-4- 3	Assembly Arrangement of PC Steel	(1)	Does the fixture fix at a right angle to the axis of the PC cable?				Check on the site
		(2)	Is the position and quantity of the PC cable in accordance with shop drawing?				Compare with the shop drawing
		(3)	Is the PC cable installed with a smooth curve?	 PC cable installed; Binding between the sheath and the holding member			Compare with the shop drawing
		(4)	Is the retention interval of PC cable wire appropriate?				Check on the site
		(5)	Is the binding between the sheath and the holding member appropriate?				Check on the site

Items			Checklist	Explanatory chart	Judgment		Method of Confirmation
					Yes	No	
		(6)	Are the connecting parts between the joint of the sheath and the fixture treated so that the mortar does not leak at the time of concrete casting?				Check on the site
		(7)	Are the connecting parts between the joint of the sheath and the fixture treated so as not to be crushed at the time of concrete casting?				Check on the site
		(8)	Is the PC cable not welded?	Welding for drawing, cutting and machining of PC cable wire will result in significant deterioration of the material, so it must never be done.			Check on the site
		(9)	Is the sheath steel not welded?	The sheath steel should be not welded.			Check on the site
		(10)	Has sufficient rebar been arranged in the fixing part?				Check on the site
		(11)	Are grout injection pipes and air vent pipes securely attached to the sheath?	It is necessary to confirm that the installation position is as shown in the drawing.			Compare with the shop drawing
		(12)	Is the above arrangement appropriate?	It is necessary to confirm that the installation position is as shown in the drawing.			Compare with the shop drawing
3-5	Concrete Work		Refer to the Common Edition (Concrete)	Refer to Concrete Edition	–	–	
3-5- 1	Material	(1)	Is the salt concentration of fine aggregate below the specified value?				Confirm the material test result
3-5- 2	Casting	(1)	Has concrete work been done in the proper time from completion of mixing to completion of concrete casting?	It is desirable that the time until the completion of concrete placement be within one hour.			Check on the site
		(2)	During concrete casting, has there been no damage to the formwork, rebar or sheath?				Check on the site
		(3)	Has the laitance been removed from the contact face between the main girder and the cross beam?				Check on the site
		(4)	Has chipping of the contact face between the main girder and the cross beam been carried out?				
		(5)	Is the casting order of the concrete and the casting method appropriate?				Compare with the construction plan Check on the site
3-5- 3	Curing	(1)	In the winter, is the curing method appropriate?				Compare with the construction plan Check on the site
		(2)	In the summer, is the curing method appropriate?				Compare with the construction plan Check on the site

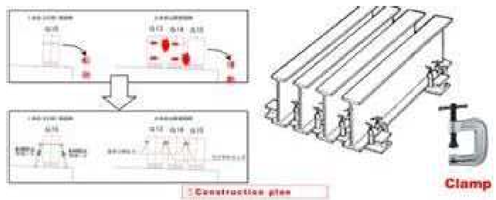
Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
3-6	Prestressing Work				—	—	
3-6- 1	Preparation	(1)	Does the strength of the concrete reach the predetermined strength?				Confirm by the concrete strength test result
		(2)	Is the maintenance and inspection of machine tools for tensioning appropriate?	Check the jack's ability. If the hydraulic pressure becomes unstable or the reading of the gauge cannot be determined during the tension work, stop the work immediately and perform the inspection.			Compare with the construction plan
		(3)	Is the calibration performed as specified?				Check on the site
			(a) Just before the first pressing				
			(b) After repairing the jack and pump				
			(c) After changing the combination of the jack and the pump				
			(d) After prestressing of 50 to 60 cables				
			(e) When prestressing work is suspicious				
			(f) In addition, when the supervisor instructs				
		(4)	Are the personnel necessary for tension work secured?	At least one person who has the appropriate capacity for each operation of jack / pump operation, PC steel material elongation measurement load and elongation recording will be assigned.			Check on the site
3-6- 2	Prestressing	(1)	Is the order of tensioning correctly carried out?	 Tension work			Compare with the construction plan
		(2)	Is the prescribed tension introduced?				Compare with the construction plan Check on the site
3-6- 3	Tension Control	(1)	Is the control method for tensioning properly carried out?	PC cable materials should be managed individual and in groups.			Compare with the construction plan
		(2)	Is the number and type of cables subject to tension testing appropriate?				Compare with the construction plan
		(3)	Does the friction coefficient of each PC cable material not exceed the control limit?				Confirm the tension control chart
		(4)	Are the design elongation amount and the amount of actual elongation amount not quite different?				Confirm the tension control chart
		(5)	Is the frictional loss of PC cable not abnormally large?				Confirm the tension control chart

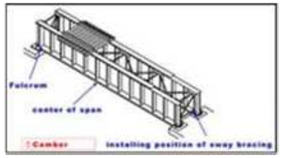
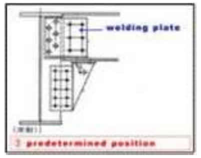
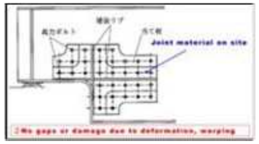
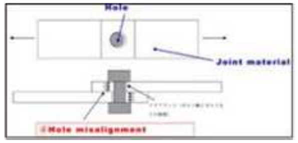
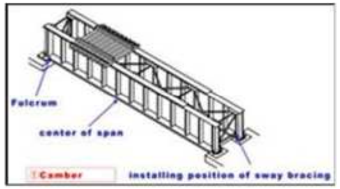
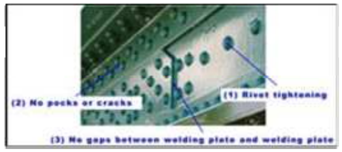
Items			Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
3-6- 4	Safe Control	(1)	Are there people standing behind the tension jack during tensioning?	No person should be behind the jack during or immediately after straining.			Check on the site
3-7	Grouting Work				—	—	
3-7- 1	Job Mix and Material	(1)	Is the prescribed job mix properly carried out?				Compare with the construction plan Check on the site
		(2)	Is the prescribed quality control test properly carried out? (under construction)	Consistency: Every 5 batches, Breathing rate: 1 time / day (3 pieces / time), Compressive strength: 1 time / day (6 pieces / time)			Confirm the quality test result
		(3)	Is the admixture used of proper quality?	 Input order is wate →admixture →cement →(other fine powder)			Compare with the construction plan Confirm quality test result
		(4)	Does the mixing water contain harmful substances?				Confirm the water quality test result
		(5)	Is order of materials being added the mixer appropriate?	Consistency test of grout			Check on the site
3-7- 2	Grouting	(1)	Is grouting promptly done after prestressing?				Compare with the tension control chart
		(2)	Has the grout been passed through a sieve before prestressing?				Check on the site
		(3)	Has the sheath been cleaned before grouting? Also, is the inside of the sheath wet enough?				Check on the site
		(4)	Is the grouting pressure and grouting rate appropriate?	If the construction is done rapidly, grout will not spread and there is a risk that airspace will remain.			Check on the site
		(5)	Is the grouting carried out continuously?				Check on the site
		(6)	Has the backflow prevention measures been taken?				Check on the site
		(7)	Is the sheath not blocked?				Check on the site
		(8)	Is the grouting carried out from the lower side?	In the case of a vertical cable or a slanted cable, it is done from a low level to facilitate are bleeding.			Check on the site
3-7- 3	Curing	(1)	In winter, is the curing method appropriate?				Compare with the construction plan
3-8	Storage, Transportation, Erection	(1)	Does the completed girder have a hazardous warping or twisting?				Compare with the construction plan Check on the site

Items	Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
	(2) Is the girder storage location appropriate?	 			Compare with the construction plan Check on the site
	(3) Is the storage method of girder appropriate?	Storage method of girder			Compare with the construction plan Check on the site
	(4) When storing for a long time, are storage measures taken for the rebar and sheath holes?	Apply cement paste or the like to the reinforcing bars connected to the floor slabs and cross beams. Provide a drain hole in the cable hole in advance, or use a wooden stopper or rubber stopper to prevent water from collecting.			Compare with the construction plan Check on the site
	(5) Are jack supporting brackets, hanging brackets, etc., provided on the girder?	 			Compare with the construction plan Check on the site
	(6) Has the fall-prevention material and the brake been installed when moving the girder sideways?				Compare with the construction plan Check on the site
	(7) Has sufficient consideration been taken for when moving the girder sideways on the upper part of the substructure?				Compare with the construction plan Check on the site
	(a) Installation position of jacking bracket				
	(b) Anchor for side movement				
	(c) The size of the bridge seat face				
	(d) Replacement at the time of jacked down				
	(8) Is the slope of the drawer track appropriate?	Be careful when the orbit gradient is 2% or more.			Compare with the construction plan Check on the site
	(9) Are the measures for fall prevention and braking sufficient?				Compare with the construction plan Check on the site
	(10) Are safety measures at the time of erection sufficient?				Compare with the construction plan Check on the site
	(a) Fulcrum position of the girder				
	(b) Transverse stability of the girder				
	(c) Longitudinal cant when lifting the girder				
	(11) Are the measures for fall prevention after erection of girders sufficient?				Compare with the construction plan Check on the site

4. Steel Bridge Edition

Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
4-1	Installation				–	–	
4-1- 1	Surveying	(1)	Has the center line (planar linear) been checked?				Measurements shall be made for each abutment and pier based on the reference point instructed by the supervisor, the reference point in the substructure work, and reference datum.
		(2)	Has the span been checked?				The distance (span) and the bridge length between the centers of all the abutments and bridge piers shall be measured by vertical line.
		(3)	Has the planned height been checked?				The bearing positions of all abutments and bridge piers shall be measured.
		(4)	Has the bearing position been checked?				All bearing positions, bearings and anchor bolt positions shall be measured.
4-1- 2	Staging	(1)	Are the materials being used in accordance with the construction plan?				Check on the site
		(2)	Is the position appropriate?				Check on the site
		(3)	Is the strength of bearing ground sufficient?				Check on the site
		(4)	Is there any fear of subsidence?				Check on the site
		(5)	Is there any fear of falling?				Check on the site
		(6)	Is the verticality appropriate?				Check on the site
4-1- 3	Truck Crane	(1)	Are the type of vehicles being used on site in accordance with the construction plan?				Check on the site
		(2)	Is the ground of the work yard sufficient?				Check on the site

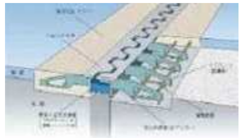
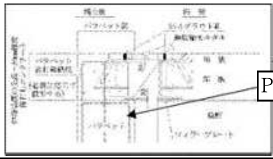
Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
4-1- 4	Cable Crane	(1)	Are the track wire, hanging wire, backstay wire, tower and crane in accordance with the construction plan?				Check on the site
		(2)	Has a performance test been conducted for cranes?				Check by loading tests
		(3)	Is there any risk of subsidence of towers?				Check on the site
		(4)	Is there any risk of falling/overturning of towers?				Check on the site
4-1- 5	Construction of Scaffolding	(1)	Are the materials being used in accordance with the construction plan?				Check on the site
		(2)	Has the scaffolding been installed in accordance with the construction plan?				Compare with the construction plan
		(3)	Has the pipe joints and intersecting parts been firmly fixed?				Check on the site
		(4)	Is the spacing of hanging chains appropriate?				Check on the site
		(5)	Is the installation width of scaffolding appropriate?				Check on the site
		(6)	Is the safety net installed?				Check on the site
		(7)	Is the installation of scaffolding board appropriate?				Check on the site
4-1- 6	Lateral Transfer	(1)	Has the lateral transfer been done in accordance with the construction plan?				Check on the site
4-1- 7	Prevention from Side Buckling of Girders	(1)	Has the prevention method for side buckling of girders been done in accordance with the construction plan?				Check on the site

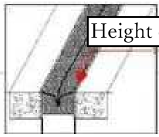
Items		Checklist		Explanatory chart	Judgment		Method of Confirmation
					Yes	No	
4-1- 8	Erection Inspection	(1)	Before releasing the support work after completing temporary tightening, inspect the following items.		–	–	Results of inspection shall be reported.
			(a) Has the cambers been checked? (fulcrum, center of span,installing position of sway bracing)				Confirmation by measurement
			(b) Are there no gaps or damage due to deformation, warping, etc. on joint materials on site?				Check on the site
			(c) Is the welding plate in its predetermined position?				Check on the site
			(d) Has an inspection for hole misalignment been carried out?				Check on the site
4-1- 9	Inspection of Completed Erection	(1)	After releasing the support work and completing tightening, inspect the following items.		–	–	Results of inspection shall be reported.
		(2)	Has the cambers been checked? (fulcrum, center of span, installing position of sway bracing)				Confirmation by measurement
		(3)	Rivet tightening inspection		–	–	
			(a) Is rivet tightening appropriate?				a) Inspection by test hammer
			(b) Are there no pocks or cracks on rivet heads?				b) Check on the site
			(c) Are there no gaps between welding plate and welding plate?				c) Check on the site
4-1- 10	On-site Tightening of High-strength Bolts	(1)	Has the axial force gauge, torque wrench and impact wrench been used according to the construction plan?				Check with quality certificate and recent test results
		(2)	Has the on-site tightening management been performed in accordance with the construction plan?				Check on the site
		(3)	Have the high-strength bolts been stored and handled in accordance with the construction plan?				Check on the site
		(4)	Is the work environment in accordance with the construction plan?				Check on the site

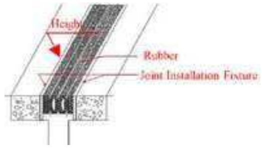
Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
		(5)	Has the tightening for the high-strength bolts been inspected?				For the tightened bolt, be sure to measure the on-site torque value for 10% or more of each bolt group by torque wrench within the day.
4-2	Factory Coating				—	—	
4-2- 1	Inspection of Work Management Record	(1)	Has the condition of used coating materials been checked?				The work management record (photo attached) shall be submitted by the contractor, and reviewed by supervisor.
		(2)	Has the work environment been checked?				The work management record (photo attached) shall be submitted by the contractor, and reviewed by supervisor.
		(3)	Has the condition of coated surfaces been checked?				The work management record (photo attached) shall be submitted by the contractor, and reviewed by supervisor.
		(4)	Has the appearance of coating film been checked?				The work management record (photo attached) shall be submitted by the contractor, and reviewed by supervisor.
		(5)	Has the coating interval been checked?				The work management record (photo attached) shall be submitted by the contractor, and reviewed by supervisor.
		(6)	Has the coating film thickness been checked?				The work management record (photo attached) shall be submitted by the contractor, and reviewed by supervisor.
4-2- 2	Appearance Inspection	(1)	Appearance inspection of the parts carried on site shall be performed.		—	—	
		(2)	Is the coated surface in the factory appropriate?				Check on the site
		(3)	Are the parts which have not been coated in factory appropriate?				Check on the site
		(4)	Are the parts which have only been coated with a primer in the factory appropriate?				Check on the site

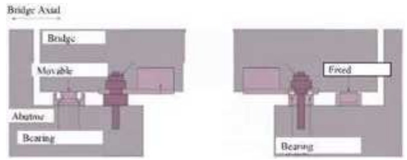
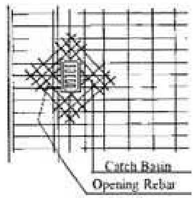
Items		Checklist		Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
4-3	Coating on the Site				—	—	
4-3- 1	Confirmation of Coating Materials	(1)	Do the coating materials conform to the prescribed standard?	 Certificate of Coating Material			Standard certificate shall be submitted by supervisor and judged.
4-3- 2	Inspection of Coating Film Condition before Construction	(1)	Are the condition of the surfaces coated in the factory appropriately clean?				Check on the site
		(2)	Have any damaged parts of surfaces coated in the factory been appropriately repaired?				Check on the site
4-3- 3	Work Environment	(1)	Is the working environment suitable for carrying out coating work?	Working environment ・Environmental conditions must observe the temperature and humidity specified for each paint. ・Do not paint in case of rain, snow or strong winds. coating interval (re-coating) ・In the case of repeated coating of paints, the paint intervals specified for each paint must be observed.			Check on the site
		(2)	Does the coating interval (re-coating) conform to the prescribed standard?				Check on the site
4-3- 4	Inspection of Coating Film Situation after Construction	(1)	Has an inspection of the coating film and confirmation that there are no defects been carried out?	 Inspection of coating film situation after construction			Check on the site
4-3- 5	Inspection of Coating Film Thickness	(1)	Is the dried film thickness of coating film appropriate?	 Inspection of coating film thickness			Film thickness control record shall be submitted by contractor and judged. In addition, sampling inspection shall be conducted as necessary.
4-3- 6	Confirmation of Used Amount of Coating Materials	(1)	Has the amount of coating materials on used site been checked?	 Coating material inspection			Empty cans of used coating materials shall be gathered and inspected (take pictures).

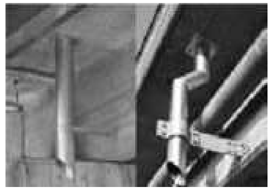
5. Bridge Ancillary Structure Edition

	Items	Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
5-1	Expansion Joint			—	—	
5-1- 1	Steel Expansion Joint			—	—	
5-1- 1-1	Material	(1) Did you confirm the certificate of quality of material?	The quality of material should be confirmed by certificate.			Confirm by the certificate of quality
5-1- 1-2	Production	(1) Is the dimension in accordance with shop drawing?	  Steel expansion joint			Check on the site
		(2) Is there no defect in welding?				Check on the site
		(3) Has the product been damaged during transportation?				Check on the site
5-1- 1-3	Installation	(1) Is the finger clearance appropriate?	 Finger clearance  Installation height			Check by the survey
		(2) Are the installation height and profile in accordance with shop drawing?				Check by the survey
		(3) Is the paint of expansion joint appropriate?				Check on the site
		(4) Is rust removal on the concrete contact surface of the expansion joint appropriate?				Check on the site
		(5) Are the slab rebar and parapet rebar in accordance with shop drawing?	 Parapet rebar			Compare with the shop drawing
5-1- 1-4	Concrete	(1) Did you check the class of concrete before concrete casting?				Compare with the shipping ticket
		(2) Have the concrete joint faces been chipped, cleaned and water sprayed?	Refer to Concrete Edition			Check on the site
5-1- 1-5	Quality Control	(1) Did you check the slump, air content and temperature at concrete casting site?				Compare with the construction plan Check on the site
		(2) Did you take sample pieces for concrete strength testing?	Refer to Concrete Edition			Check on the site Confirm by the test result
		(3) Does the concrete strength satisfy the reference value?				Check on the site Confirm by the test result
		(4) Is the strength of the concrete properly managed?				Check on the site Confirm by the test result

Items		Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
		(5) Is the curing of concrete appropriate?				Check on the site
5-1- 1-6	Shrinkage-compensating Mortar	(1) Is the quality of shrinkage-compensating mortar in accordance with the specification?	The quality of material should be confirmed by certificate.			Check on the site Confirm by the test result
		(2) Is the casting timing of shrinkage-compensating mortar appropriate?				Check on the site
		(3) Is the casting method of shrinkage-compensating mortar appropriate?				Check on the site
5-1- 2	Butt, Rubber Joint			–	–	
5-1- 2-1	Material	(1) Did you confirm the certificate of quality of material?	The quality of material should be confirmed by certificate.			Confirm by the certificate of quality
5-1- 2-2	Production	(1) Is the dimension in accordance with the shop drawings?	 Butt type rubber joint			Check by the survey
5-1- 2-3	Pavement	(1) Are you protecting the finger clearance and the floor slab with steel plate, sand, etc., before paving?				Check on the site
5-1- 2-4	Removal of Pavement	(1) Are you accurately marking the cutting position?	 Floor slab hipped and cleaned			Check on the site
		Are you accurately marking the cutting position before removing the pavement?				Check on the site
5-1- 2-5	Cleaning the Butt Joint	(1) Is the floor slab chipped and cleaned?				Check on the site
5-1- 2-6	Installation of Formwork	(1) Is the level adjustment bracket installed?				Check on the site
5-1- 2-7	Resin Mortar Layer	(1) Has the floor slab been dried enough before applying the primer?	 Resin mortal layer			Check on the site
		(2) Did you confirm the resin mortar job mix?				Check on the site
		(3) Did you check the finishing height of resin mortar?	 Height of Sealing Rubber Check the height			Check by the survey
5-1- 2-8	Set of Sealing Rubber	(1) Did you check the height of sealing rubber?				Check by the survey

Items		Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
5-1- 3	Rubber Joint			—	—	
5-1- 3-1	Installation	(1) Is the concrete joint face chipped and cleaned?	 Rubber joint  Floor slab chipped and cleaned			Check on the site
		(2) Did you check the installation height of the joint installation fixture?				Check on the site
		(3) Did you check the arrangement of reinforcing bars and anchors?				Compare with the shop drawing
		(4) Has the joint installation fixture been fixed firmly so as not to be displaced during concrete casting?				Check on the site
5-1- 3-2	Concrete	(1) Is the quality of concrete appropriate?	Refer to Concrete Edition			Check on the site
		(2) Is the curing of concrete appropriate?				Check on the site
5-1- 3-3	Set of Sealing Rubber	(1) Has the tightening nut been sufficiently tightened?	 Joint installation fixture  Arrangement of reinforcing bars and anchors			Check on the site
		(2) Did you check the finishing height of sealing gum?				Check by the survey
5-2	Bearing			—	—	
5-2- 1-1	Material	(1) Did you confirm the quality of material?	The quality of material should be confirmed by certificate.			Confirm by the certificate of quality
5-2- 1-2	Production	(1) Is the dimension in accordance with the shop drawings?	 Bearing  Blockout  Blockout fixing			Check by the survey
5-2- 1-3	Blockout	(1) Did you check the position and the size of the blockout?				Check on the site
		(2) Is the blockout firmly fixed so that it will not be pulled out easily?				Check on the site
5-2- 1-4	Shoe Seat	(1) Did you check the arrangement of reinforcing bars of the shoe seat?	 Reinforcing bars of the shoe seat  Check the height and position of bearing			Compare with the shop drawing
5-2- 1-5	Installation	(1) Did you check the height and position of bearing?				Check by the survey
		(2) Did you check the direction of bearing?				Check by the survey

Items		Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
		(3) Is the type of bearing (fixed bearing / movable bearing) in accordance with the shop drawings?	 Bearing clearance			Compare with the shop drawing
		(4) Is the bearing clearance appropriate?				Check by the survey
5-2- 1-6	Shrinkage-compensating Mortar	(1) Is the material of shrinkage-compensating mortar in accordance with the specification?	The quality of material should be confirmed by certificate.			Confirm by the certificate of quality
		(2) Did you check whether the inside of the blockout had been cleaned?	 Completed shrinkage-compensating mortar  Completed installation of bearing			Check on the site
		(3) Is the quality of shrinkage-compensating mortar in accordance with the specification?				Check on the site Confirm by the test result
		(4) Is the casting timing of shrinkage-compensating mortar appropriate?				Check on the site
		(5) Is the casting method of shrinkage-compensating mortar appropriate?				Check on the site
5-2- 1-7	Anchor Bolt	(1) Have the anchor bolt and set bolt been tightened sufficiently?				Check on the site
5-3	Drainage Apparatus			–	–	
5-3- 1	Catch Basin			–	–	
5-3- 1-1	Material	(1) Did you confirm the quality of the catch basin material?	The quality of material should be confirmed by certificate.			Confirm by the certificate of quality
5-3- 1-2	Production	(1) Is the dimension in accordance with the shop drawings?	 Catch basin  Arrangement of the opening rebar			Compare with the shop drawing
5-3- 1-3	Installation	(1) Did you check the position and height of the catch basin?				Check by the survey
		(2) Did you check the arrangement of the rebar?				Compare with the shop drawing
		(3) Before paving, is catch basin sufficiently covered so that asphalt mixture cannot enter it?				Check on the site
5-3- 2	Drain Pipe			–	–	
5-3- 2-1	Material	(1) Did you confirm the quality of the material?	The quality of material should be confirmed by certificate.			Confirm by the certificate of quality

Items		Checklist	Explanatory chart	Judgment Yes	Judgment No	Method of Confirmation
5-3- 2-2	Production	(1) Are the dimensions in accordance with the shop drawings?	 Drain pipe			Compare with the shop drawing
5-3- 2-3	Installation	(1) Is the drain slope in accordance with the shop drawings?				Check by the survey
		(2) Is the fitting bracket painted or hot-dip galvanized?				Check on the site
		(3) Did you carry out a water flow test after completion?				Check on the site
5-4	Curbstone			–	–	
5-4- 1	Concrete	(1) Is the quality of concrete appropriate?	Refer to Concrete Edition			Check on the site
		(2) Is the curing of concrete appropriate?				Check on the site
5-4- 2	PC Products	(1) Are there no breakages, cracks or defective products in the curb installation?				Check on the site
		(2) Is the installation position in accordance with the shop drawings?				Check on the site
5-5	Guard Fence			–	–	
5-5- 1	Material	(1) Did you confirm the quality of material?	The quality of material should be confirmed by certificate.			Confirm by the certificate of quality
5-5- 2	Production	(1) Are the dimensions in accordance with the shop drawings?	 Guard fence			Compare with the shop drawing
		(2) Is the curing of concrete appropriate?				Check on the site
		(3) Have no joint bolts been left out?				Check on the site
		(4) Is the installation position in accordance with the shop drawings?				Check on the site
5-6	Wall Balustrade			–	–	
5-6- 1	Concrete	(1) Is the quality of concrete appropriate?	Refer to Concrete Edition			Check on the site
		(2) Is the curing of concrete appropriate?	 Wall balustrade			Check on the site
		(3) Is the installation position in accordance with the shop drawings?				Check on the site

MANUAL 4 : Guideline for Field Checklist on the Basic Items on Safety Control for Bridge Construction

CAMBRIDGE

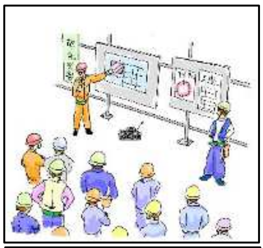
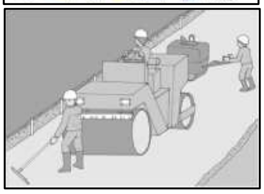
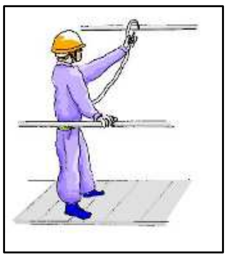
Technical Cooperation Project for Capacity Development in Construction and Maintenance of Bridges in the Kingdom of Bhutan

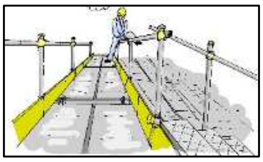
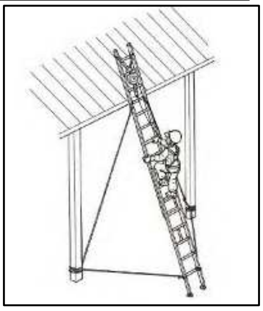
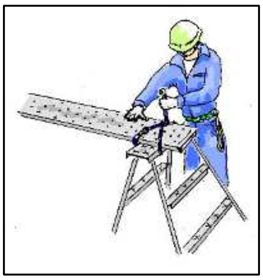
Guideline for Field Checklist on the Basic Items on Safety Control for Bridge Construction

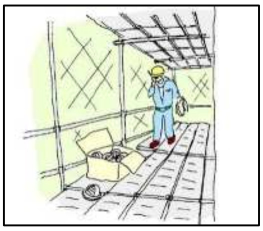
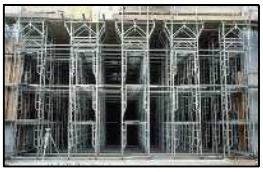
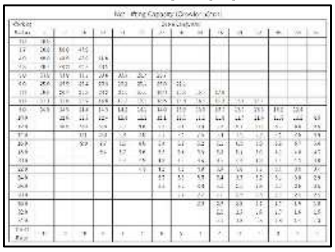
April 2022

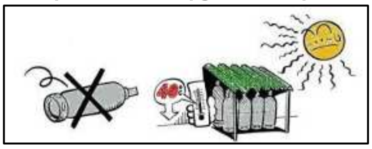
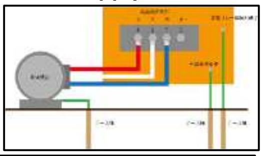
Department of Road
Ministry of Works & Human Settlement
Royal Government of Bhutan

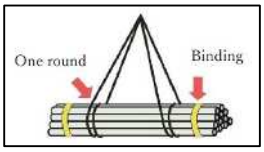
Japan International Cooperation Agency

Work Item	Check Points	Plan /Site	Answer
Preparatory Item			
	Is Construction Work notified to MoLHR	Plan	Yes / No / NA
	Is the Safety Plan submitted?	Plan	Yes / No / NA
Daily Works			
Accident Cases  (Regulation of MoLHR)	Are there any accidents happened in the project sits?	Records	Yes / No / NA
	Did you report the cases to Client/Police/MoLHR?	Records	Yes / No / NA
	Are there any accidents reports if there were accidents?	Records	Yes / No / NA
Morning Meeting  Morning Meeting  THP	Is the morning meeting being conducted every day?	Site	Yes / No / NA
	Is the status of the attendance of the workers being confirmed in the meeting?	Site	Yes / No / NA
	Is the presence of the drunken, child and aged labors being confirmed for exclusion?	Site	Yes / No / NA
	Is the health condition of the workers being confirmed?	Site	Yes / No / NA
	Is the work schedule on the day being confirmed among the workers?	Site	Yes / No / NA
	Is the potential hazardous works being identified? Is its measures being explained to all the workers?	Site	Yes / No / NA
	Is THP（Training for Hazard Prediction）being conducted regularly?	Site	Yes / No / NA
Safety Goal and Sign Board	Is Safety Goal for the project prepared?	Site	Yes / No / NA
	Is the sign board minimum 30cm×100cm indicating "Safety First" prepared and being placed at the arrestive place?	Site	Yes / No / NA
Clothes and Safety Gadget of Workers 	Do the workers wear helmets during working time in construction site?	Site	Yes / No / NA
	Do the workers wear the proper shoes?	Site	Yes / No / NA
	Do the workers wear the proper uniform?	Site	Yes / No / NA
	Do the workers use the proper safety gadgets such as safety belt, goggles, gloves, etc?	Site	Yes / No / NA

Work Item			
Common Works Scaffolding			
	Is the scaffolding prepared as per the safety plan?	Site	Yes / No / NA
 Railings	Is the sufficient work space with proper staging prepared?	Site	Yes / No / NA
	Is strong railings whose heights are 85cm properly placed at high places? High place means the place where the workers may drop 2m in height?	Site	Yes / No / NA
	Is the strong railings properly provided on the stairs?	Site	Yes / No / NA
 stairs for access	Are the proper stairs or ladders provided for the access to the working areas?	Site	Yes / No / NA
 Ladder fixed	Are the ladders fixed at the bottom and top?	Site	Yes / No / NA
 Both end Fixed	Are the foot boards staging fixed to the strong parts at the both end?	Site	Yes / No / NA
 Scaffolding Material	Are the sound and proper materials used for the scaffoldings?	Site	Yes / No / NA
 Slip Stopper	Are the slip stoppers properly provided?	Site	Yes / No / NA

	Protection of Openning	Are all the openings properly covered?	Site	Yes / No / NA
	Safety Net	Are the fall prevention measures such as safety net properly provided at hazardous points?	Site	Yes / No / NA
	Obstractions on the access	Are unnecessary things to hinder the access placed on the walkway of the scaffolding?	Site	Yes / No / NA
	Assembling of Scaffolding	Are the assembly and dismantling done safely?	Site	Yes / No / NA
Shoring Works				
	Shoring	Is the shoring prepared as per the safety plan?	Site	Yes / No / NA
		Is the shoring dismantled after the required strength of concrete is achieved?	Site	Yes / No / NA
		Are the assembly and dismantling of the shoring done safely?	Site	Yes / No / NA
Crane and Heavy Equipment				
	lifting Capacity	Is the capacity of the crane and heavy equipment sufficient for the works to be scheduled?	Site	Yes / No / NA
		Are all the function of the crane and heavy equipment such as outrigger, safety limit switch and lights worked?	Site	Yes / No / NA
		Are the dairy inspection and maintenance being done properly?	Site	Yes / No / NA
		Do the operators have the necessary licenses?	Site	Yes / No / NA
		Is the list of net lifting capacity placed at eye-catching place of the crane?	Site	Yes / No / NA
	Outrigger	Is the outrigger of Crane fully being extended?	Site	Yes / No / NA

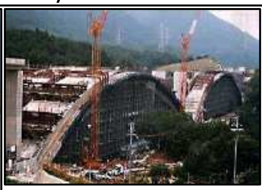
Acetylene and Oxygen Gas Cylinder 			
	Are the Acetylene and Oxygen Gas cylinders being kept standing in the storage?	Site	Yes / No / NA
	Are the fall preventive measures for the standing acetylene gas cylinders being provided?	Site	Yes / No / NA
 standing & fall prevention measure	Are the Acetylene and Oxygen Gas cylinders being kept in shade and less than 40°in temperature?	Site	Yes / No / NA
	Are the Acetylene gas cylinder being kept standing in use?	Site	Yes / No / NA
	Is the firearm being used 5m away from acetylene and oxygen gas cylinder?	Site	Yes / No / NA
Power Supply			
 Grounding	Is the grounding for generator properly provided?	Site	Yes / No / NA
 Cabe size?	Is the size of the transmission cable sufficient?	Site	Yes / No / NA
 Cabe Connection	Are the connections of the cable properly done?	Site	Yes / No / NA
	Do the cables being laid in dry condition / not be in the water?	Site	Yes / No / NA
 Panel Board	Are the power distribution panel boards provided?	Site	Yes / No / NA

Lifting				
	Lifting Wire	Are the sizes of the lifting wires and shackles sufficient?	Site	Yes / No / NA
	Damaged Wire	Do the lifting wire have no kinks or defects?	Site	Yes / No / NA
	Slinging Method	Are the slinging methods proper?	Site	Yes / No / NA
	No workers under lifted loads	Are no workers under the lifted loads?	Site	Yes / No / NA
	Hoisting	Are the signal men and signal patterns identified among all the workers?	Site	Yes / No / NA
		Are the signals for lifting works being properly done according to the identified patterns?	Site	Yes / No / NA
Preparatory Works				
Site / Temporary Yard				
	Barricade	Is the site including temporary yard identified by barricade or fence?	Site	Yes / No / NA
	Temporary Yard	Are the site including temporary yard tidy and cleaned?	Site	Yes / No / NA
		Are equipment and materials organized by the types?	Site	Yes / No / NA
	Fence for Access Road	Are the access roads secured and identified by the fence or rope?	Site	Yes / No / NA
	Sign Board	Are the proper sign boards placed at the appropriate locations?	Site	Yes / No / NA
			Site	

		Are the measures for flying of the construction materials by wind taken?		Yes / No / NA
Detour Road / Bridge				
	Detour Road	Is the width of the detour road sufficient?	Site	Yes / No / NA
	Detour Bridge	Is the design of the detour bridge properly prepared based on the structural calculation?	Plan	Yes / No / NA
		Are the measures for the flood be properly prepared?	Plan	Yes / No / NA
		Are the fall prevention measures into river such as guard rails taken?	Site	Yes / No / NA
		Is the construction of the detour bridge properly done?	Site	Yes / No / NA
	Lighting for Road	Are the lights and/or reflectional facilities properly provided?	Site	Yes / No / NA
	Signal Man	Is the flag man properly deployed?	Site	Yes / No / NA
Dewatering				
		Are the soil or steel sheet pile cofferdam properly designed and planed?	Plan	Yes / No / NA
		Are the soil or steel sheet pile cofferdam properly constructed?	Site	Yes / No / NA
		Is the working space in the cofferdam sufficient?	Site	Yes / No / NA
		Is the capacity of the submersible pump sufficient?	Site	Yes / No / NA
		Are the measures for the flood properly prepared?	Plan	Yes / No / NA

Earth Works			
 	Are the Specifications and condition of the equipment such as backhoe, bulldozer or dump trucks proper and good?	Plan/ Site	Yes / No / NA
 	Are the design and the work of the soil cofferdam properly done?	Plan/ Site	Yes / No / NA
 	Is the gradient of the cut slope proper?	Site	Yes / No / NA
 	Is the drainage plan for surface and underground water properly prepared?	Plan/ Site	Yes / No / NA
 	Is the ground or stage for heavy equipment proper and stable?	Site	Yes / No / NA
 	Is the access road for the hauling of soil material properly secured?	Site	Yes / No / NA
 	Are the measures for the falling rocks such as head guard of equipment or barricade properly taken?	Site	Yes / No / NA
	Are the barricades properly placed?	Site	Yes / No / NA
	Are the signal men properly deployed?	Site	Yes / No / NA

Foundation Works			
 Driving piles	Is the capacity of the crane for driving and excavation work sufficient?	Plan/ Site	Yes / No / NA
 Stage	Is the staging for the crane properly planned and executed?	Plan/ Site	Yes / No / NA
	Are the measures for the flood properly prepared?	Plan	Yes / No / NA
Abutment and Pier			
Reinforcing Bar			
 Cutting and Bending Yard	Is the rebar cutting and bending yard wide enough and tidy?	Site	Yes / No / NA
 Scaffolding	Is the scaffolding for rebar fabrication prepared as mention in clause 2.3.3?	Site	Yes / No / NA
	Is the lifting of the rebar proper?	Site	Yes / No / NA
	Is the safety belt properly used in case proper scaffolding with railing cannot be prepared?	Site	Yes / No / NA
Form Work			
 Fabrication Yard	Is the form preparation yard wide enough and tidy?	Site	Yes / No / NA
 Froms	Are the forms properly fabricated based on the structural calculation?	Plan/ Site	Yes / No / NA
	Are the forms free from rotten and damaged materials?	Site	Yes / No / NA
	Is the scaffolding for form assembly prepared as mention in clause 2.3.3?	Site	Yes / No / NA
	Is the lifting of the forms properly done?	Site	Yes / No / NA
	Is the safety belt properly used in case proper scaffolding with railing cannot be prepared?	Site	Yes / No / NA

Concreting			
 Concrete Pump	Are the pouring methods (crane, concrete pump, chute, direct, etc) properly selected?	Plan/ Site	Yes / No / NA
	Is the ground or stage for setting of concrete pump and transit mixer cars stable?	Site	Yes / No / NA
	Is the size and condition of the lifting wire for concrete bucket good and proper?	Site	Yes / No / NA
	Is the signal man being deployed?	Site	Yes / No / NA
	Is the scaffolding for concreting prepared as mention in clause 2.3.3?	Site	Yes / No / NA
Fabrication and hauling of the girder			
 Stressing of PV	Is the PC wire stressing plan proper? Does the plan include the expert of PC stressing?	Plan/ Site	Yes / No / NA
	Are the hauling route with the alignment and bridge load limit checked in advance?	Site	Yes / No / NA
 	Is the hauling method including lifting and fixing properly prepared?	Plan	Yes / No / NA
Girder Erection  	Is the erection plan properly prepared based on the structural calculation?	Plan	Yes / No / NA
	Is the stage of the crane properly planned and stable?	Plan/ Site	Yes / No / NA
	Is the capacity of the crane sufficient?	Plan/ Site	Yes / No / NA
	Is the condition of the crane good?	Plan/ Site	Yes / No / NA
	Is the measures for the flood properly prepared?	Plan	Yes / No / NA
Cast-in-place Concrete Girder / Slab			
 	Is the shoring plan properly prepared based on the structural calculation?	Plan	Yes / No / NA
	Is the scaffolding properly planned and prepared as mention in clause 2.3.3?	Plan/ Site	Yes / No / NA
	Are the forms safely and properly being assembled?	Site	Yes / No / NA
	Is the measures for the flood properly prepared?	Plan	Yes / No / NA

MANUAL 5 : Action Plan for Bridge Maintenance

CAMBRIDGE

Technical Cooperation Project for Capacity Development
in Construction and Maintenance of Bridges
in the Kingdom of Bhutan

Action Plan
for
Bridge Maintenance

April 2022

Department of Road
Ministry of Works & Human Settlement
Royal Government of Bhutan

Japan International Cooperation Agency

Table of Contents

1. Objective of the Action Plan

This action plan is to define action plan to be taken to implement bridge maintenance.

2. Bridge Maintenance Cycle

The concept of Bridge Maintenance Cycle to implement is shown in Figure-1. There are two cycle. One is usual maintenance cycle and another one is emergency cycle for disaster. Maintenance Operation Meeting (MOM) should be held before budget proposal.

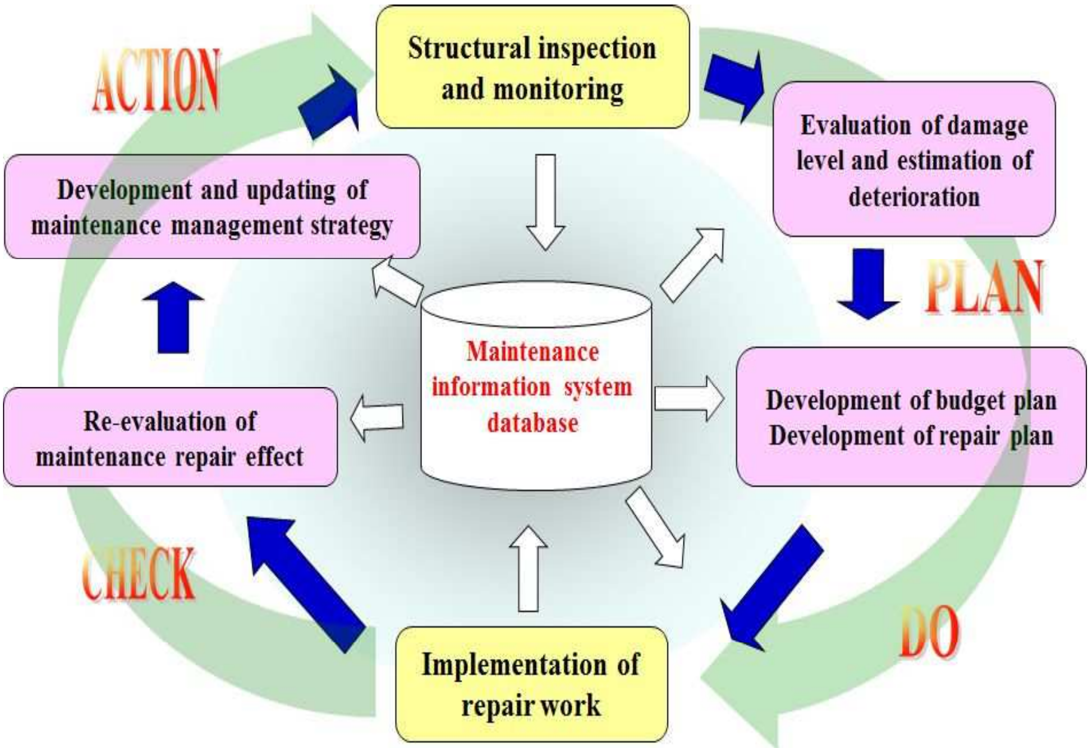


Figure-1 Bridge Maintenance Cycle

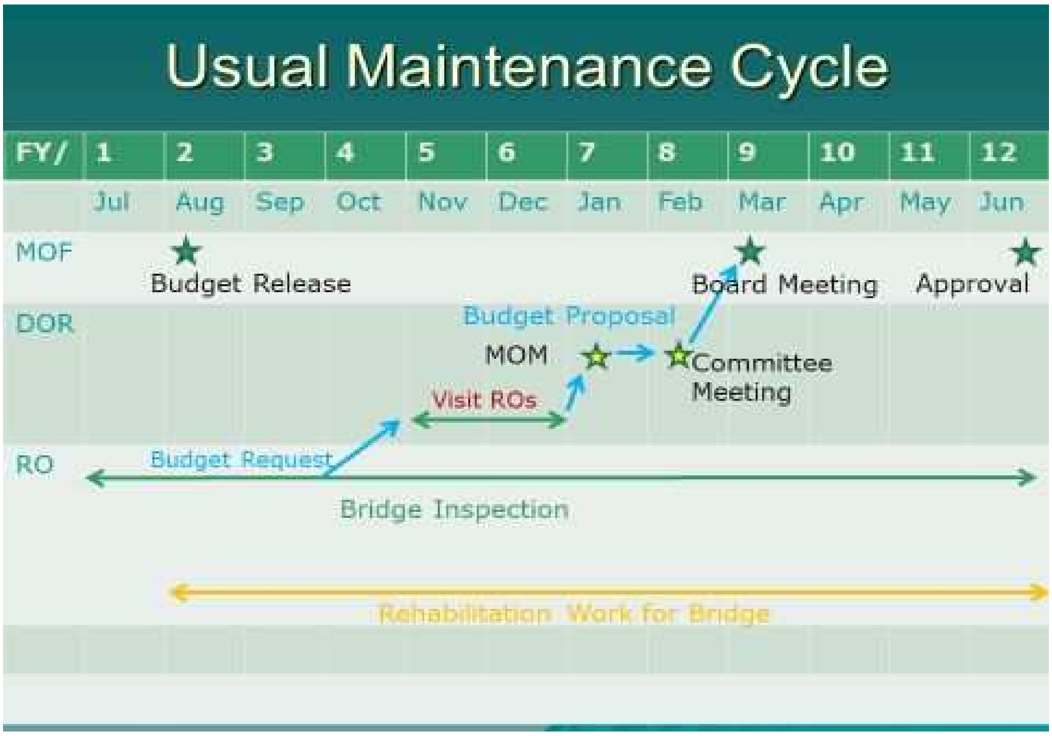


Figure-2 Usual Maintenance Cycle

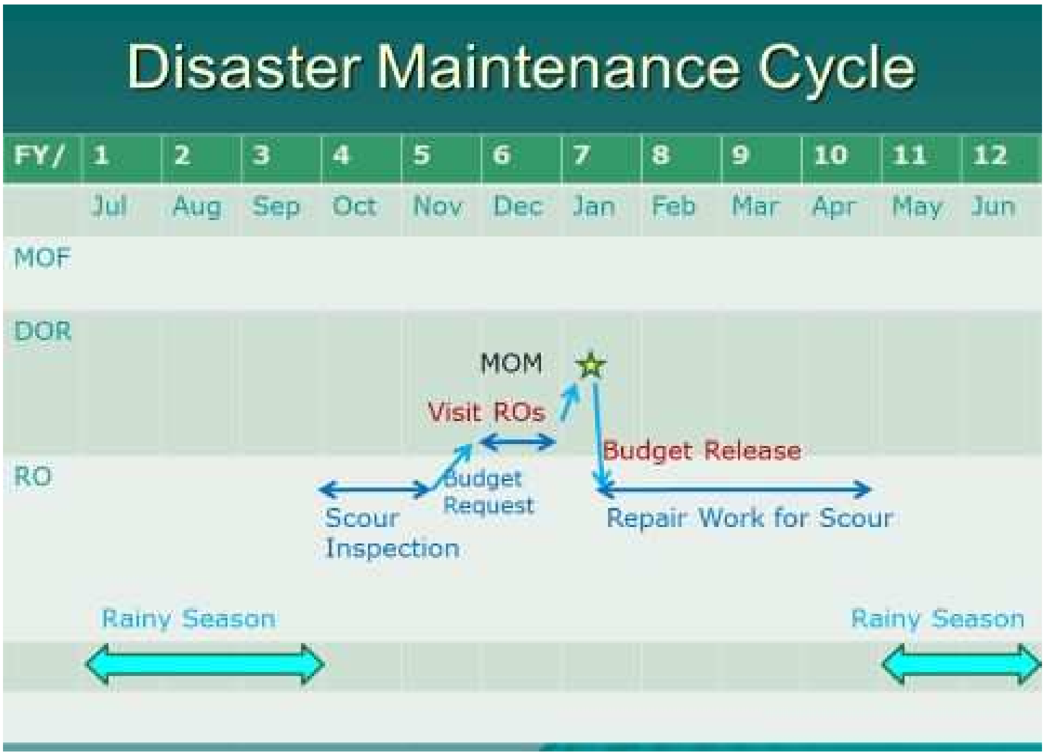


Figure-3 Disaster Maintenance Cycle

3. Action Plan

Action plan to implement the bridge maintenance cycle continuously is hereinafter explained.

3.1 Bridge Inspection

(1) Action to take

{1-1} Routine Inspection: Conducting Routine Inspection along with road inspection

{1-2} Periodic Inspection: Conducting Periodic Inspection of all bridges every year. Additionally, Post Rainy Season Inspection of all bridge right after rainy season should be carried out to check the bridge conditions especially for scouring.

{1-3} Detailed Inspection: The detailed Inspection is to be conducted for the selected bridges (approximately 5 to 10 bridges per year) from Periodic Inspection result in the Maintenance Operation Meeting(MOM)

(2) Implementer

EE (Maintenance section) of Regional Office, Subdivision Office

Support from DOR HQ

3.2 Condition Assessment

(1) Action to take

{2-1} Initial Assessment: Review and evaluation of the periodic inspection/post rainy season inspection results. The evaluation will be verified in Maintenance Operation Meeting. Prepare long list.

{2-2} Second Assessment: Assessment of detailed survey result. Select priority bridges to prepare short list.

(2) Implementer

EE (Maintenance section) of Regional Office, Subdivision Office

Support from DOR HQ

3.3 Planning and Budgeting

(1) Action to take

{3-1} Countermeasure Study and Budget Plan: Study countermeasure based on the detailed survey and prepare budget plan. Prepare the final list.

{3-2} Donor Partner Coordination if any: Coordination with donor fund project and reflect to short list.

(2) Implementer

EE (Maintenance section) of Regional Office, Subdivision Office

Support from DOR HQ

3.4 Information and Database Management

(1) Action to take

{4-1} Record the inspection data to the system

- Update of the database
- Provision of data to DOR

{4-2} Management of the bridge database

{4-3} Data collection: Collection of the general drawings of past projects, especially donor fund projects. Add and update the database.

{4-4} Server management: Setting of server and its maintenance.

(2) Implementer

Responsible person in DOR HQ

EE (Maintenance) Regional Office, Focal Person of Regional Office

3.5 Maintenance Operation Meeting (MOM)

DOR has the principal responsible to manage the various maintenance operations which includes inspection, assessment, countermeasure work and recording. Maintenance Operation Meeting (MOM) is the meeting to supervise the bridge maintenance operations and to make decisions on bridge maintenance related plan. DOR shall organize the meeting every January. MOM can be held any time if necessary.

(1) Action to take

{5-1} Verifying followings

- Inspection results
- Selection of priority bridges (long list)
- Report on detailed survey
- Final selection of bridges for next FY (Final List)
- Countermeasure/cost plan

(2) Implementer

Chief Engineer (Bridge), EE (Construction and Maintenance)

Chief Engineers of Regional Office, EE (Maintenance) of Regional Office

3.6 Committee Meeting

The Committee meeting is the meeting to prioritize the bridges according to the report presented by the assessment team. DOR shall organize the meeting latest by February.

(1) Action to take

{6-1} Verifying followings

- Inspection results
- Selection of priority bridges (long list)
- Final selection of bridges for next FY (Final List)

(2) Implementer

Director General, DOR

Chief Engineer DOR HQ

3.7 Budget Negotiation and Finalization

(1) Action to take

{7-1} DOR will negotiate with MOF for the selected bridges for the next fiscal year referring to the meeting's decision

{7-2} After negotiation, MOF will take appropriate action.

(2) Implementer

DOR & MOF

4. Execution Plan

4.1 Prepare Execution Plan

(1) Action to take

{1-1} 'e' ranked bridges should be given priority.

{1-2} Segregate bridges which should be repaired or strengthen and which should be reconstructed.

{1-3} 'e' ranked bridges which are to be repaired should be given priority.

{1-4} Separate budget should be proposed for the bridges which are to be strengthen or reconstructed.

(2) Implementer

Regional office and DOR HQ

Support by MOWHS and MOF

4.2 Repair and Strengthen Work

(1) Action to take

{2-1} "e" Rank Damage: "e" rank damages should be repaired within next fiscal year. Appropriate countermeasures should be selected along with the cost estimation.

{2-2} Other Rank Damage: Other rank damages should be repaired in appropriate stage referring BMS Priority Rank. Appropriate countermeasures should be selected along with the cost estimation.

{2-3} Preventive Work: Preventive work such as scour protection for masonry abutment should be carried out in appropriate stage referring BMS Priority Rank. Appropriate countermeasures should be selected along with the cost estimation.

{2-4} Emergency Work: Emergency work such as scour protection should be carried out as soon as possible.

(2) Implementer

Regional office

Support by DOR HQ

5. Reconstruction

(1) Action to take

{1-1} Selection of Target Bridges: Target bridges should be selected considering structure type, load capacity, width, age, deterioration, inhibition of cross sectional area of a river etc.

{1-2} Elements and Dimensions: Elements and dimensions such as superstructure type, substructures type, length, height are assumed and cost should be approximated for all target bridges. Length and height are studied carefully considering bridge site conditions such as landform, catchment area, rainfall etc.

{1-3} Prioritization: Prioritization of reconstruction should be based on BMS priority ranking.

{1-4} Prioritization for next Five Year Plan (FYP): Bridges which cannot be reconstructed during the current FYP should be planned to reconstruct in the next FYP.

(2) Implementer

Regional office

Support by DOR HQ

6. List of Appendix

Appendix-1 Technical Manual on Inspection and Diagnosis of Bridge (April 2022)

Appendix-2 Technical Manual for repair and Reinforcement of Bridge (April 2022)

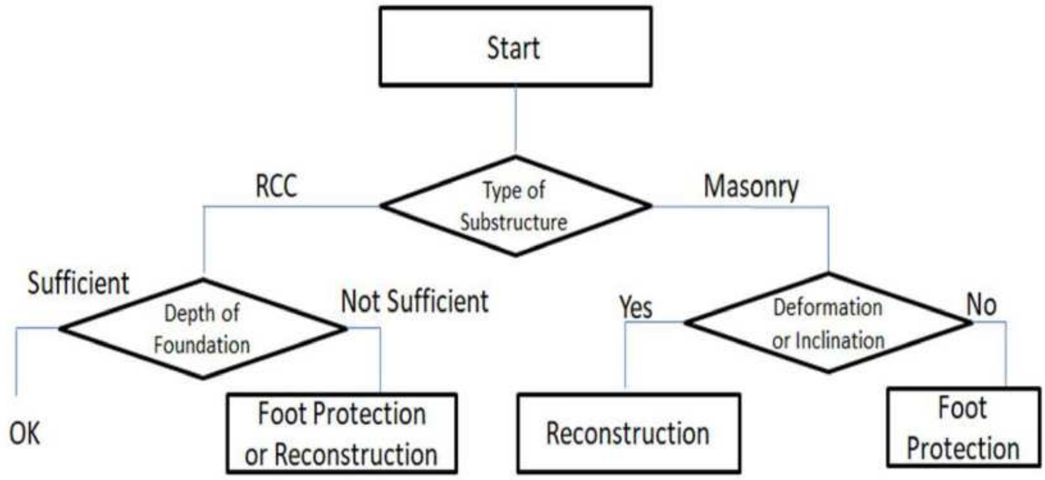
Appendix-3 Principle for Rehabilitation or Reconstruction of Substructures

Appendix-4 Flowchart for Measures against Scour

Principle for Rehabilitation or Reconstruction of Substructures

- Immediate action should be implemented for "e" rank result of Scour or Deformation (All Substructures)
- Second action should be implemented for "c" rank result of Scour or Deformation (Masonry Substructures)
- Third action should be implemented for "c" rank result of Scour or Deformation (RCC Substructures)
- Forth action is preventive countermeasures for all Masonry Substructures
- Reconstruction for all masonry substructures on PNH and SNH
- Rehabilitation for another substructures

Flowchart for Measures against Scour



MANUAL 6 : Operation Manual on Bridge Management System

CAMBRIDGE

Technical Cooperation Project for Capacity Development in Construction and Maintenance of Bridges in the Kingdom of Bhutan

Operation Manual on Bridge Management System

April 2022

Department of Road
Ministry of Works & Human Settlement
Royal Government of Bhutan

Japan International Cooperation Agency

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1 General

The Bridge Management System is developed to efficiently accumulate and update the Bride Ledge and Bridge inspection sheet. Additionally, the prioritization for repairing and reinforcement of bridge can be estimated by weighed factor point for each damaged item. The system also has the function to calculate the repairing cost estimation. Calculated cost is summarized by regional office wise and will contribute to annual budget plan for repair and replace bridges in Bhutan.

➢ Module Structure

The database mainly consist of four modules as follows.

a. Bridge Ledger

The purpose of this module is to stock the Bridge Ledger that consist of geographic data, Bridge data and Photograph. Each bridge ledger connects Inspection sheet and Map function.

b. Bridge Inspection Sheet

The purpose of this module is to accumulate inspection sheet in inspection date order. all damaged item's category, Damaged sketch and damaged photo can be stocked in each inspection.
Each inspection sheet connects damage scale input sheet that can calculate repairing cost based on each inspection result

c. Prioritization function

The purpose of this module is to evaluate the prioritization for repairing and reinforcement of bridges. The prioritization is described as point that add each point based on the bridge ledger critical information and damage category. The calculation result is displayed in bridge inventory list and sorted by prioritization order.

d. Bridge repairing cost estimation

The purpose of this module is to estimate repairing cost based on the defined unit cost multiple damaged scale for each inspection result. The calculated repairing cost will be displayed in bridge inventory list and sorted by cost.

The structure of this module in the system is shown in Figure1.1. Each module and function systematically link each other in BMS system. Especially for "Prioritization of repairing and replacement" and "Repairing and Reinforcement cost calculation", input data connects in system to effectively evaluate and calculate.

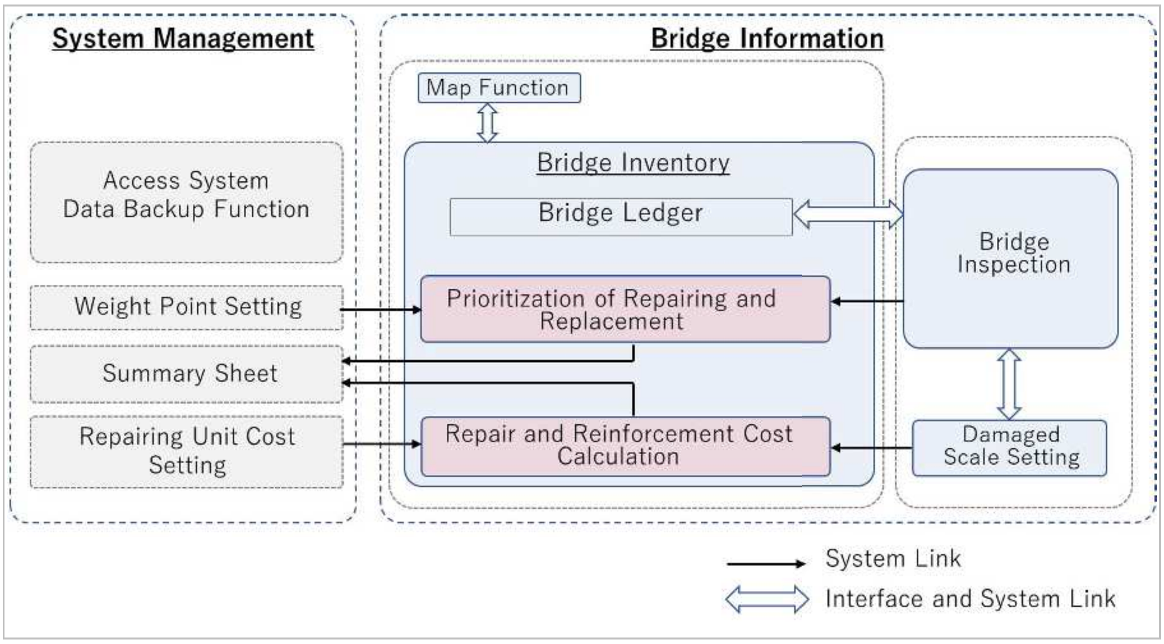


Figure 1.1 The general structure of BMS

➢ System feature and structure

I. Web-based System

By accessing BMS via Web, the System that can be used not only by DoR headquarters bridge division staff but also by regional office staff was developed.

III. Server PC Setting

The server PC for BMS is managed by ICT division MoWHS in the server room. The server management environment is prepared 24 hours a day with air conditions and blackout curtains.

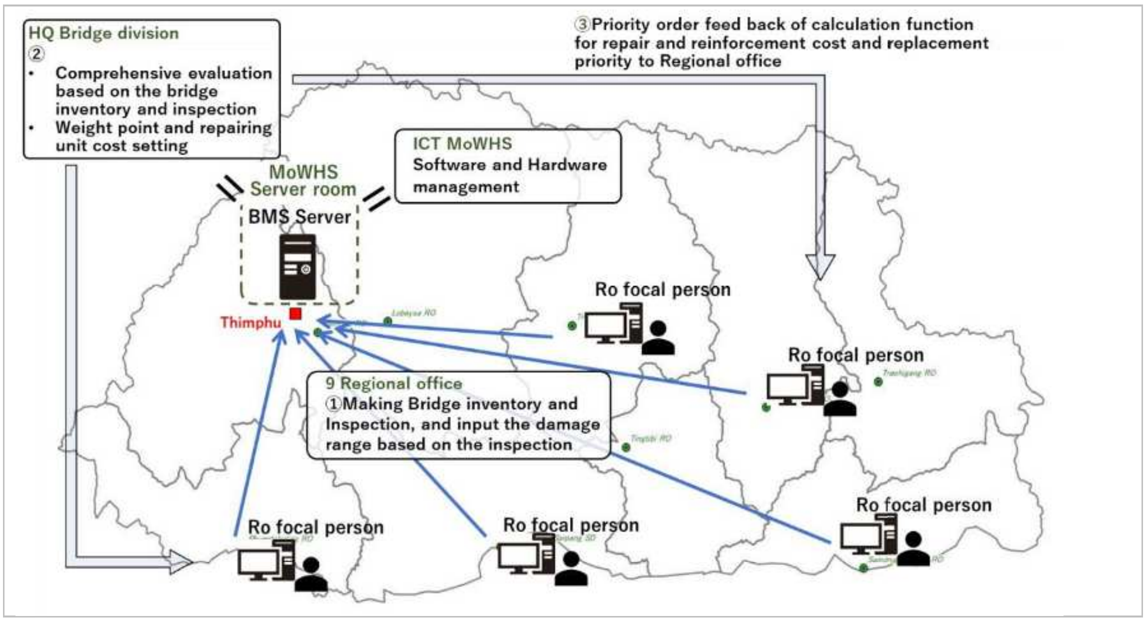
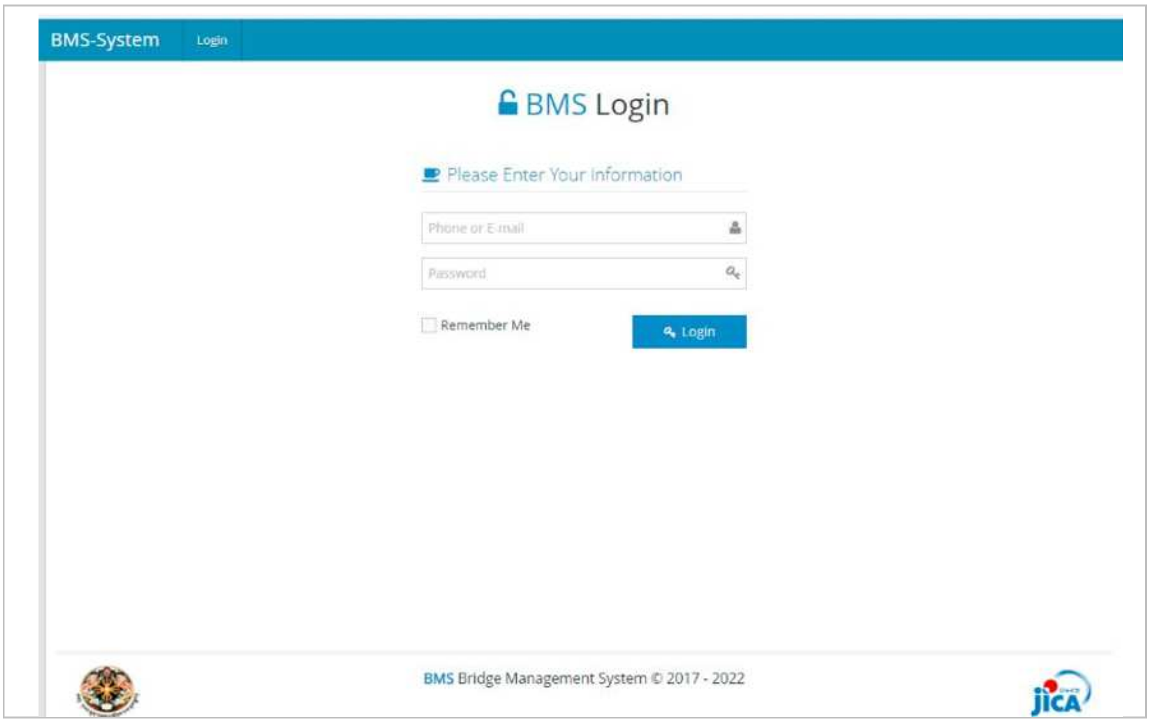


Figure 1.2 Cooperation between HQ and Regional office

2 Initial Operation

2.1 How to Access BMS

The BMS link webpage of MoWHS. All users can access from web page. Additionally for other way to link. The user can access by web link as “http://202.144.157.83/bms/public/p”. The initial display is shown as follows.



URL: http://202.144.157.83/bms/public/p

3 Module Operation

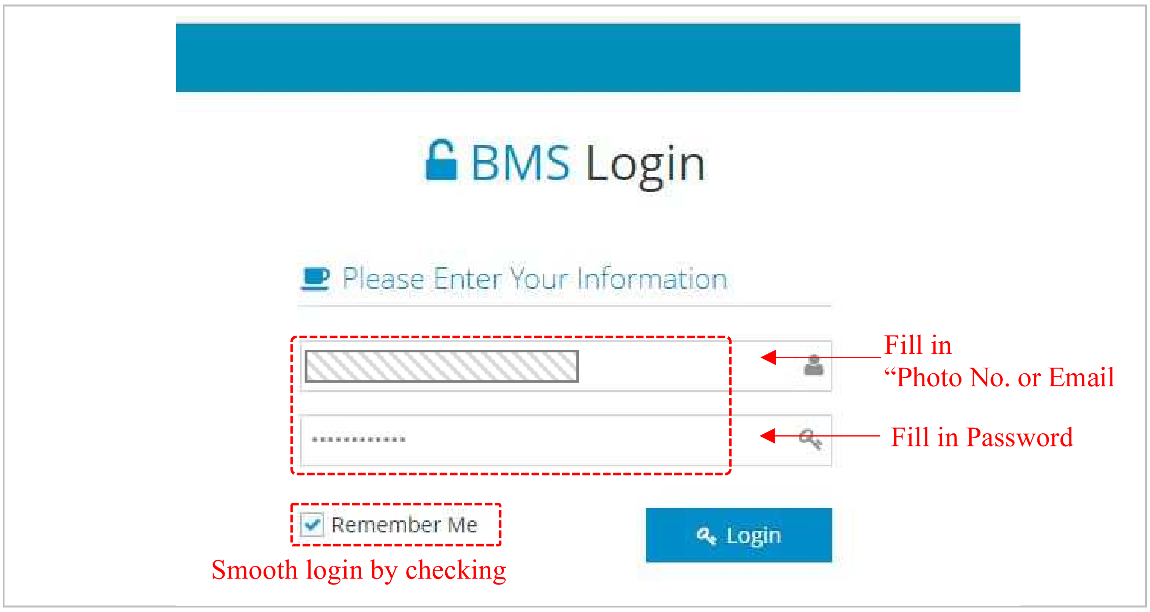
3.1 The Bridge Inventory

Bridge inventory interface is the main display of BMS, and BMS operation starts from this interface. Because the access area in this system is restricted by user mandatory managed by administrator, the user's manual instruction is partially difference of the user mandatory. The instruction is following by interface of administrator user's case.

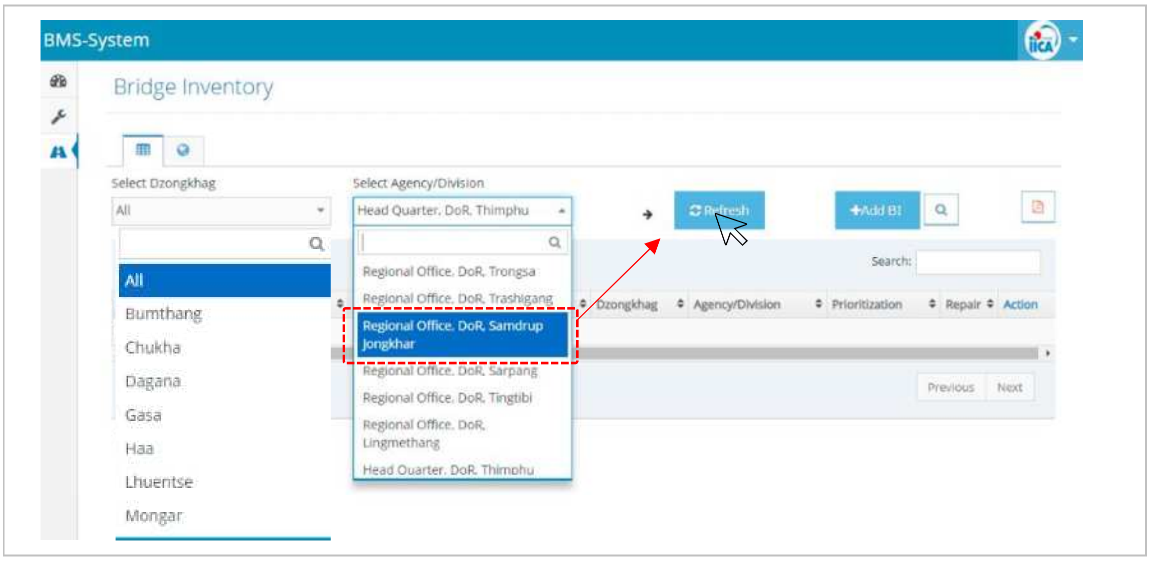
3.1.1 Bridge Inventory List

- How to operate in BMS –

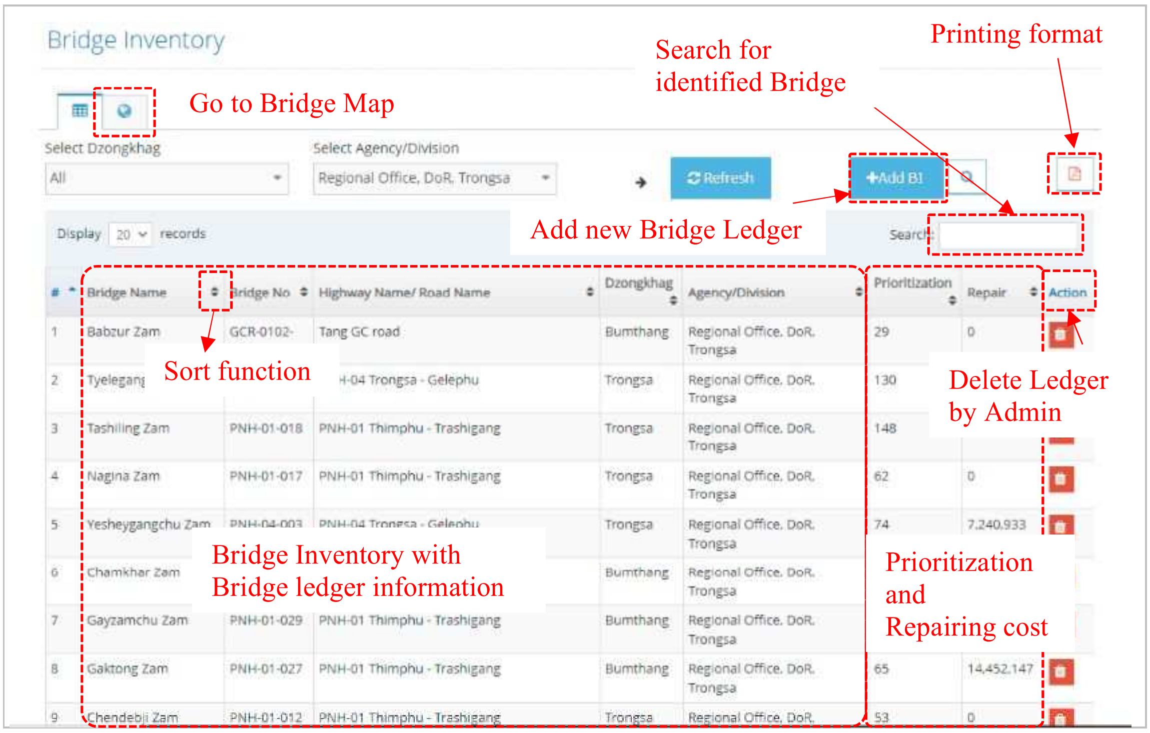
1.



2. How to display Bridge inventory by sorting



3.

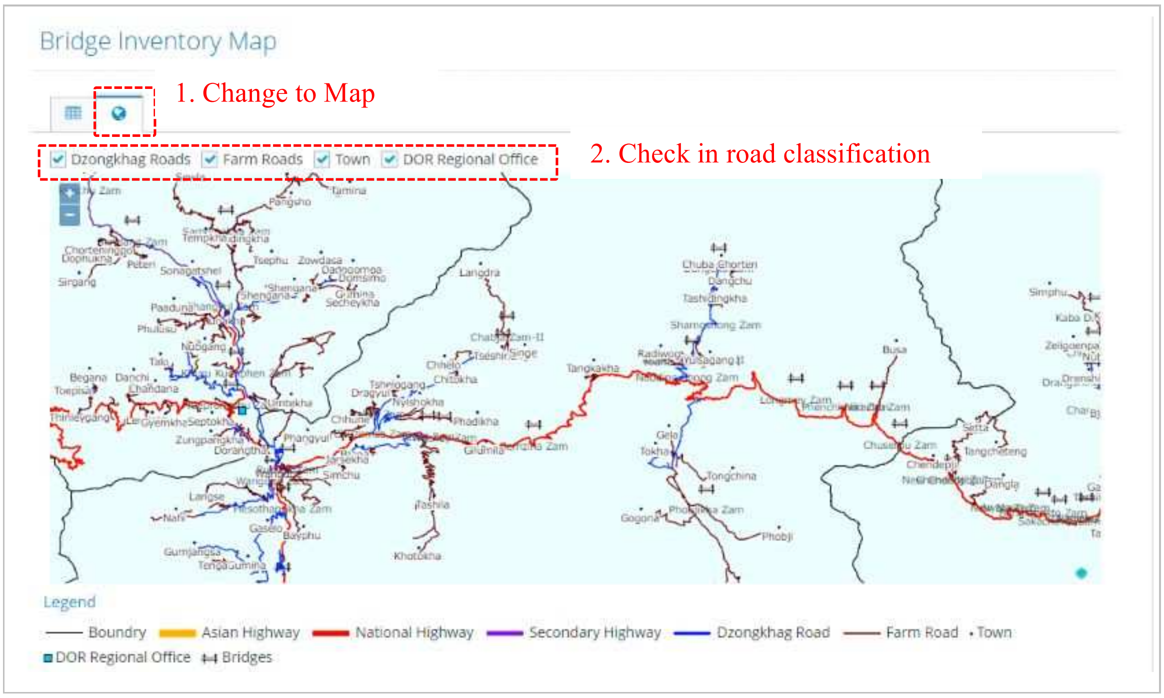

Bridge Inventory
Go to Bridge Map
Search for identified Bridge
Printing format
Select Dzongkhag
All
Select Agency/Division
Regional Office, DoR, Trongsa
Refresh
+Add BI
Add new Bridge Ledger
Display 20 records
Search:
Bridge Name
Bridge No
Highway Name/ Road Name
Dzongkhag
Agency/Division
Prioritization
Repair
Action
Sort function
Delete Ledger by Admin
Bridge Inventory with Bridge ledger information
Prioritization and Repairing cost
1 Babzur Zam GCR-0102- Tang GC road Bumthang Regional Office, DoR, Trongsa 29 0
2 Tyelegang H-04 Trongsa - Gelephu Trongsa Regional Office, DoR, Trongsa 130
3 Tashiling Zam PNH-01-018 PNH-01 Thimphu - Trashigang Trongsa Regional Office, DoR, Trongsa 148
4 Nagina Zam PNH-01-017 PNH-01 Thimphu - Trashigang Trongsa Regional Office, DoR, Trongsa 62 0
5 Yesheygangchu Zam PNH-04-003 PNH-04 Trongsa - Gelephu Trongsa Regional Office, DoR, Trongsa 74 7,240,933
6 Chamkhar Zam Bumthang Regional Office, DoR, Trongsa
7 Gayzamchu Zam PNH-01-029 PNH-01 Thimphu - Trashigang Bumthang Regional Office, DoR, Trongsa
8 Gaktong Zam PNH-01-027 PNH-01 Thimphu - Trashigang Bumthang Regional Office, DoR, Trongsa 65 14,452,147
9 Chendebji Zam PNH-01-012 PNH-01 Thimphu - Trashigang Trongsa Regional Office, DoR, 53 0

3.1.2 Map function

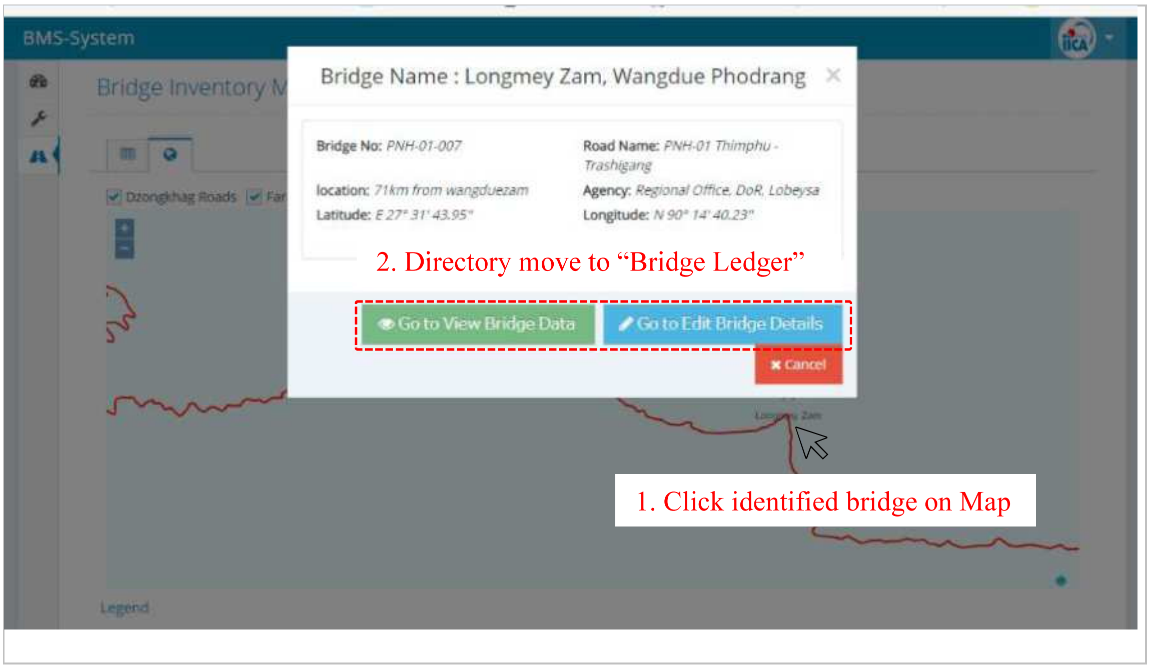
The location of bridge can be displayed by Map function. The location is pointed by the coordinate based on the Bridge Ledger coordinate information.

- How to operate in BMS –

1.



2.



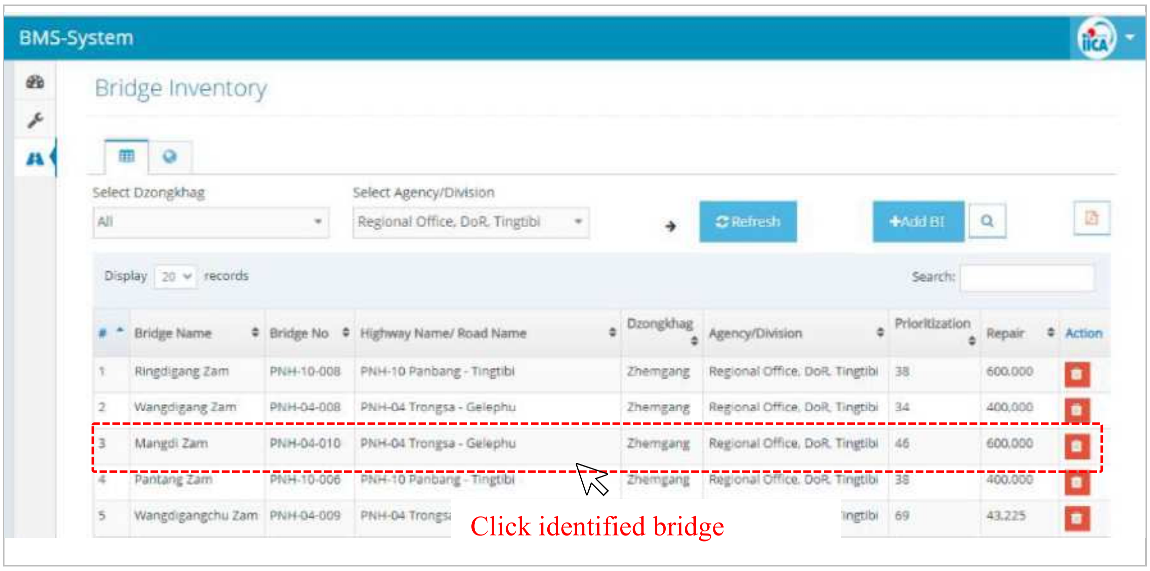
3.2 The Bridge Ledger

The function is to stock the Bridge Ledger with "Geographic data", "Bridge data", and "Photograph". BMS user can view, edit and add new ledger.

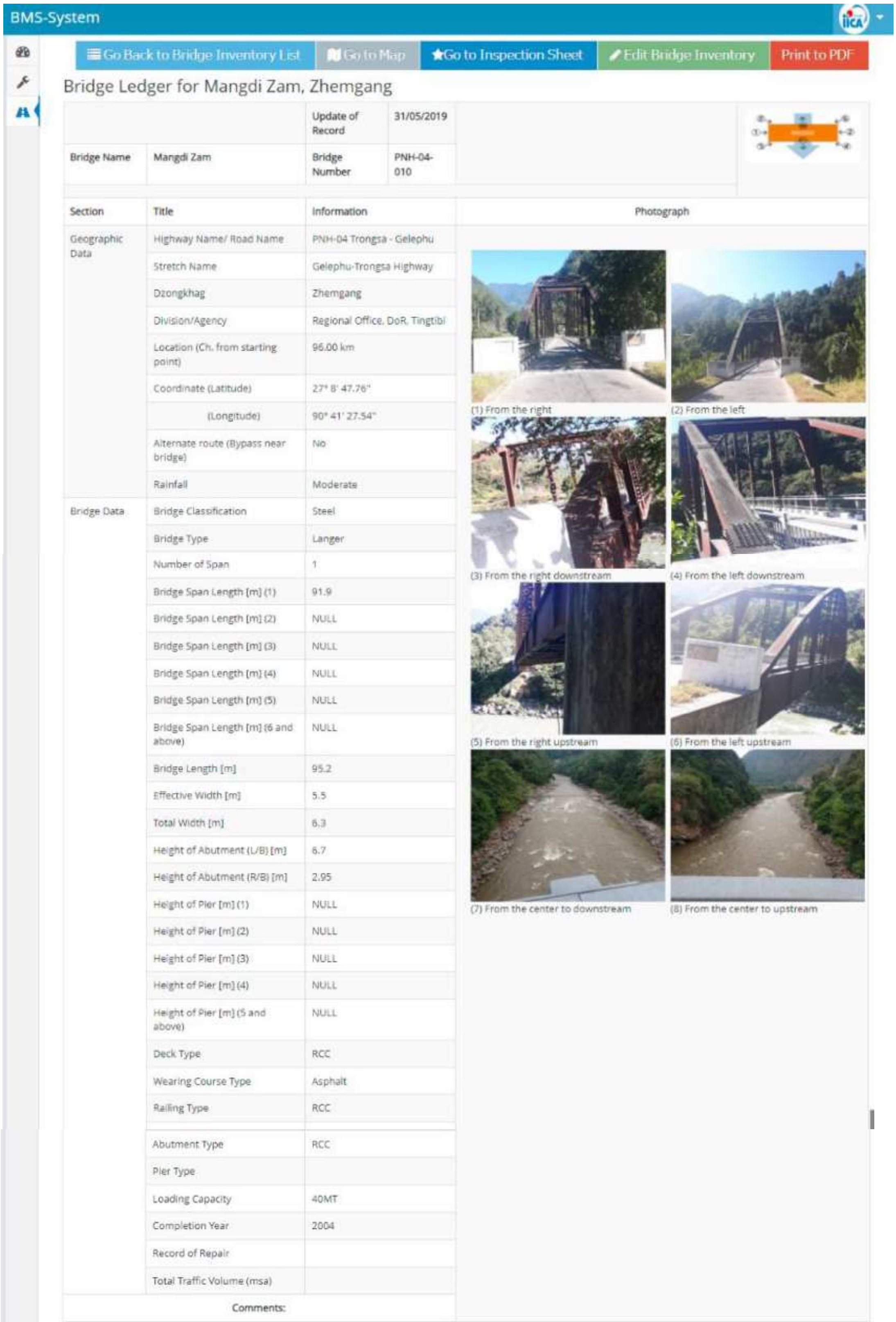
3.2.1 How to view Bridge Ledger

- How to operate in BMS –

1.



2.



BMS-System

Go Back to Bridge Inventory List | Go to Map | Go to Inspection Sheet | Edit Bridge Inventory | Print to PDF

Bridge Ledger for Mangdi Zam, Zhemgang

		Update of Record	31/05/2019
Bridge Name	Mangdi Zam	Bridge Number	PNH-04-010

Section	Title	Information
Geographic Data	Highway Name/ Road Name	PNH-04 Trongsa - Gelephu
	Stretch Name	Gelephu-Trongsa Highway
	Dzongkhag	Zhemgang
	Division/Agency	Regional Office, DoR, Tingtibi
	Location (Ch. from starting point)	96.00 km
	Coordinate (Latitude)	27° 8' 47.76"
	(Longitude)	90° 41' 27.54"
	Alternate route (Bypass near bridge)	No
	Rainfall	Moderate
Bridge Data	Bridge Classification	Steel
	Bridge Type	Langer
	Number of Span	1
	Bridge Span Length [m] (1)	91.9
	Bridge Span Length [m] (2)	NULL
	Bridge Span Length [m] (3)	NULL
	Bridge Span Length [m] (4)	NULL
	Bridge Span Length [m] (5)	NULL
	Bridge Span Length [m] (6 and above)	NULL
	Bridge Length [m]	95.2
	Effective Width [m]	5.5
	Total Width [m]	6.3
	Height of Abutment (L/B) [m]	6.7
	Height of Abutment (R/B) [m]	2.95
	Height of Pier [m] (1)	NULL
	Height of Pier [m] (2)	NULL
	Height of Pier [m] (3)	NULL
	Height of Pier [m] (4)	NULL
	Height of Pier [m] (5 and above)	NULL
	Deck Type	RCC
	Wearing Course Type	Asphalt
	Railing Type	RCC
	Abutment Type	RCC
	Pier Type	
	Loading Capacity	40MT
	Completion Year	2004
	Record of Repair	
	Total Traffic Volume (msa)	
	Comments:	

Photograph

(1) From the right

(2) From the left

(3) From the right downstream

(4) From the left downstream

(5) From the right upstream

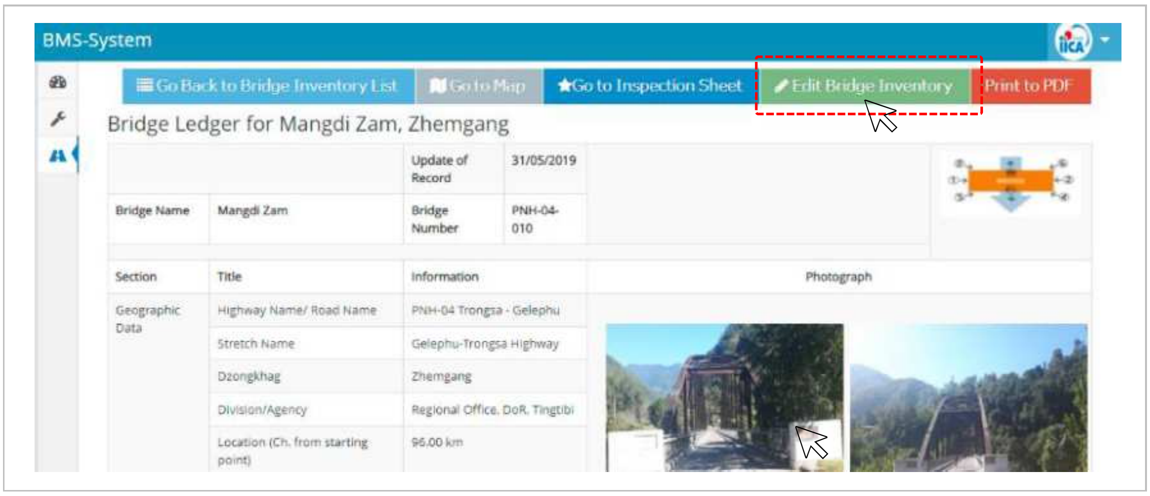
(6) From the left upstream

(7) From the center to downstream

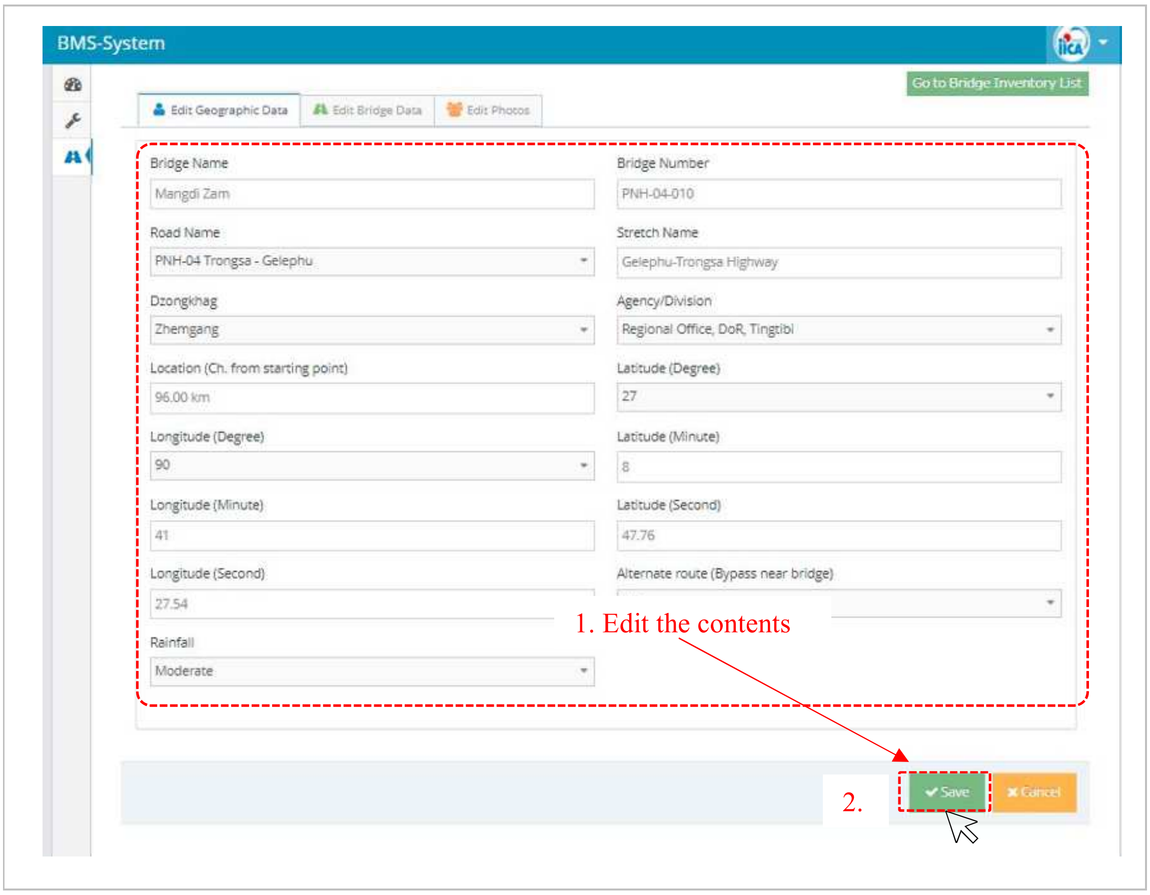
(8) From the center to upstream

3.2.2 How to edit Bridge ledger

1.

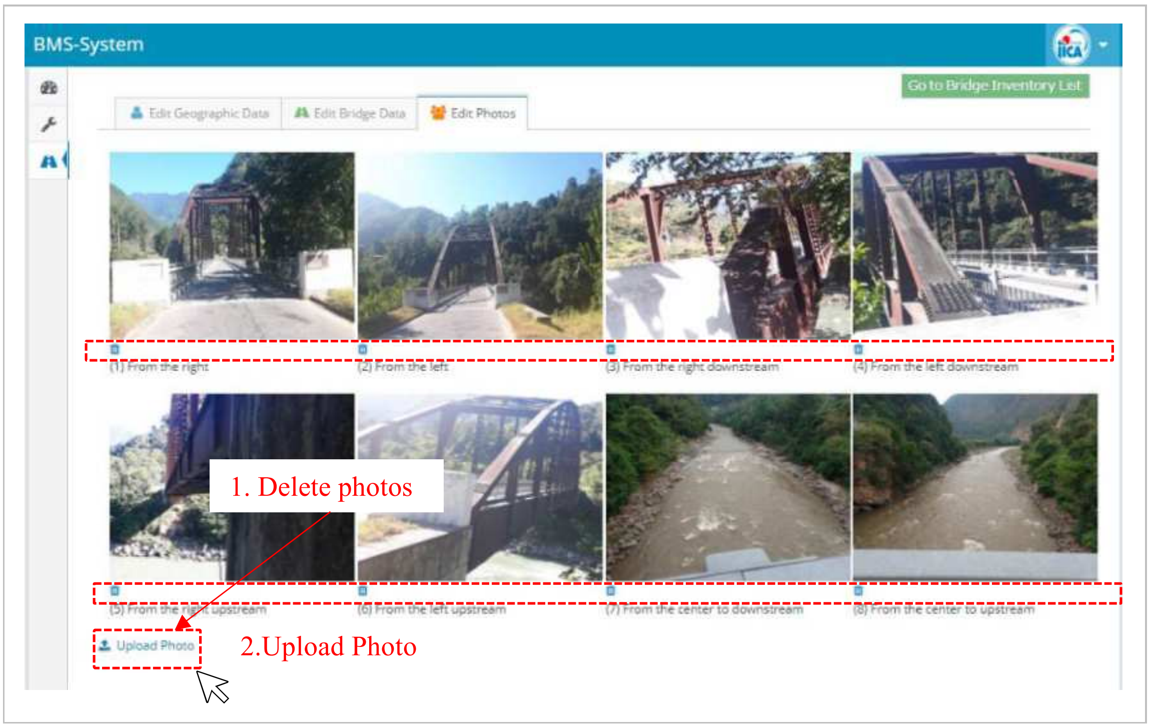


2.



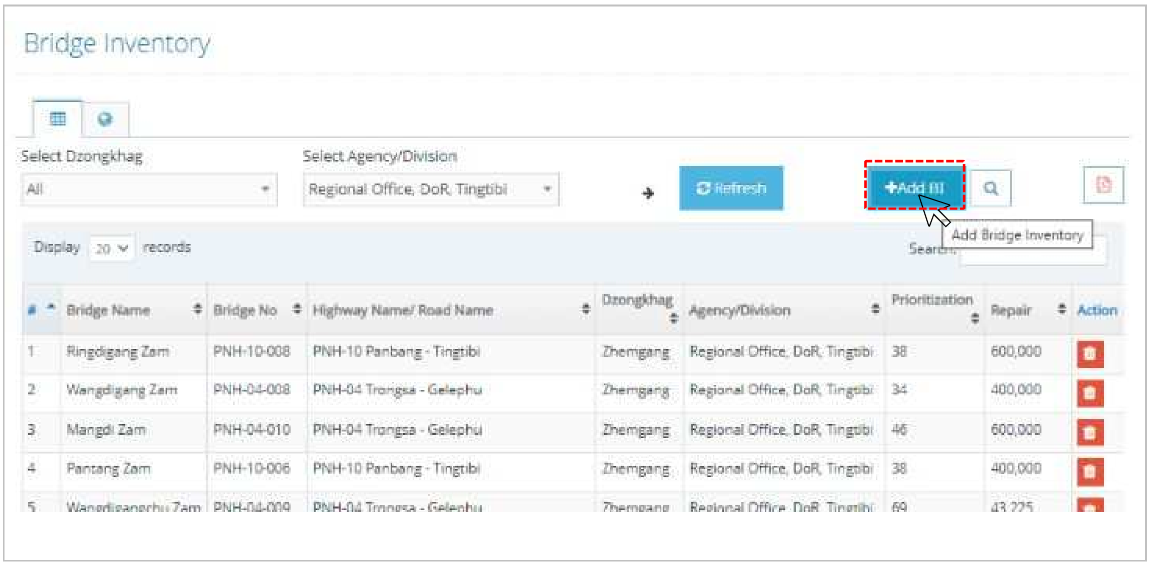
"Bridge Data" is same process with "Geographic Data"

3.

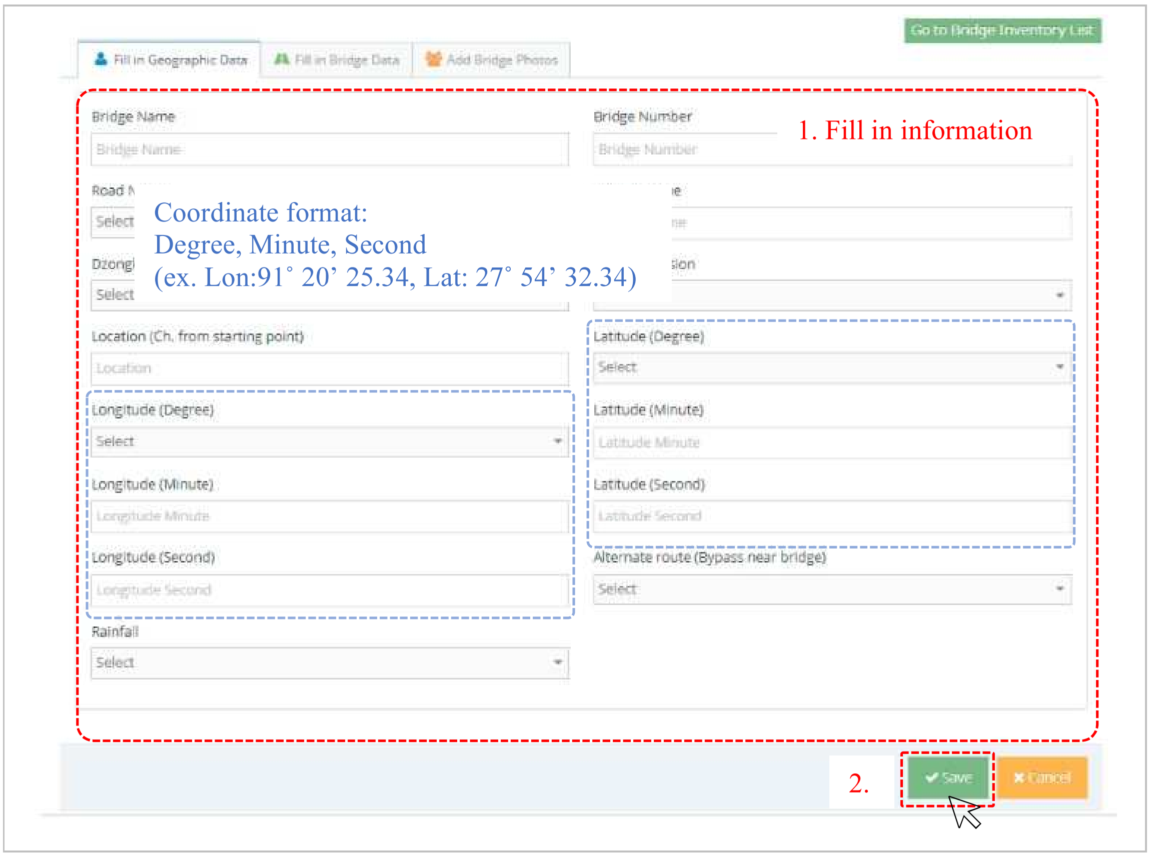

BMS-System
Go to Bridge Inventory List
Edit Geographic Data
Edit Bridge Data
Edit Photos
(1) From the right
(2) From the left
(3) From the right downstream
(4) From the left downstream
(5) From the right upstream
(6) From the left upstream
(7) From the center to downstream
(8) From the center to upstream
1. Delete photos
Upload Photo
2.Upload Photo

3.2.3 How to make new Bridge Ledger

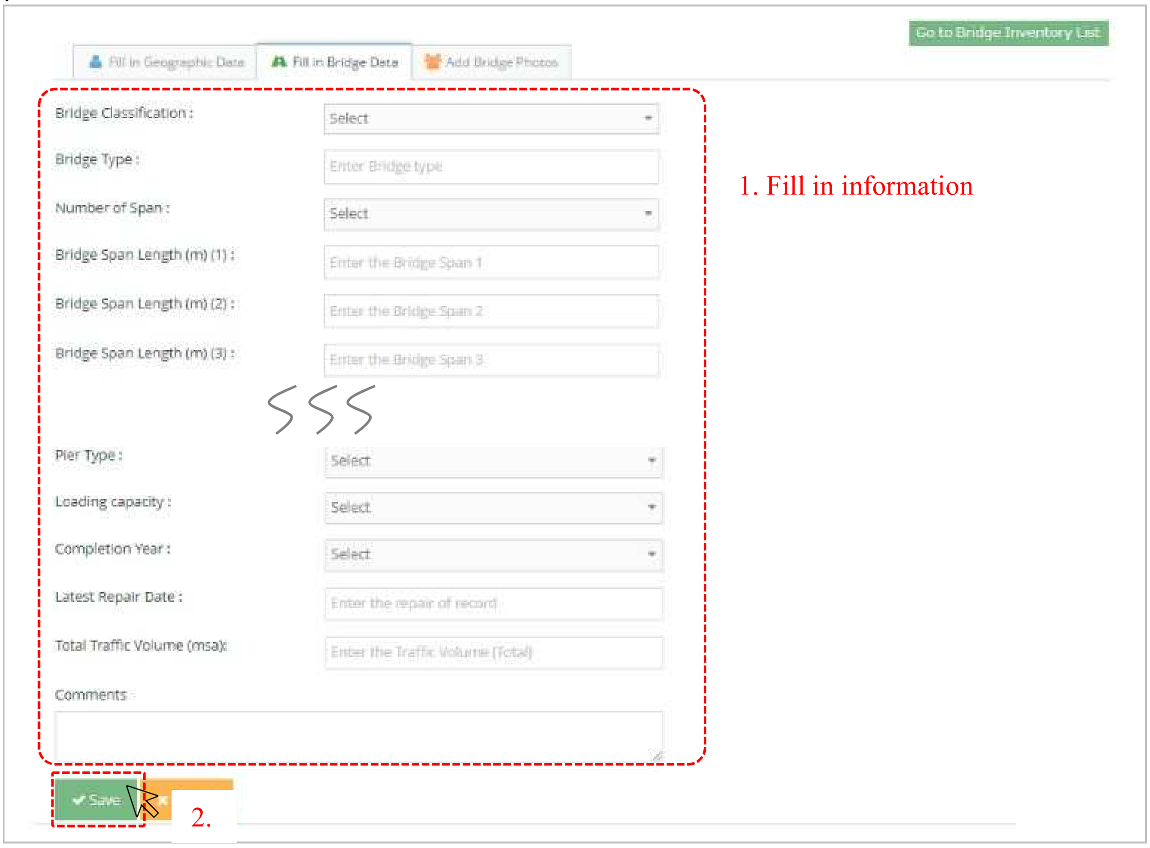
1.



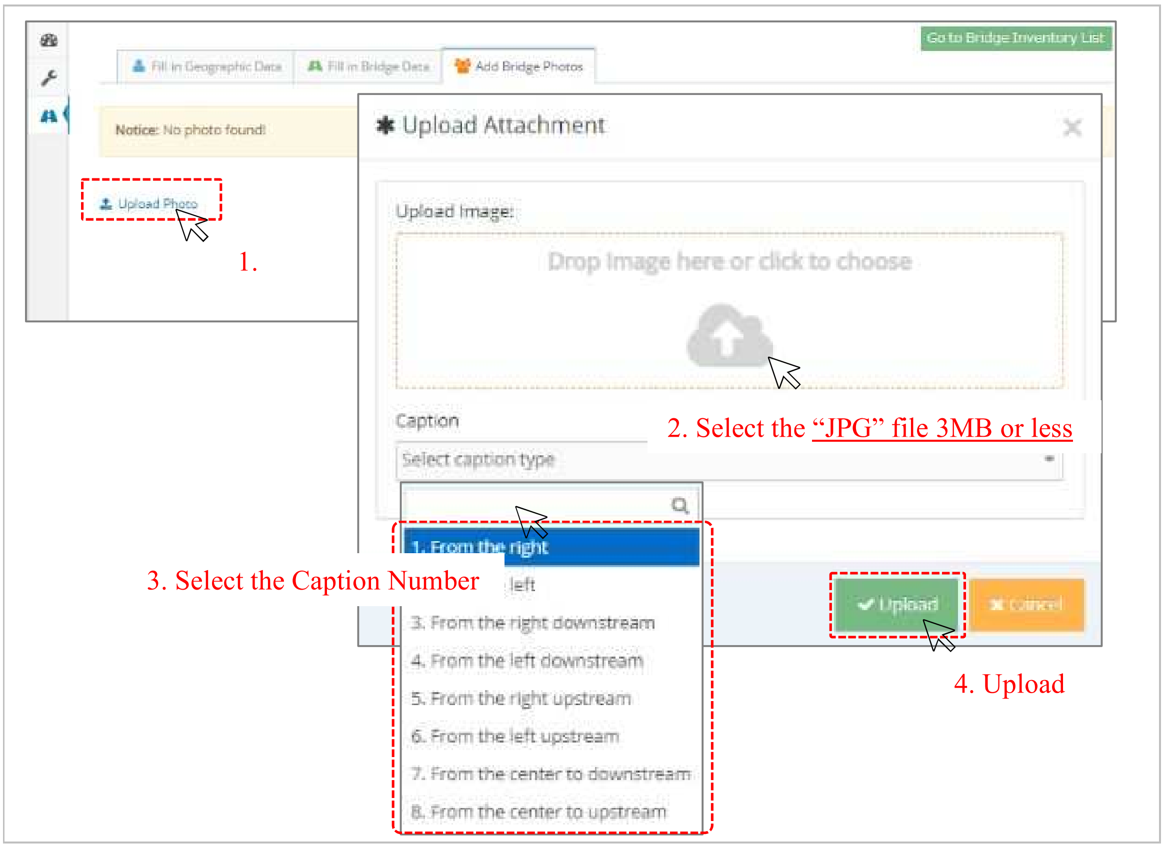
2.



3.


Go to Bridge Inventory List
Fill in Geographic Data
Fill in Bridge Data
Add Bridge Photos
Bridge Classification :
Select
Bridge Type :
Enter Bridge type
Number of Span :
Select
Bridge Span Length (m) (1) :
Enter the Bridge Span 1
Bridge Span Length (m) (2) :
Enter the Bridge Span 2
Bridge Span Length (m) (3) :
Enter the Bridge Span 3
Pier Type :
Select
Loading capacity :
Select
Completion Year :
Select
Latest Repair Date :
Enter the repair of record
Total Traffic Volume (msa):
Enter the Traffic Volume (Total)
Comments
Save
1. Fill in information
2.

4.


Go to Bridge Inventory List
Fill in Geographic Data
Fill in Bridge Data
Add Bridge Photos
Notice: No photo found!
Upload Photo
1.
Upload Attachment
Upload Image:
Drop Image here or click to choose
Caption
2. Select the "JPG" file 3MB or less
Select caption type
1. From the right
left
3. From the right downstream
4. From the left downstream
5. From the right upstream
6. From the left upstream
7. From the center to downstream
8. From the center to upstream
3. Select the Caption Number
Upload
Cancel
4. Upload

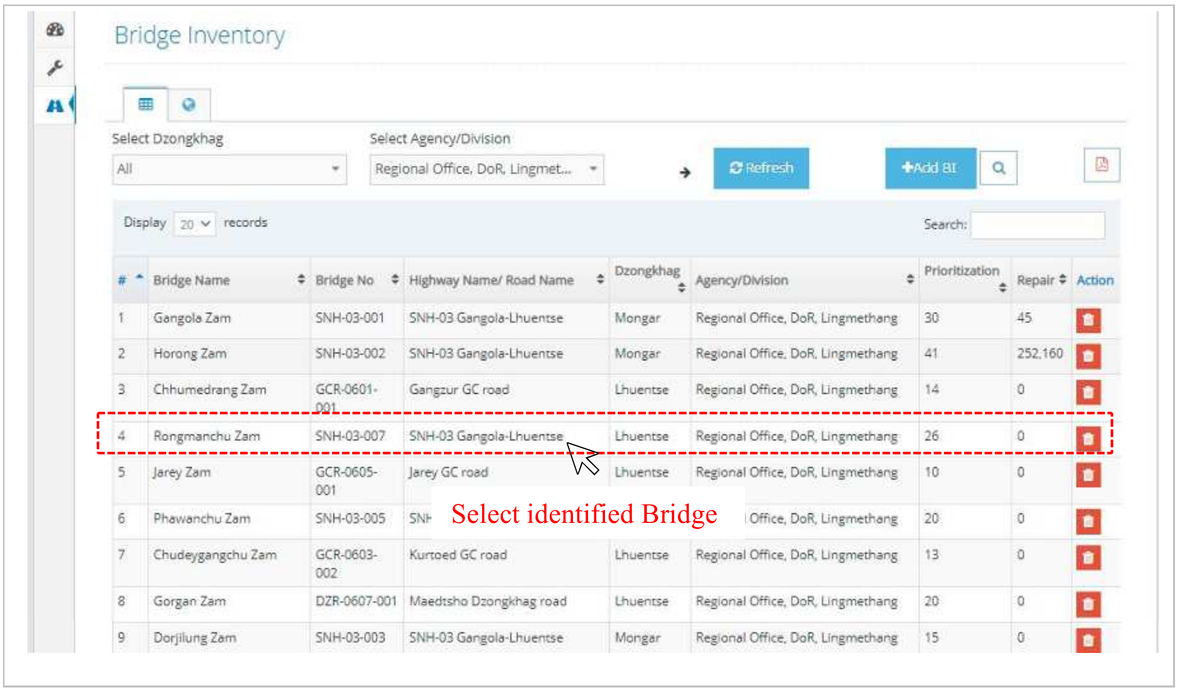
3.3 The Bridge Inspection

The function is to accumulate Bridge inspection record in date order. The BMS user can check the existing inspection result and add the new inspection result. Additionally, the latest inspection result automatically connects to "Prioritization" and "Repairing and reinforcement cost" in system.

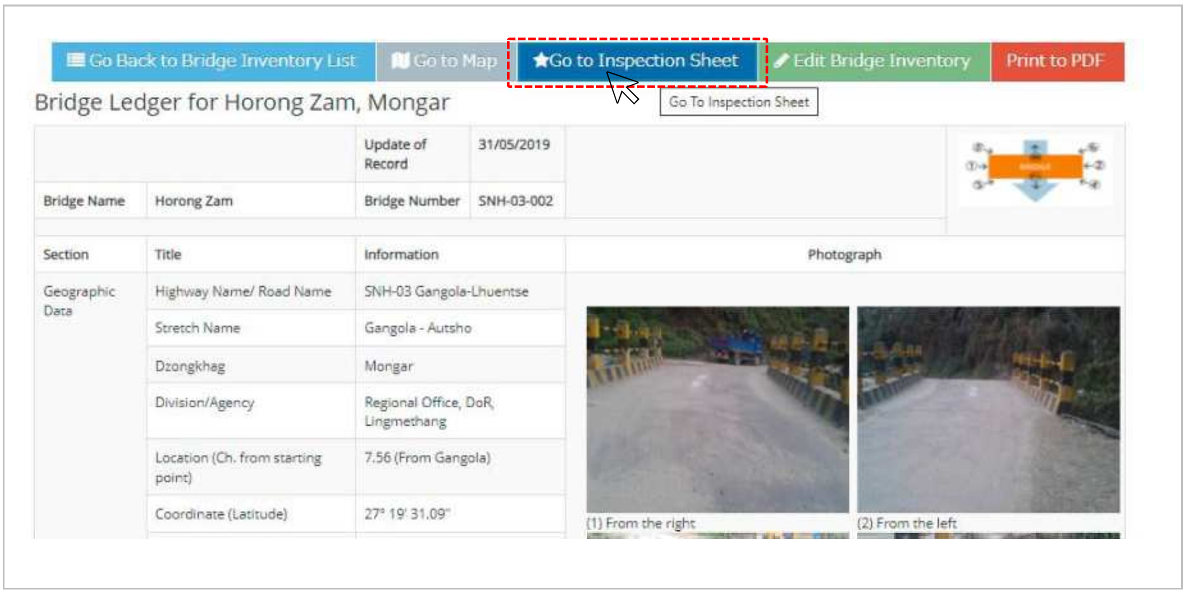
3.3.1 How to view the existing inspection result

- How to operate in BMS –

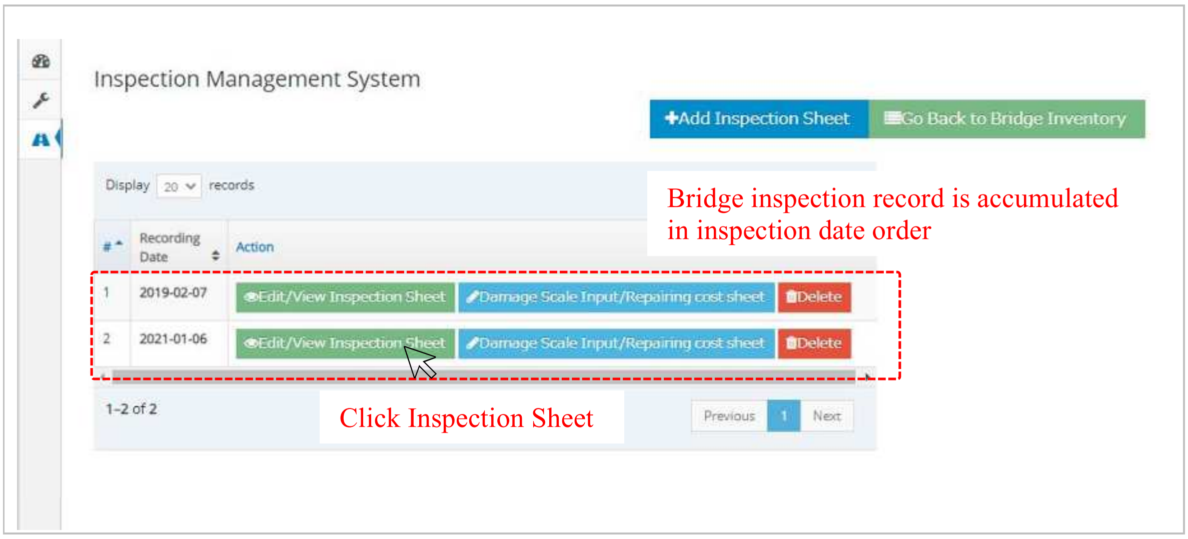
1.



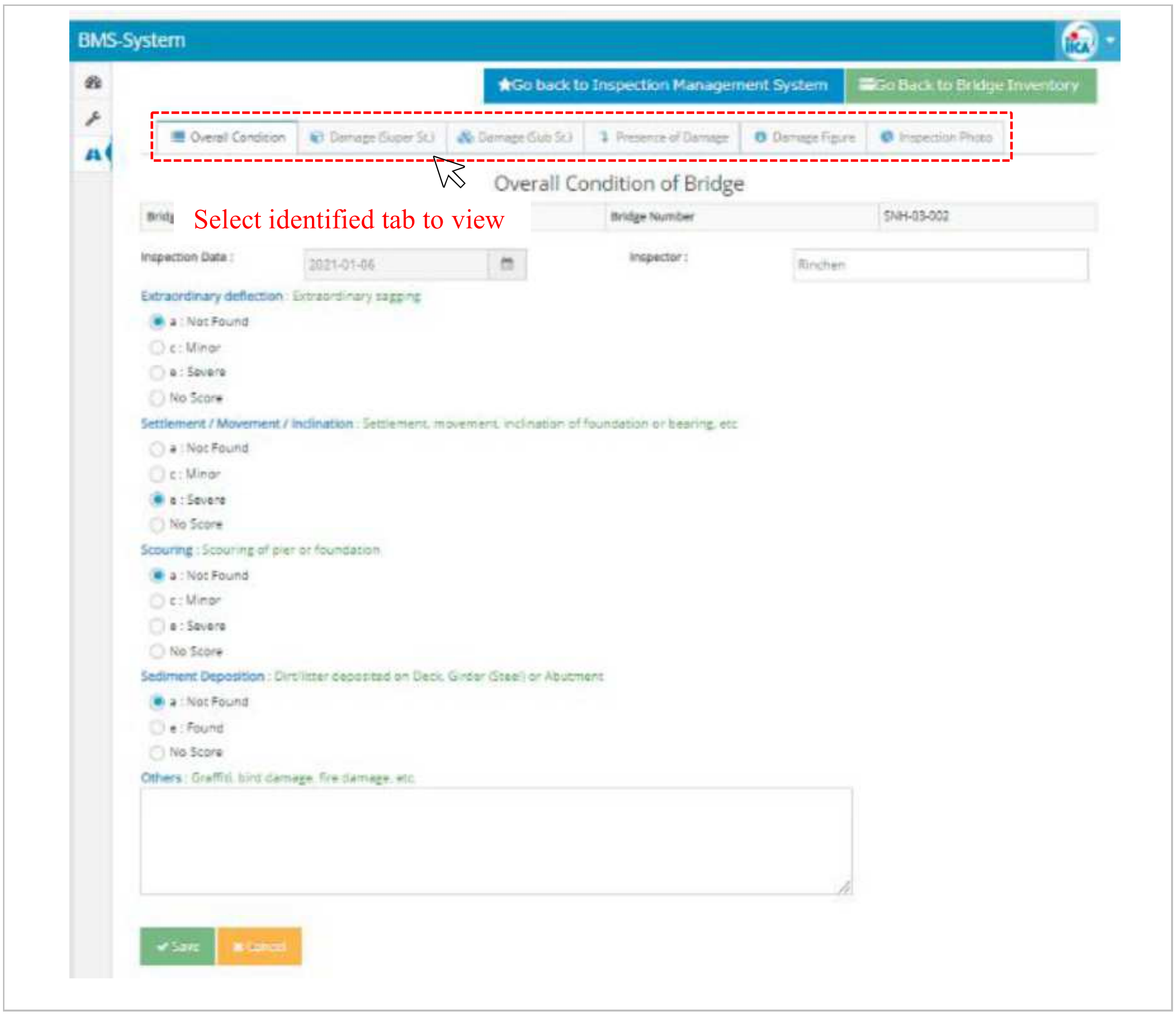
2.



3.

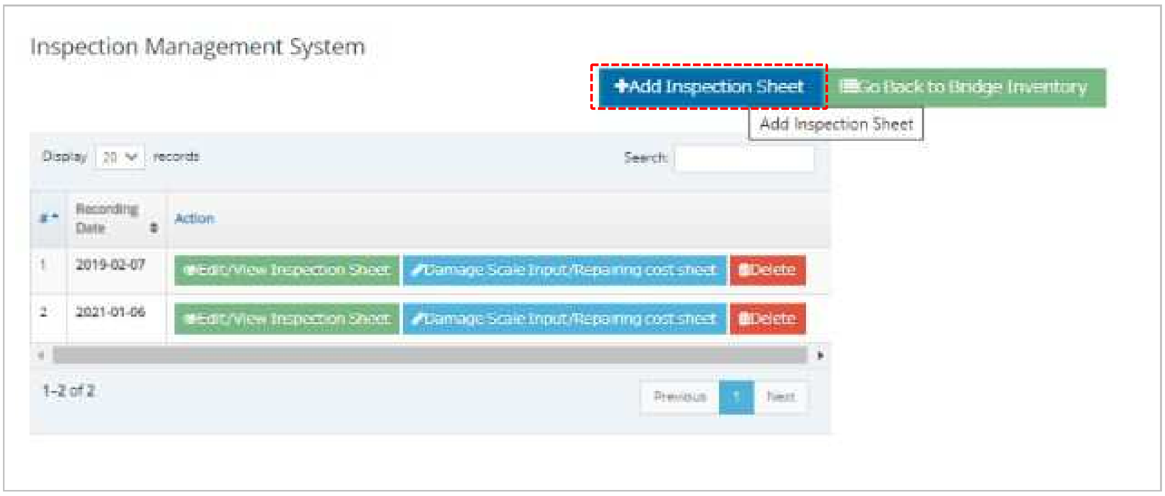

Inspection Management System
+Add Inspection Sheet
Go Back to Bridge Inventory
Display 20 records
Bridge inspection record is accumulated in inspection date order
Recording Date
Action
1 2019-02-07
Edit/View Inspection Sheet
Damage Scale Input/Repairing cost sheet
Delete
2 2021-01-06
Edit/View Inspection Sheet
Damage Scale Input/Repairing cost sheet
Delete
1-2 of 2
Click Inspection Sheet
Previous
1
Next

4.

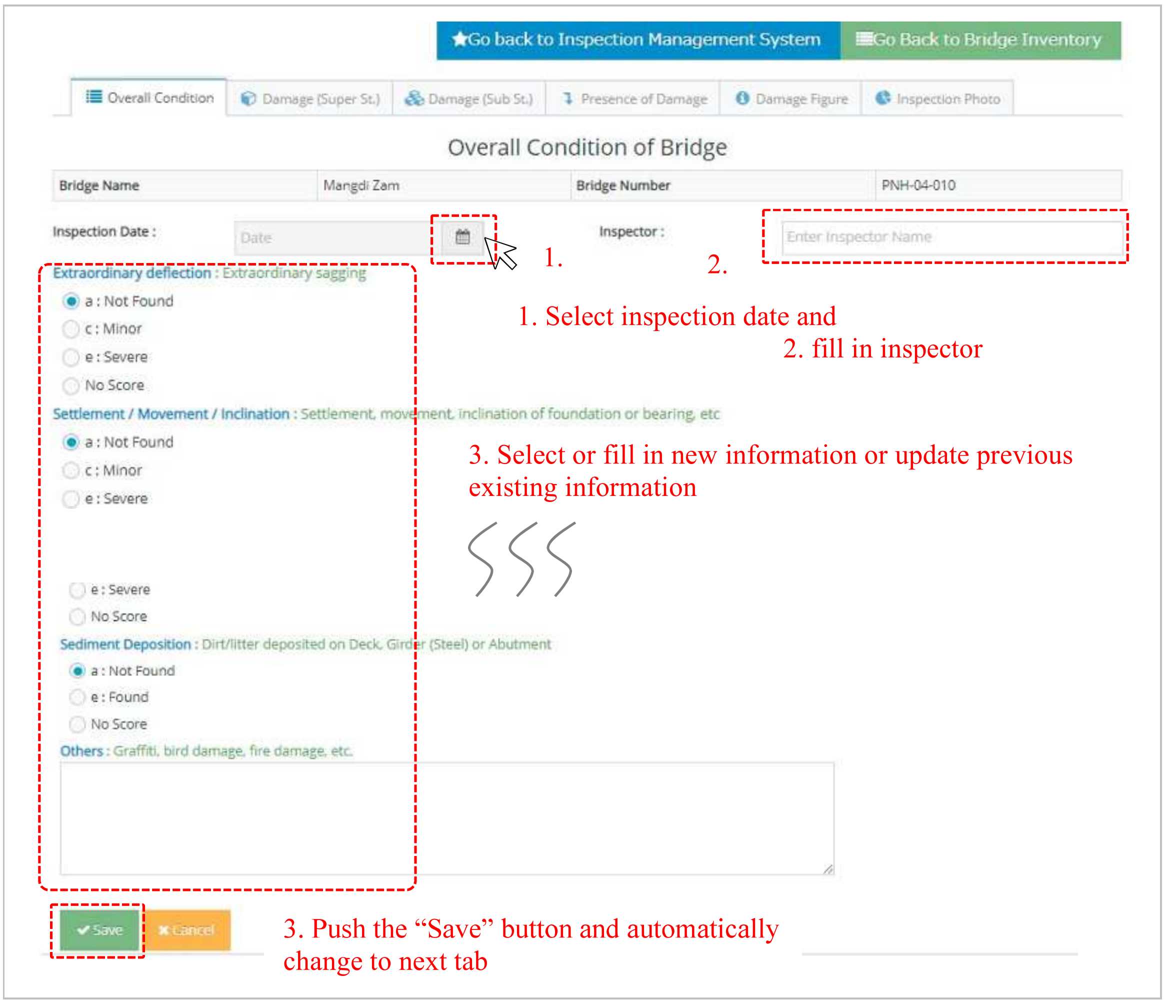

BMS-System
Go back to Inspection Management System
Go Back to Bridge Inventory
Overall Condition
Damage (Super St.)
Damage (Sub St.)
Presence of Damage
Damage Figure
Inspection Photo
Overall Condition of Bridge
Select identified tab to view
Bridge Number
SNH-03-002
Inspection Date :
2021-01-06
Inspector :
Rinchen
Extraordinary deflection : Extraordinary sagging
a : Not Found
c : Minor
e : Severe
No Score
Settlement / Movement / Inclination : Settlement, movement, inclination of foundation or bearing, etc
a : Not Found
c : Minor
e : Severe
No Score
Scouring : Scouring of pier or foundation
a : Not Found
c : Minor
e : Severe
No Score
Sediment Deposition : Dirt/litter deposited on Deck, Girder (Steel) or Abutment
a : Not Found
e : Found
No Score
Others : Graffiti, bird damage, fire damage, etc
Save
Cancel

3.3.2 How to add new inspection record (Inspection sheet)

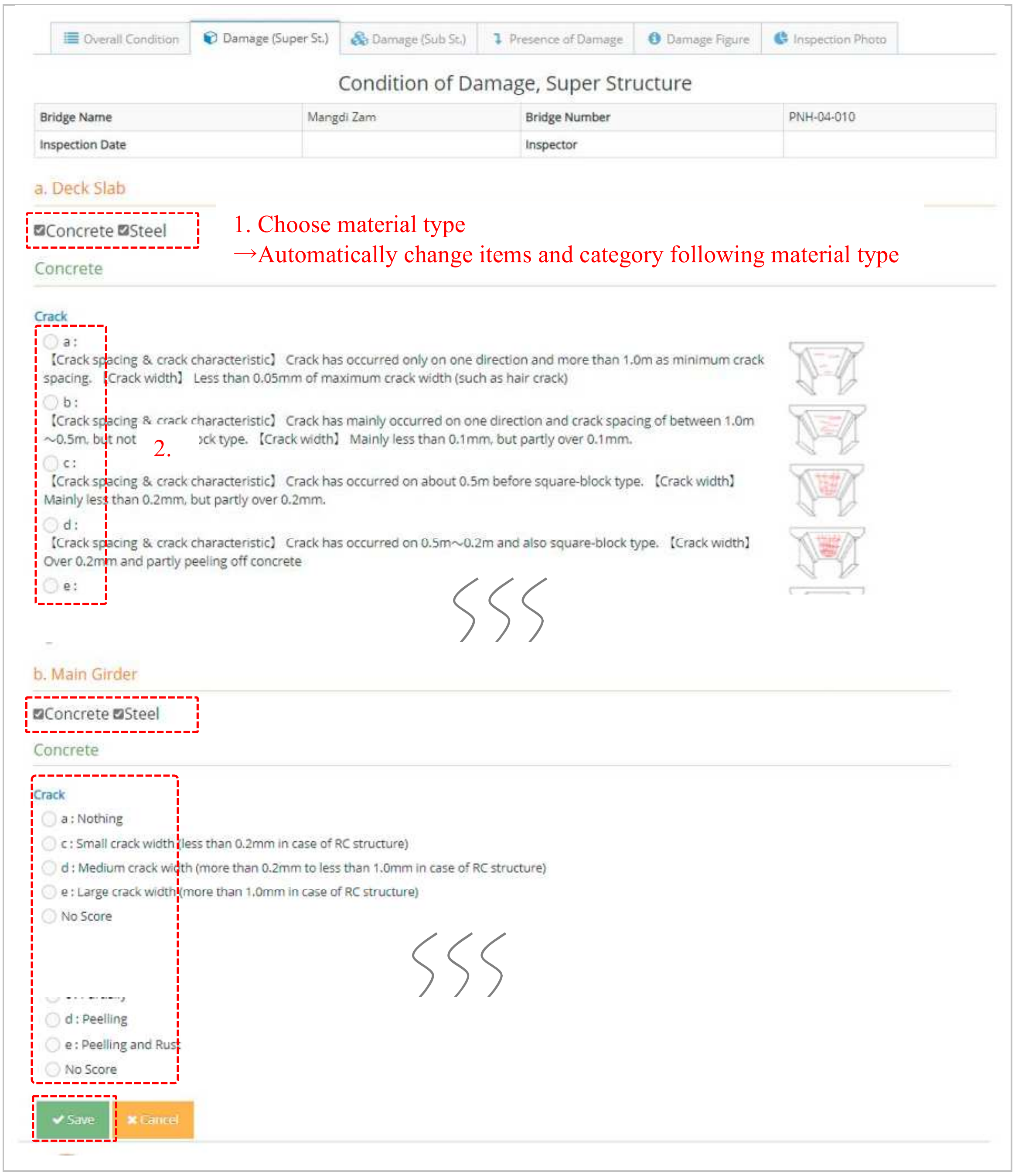
1.



2. Overall Condition

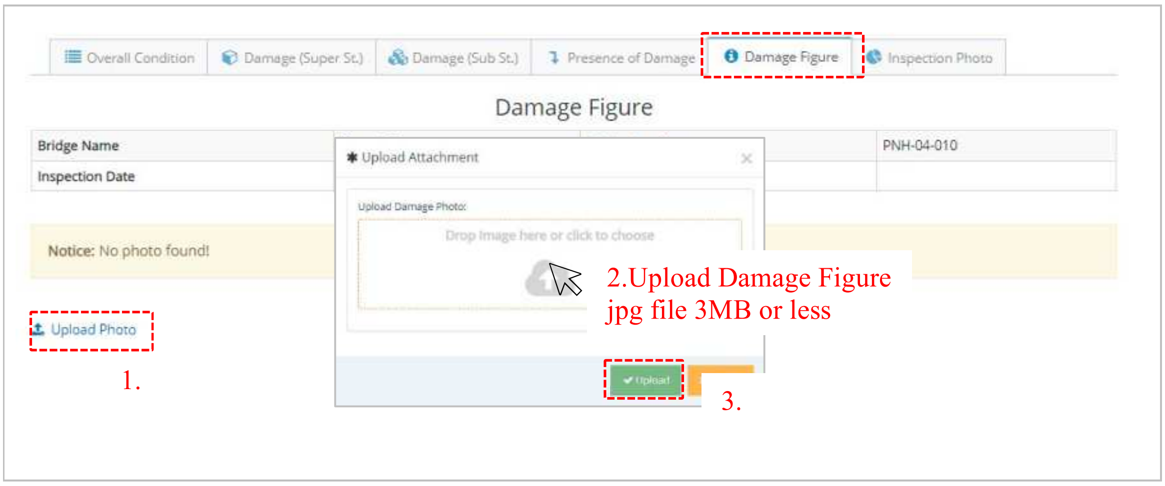


3. Damage (Super St)

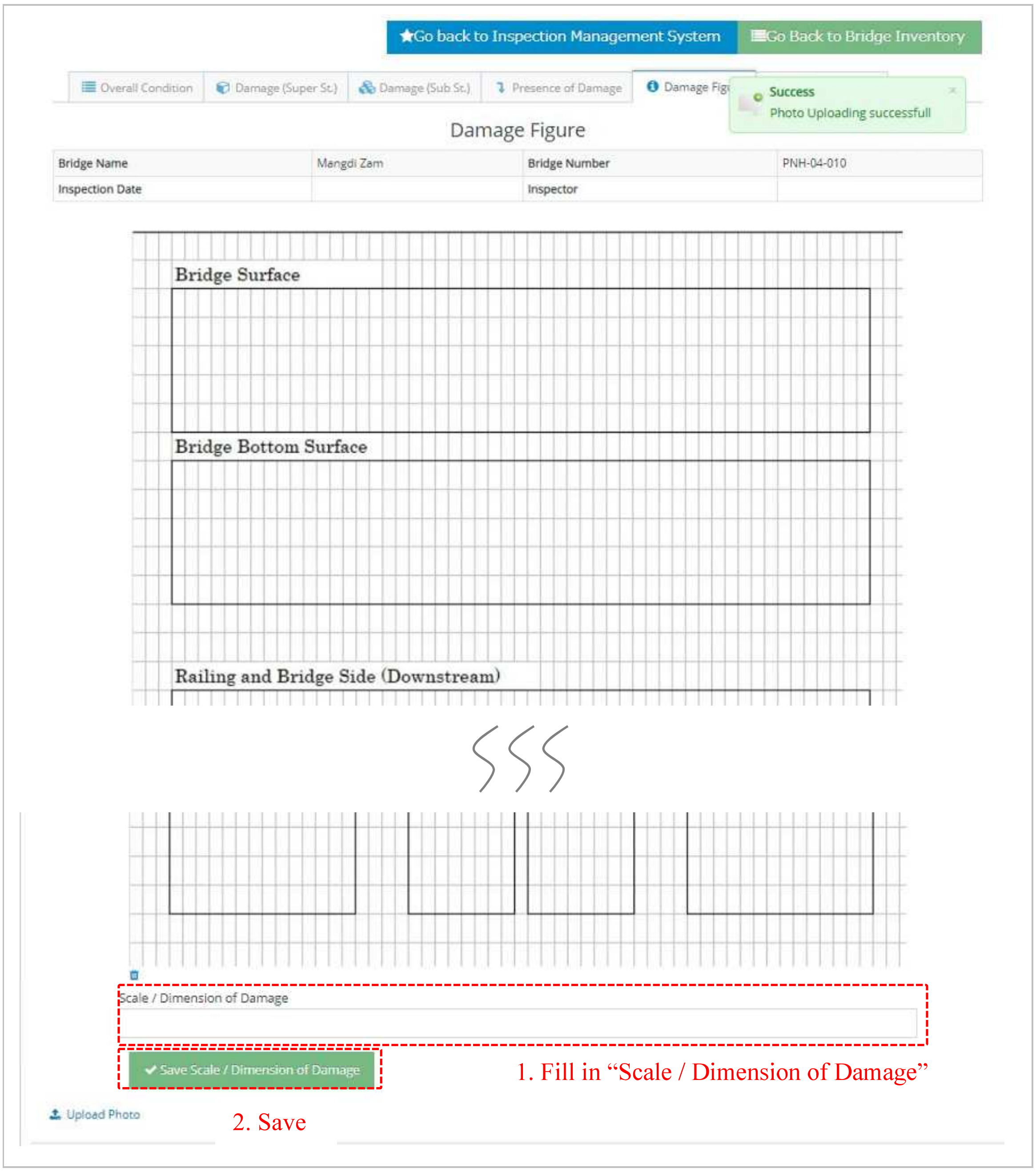


The procedure of the tabs for "Damage (Sub St.)", "Presence of Damage" is same as "Overall Condition", "Damage (Super St.)"

4. Damage Figure

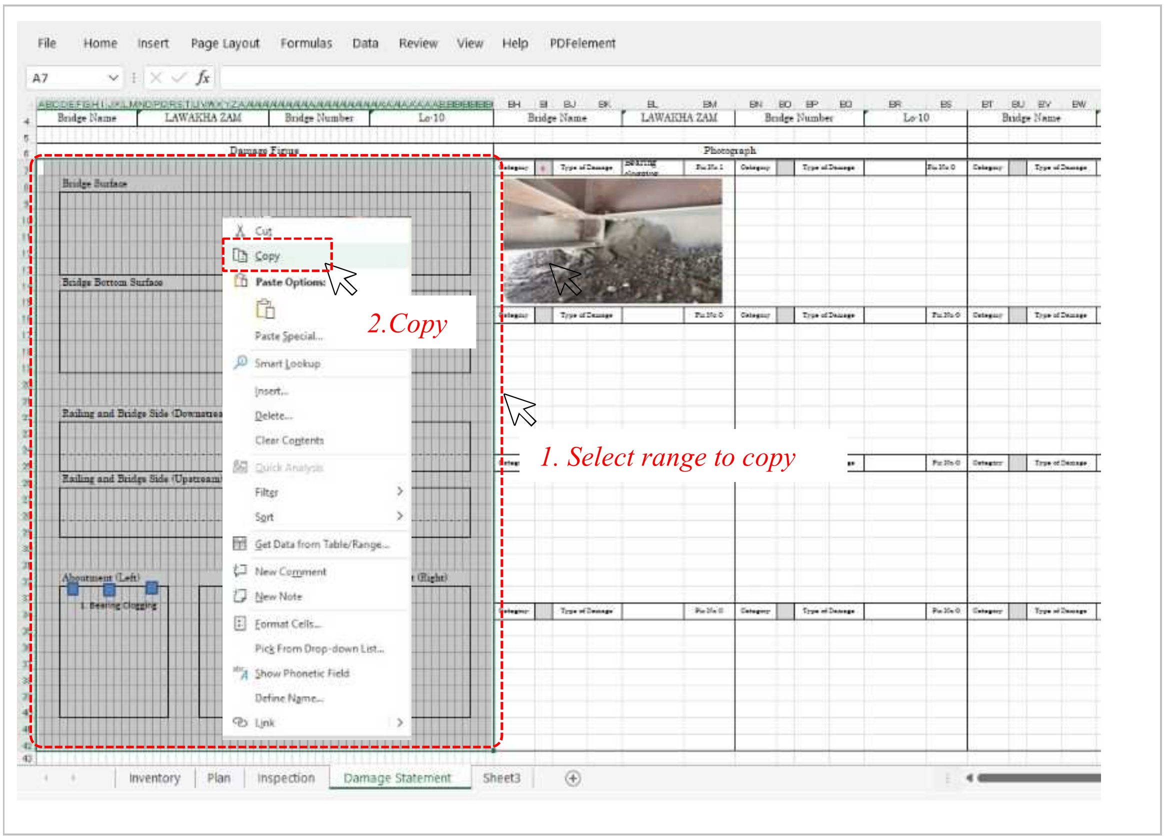


5.

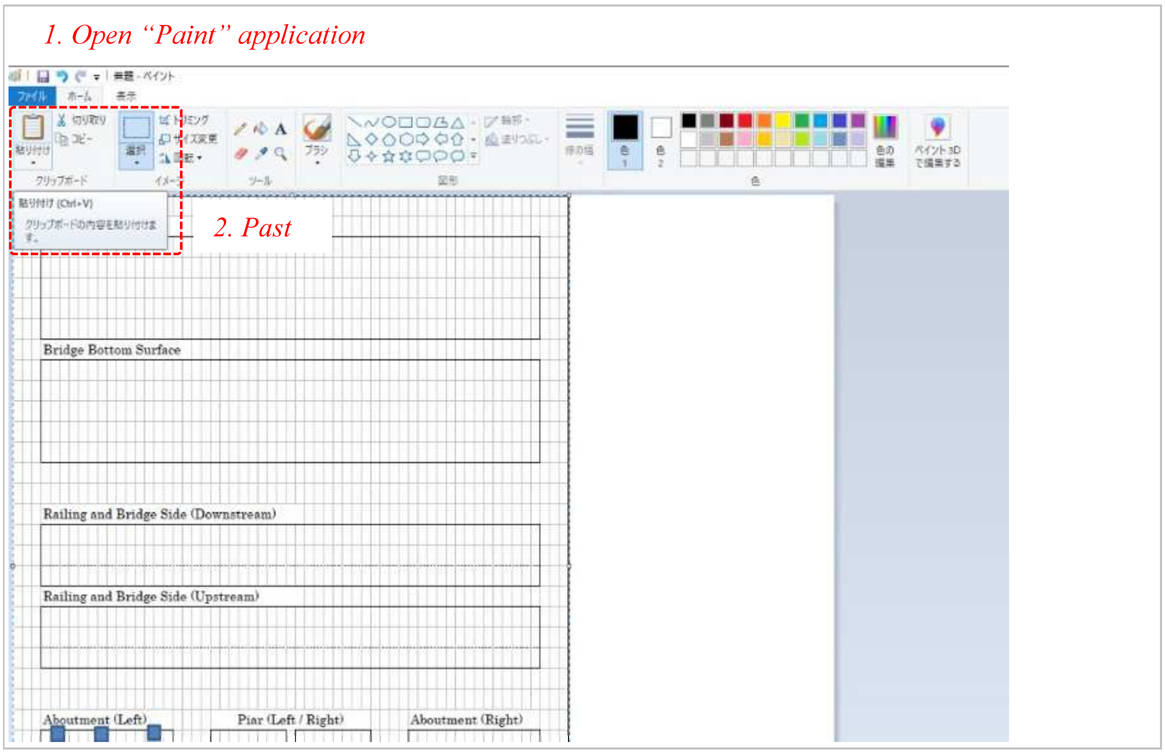

Go back to Inspection Management System
Go Back to Bridge Inventory
Overall Condition
Damage (Super St.)
Damage (Sub St.)
Presence of Damage
Damage Fig
Success
Photo Uploading successfull
Damage Figure
Bridge Name
Mangdi Zam
Bridge Number
PNH-04-010
Inspection Date
Inspector
Bridge Surface
Bridge Bottom Surface
Railing and Bridge Side (Downstream)
Scale / Dimension of Damage
Save Scale / Dimension of Damage
1. Fill in “Scale / Dimension of Damage”
Upload Photo
2. Save

------------How to make Damage Figure jpg file from Microsoft excel------------

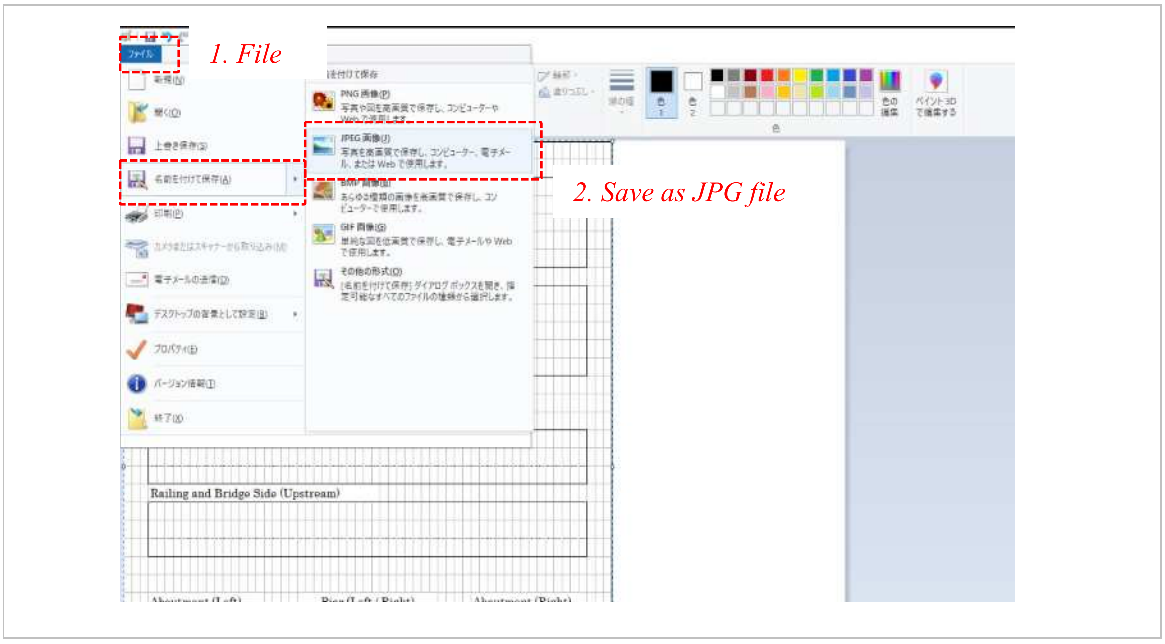
1.



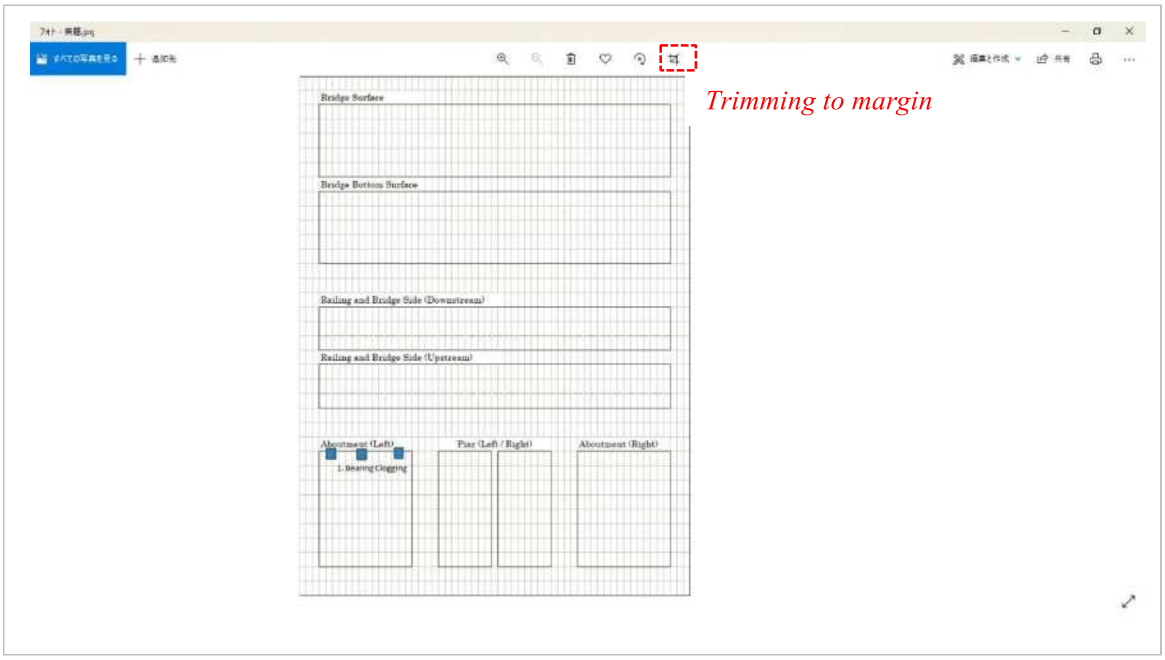
2.



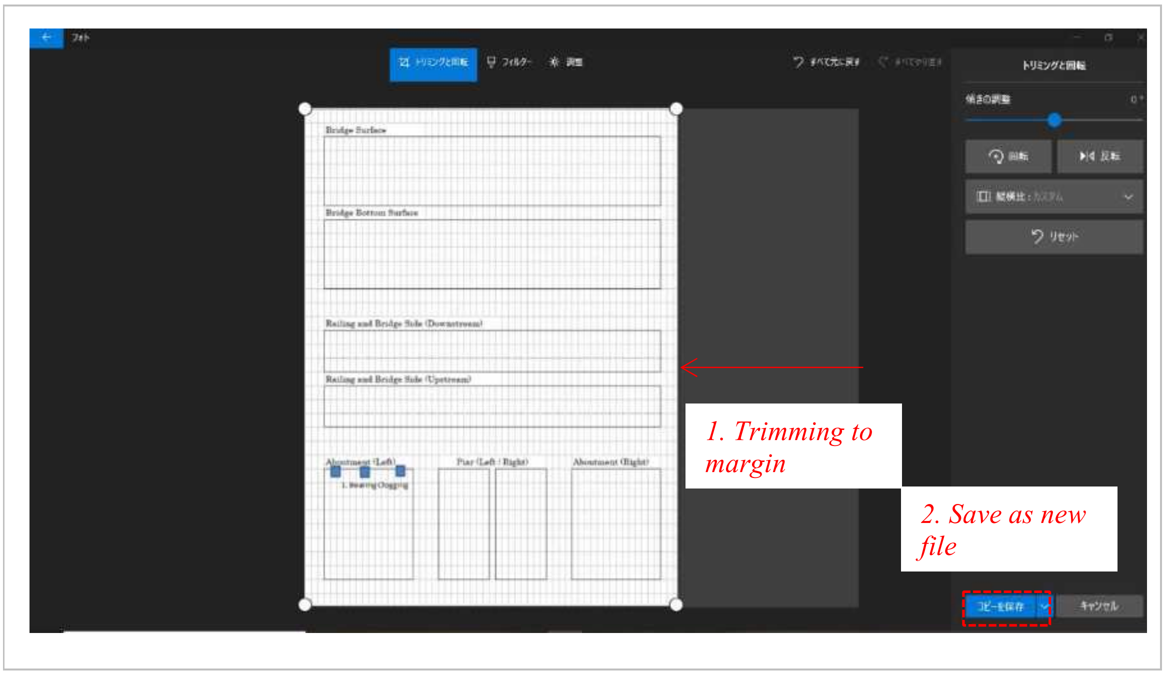
3.



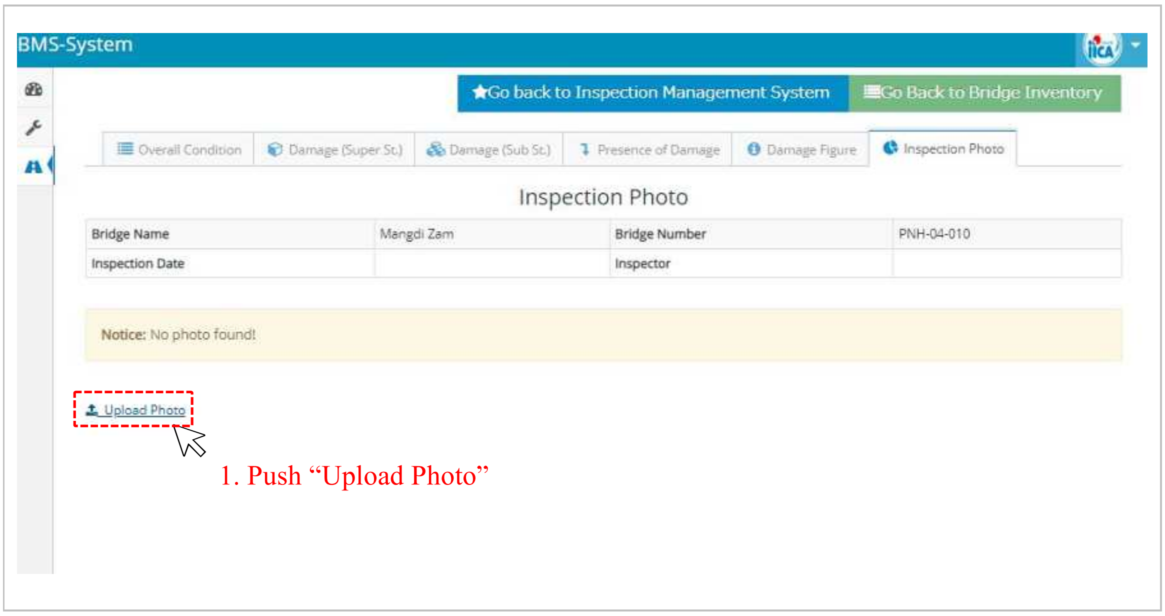
4.Open jpg file by photo viewer (General photo viewer application)



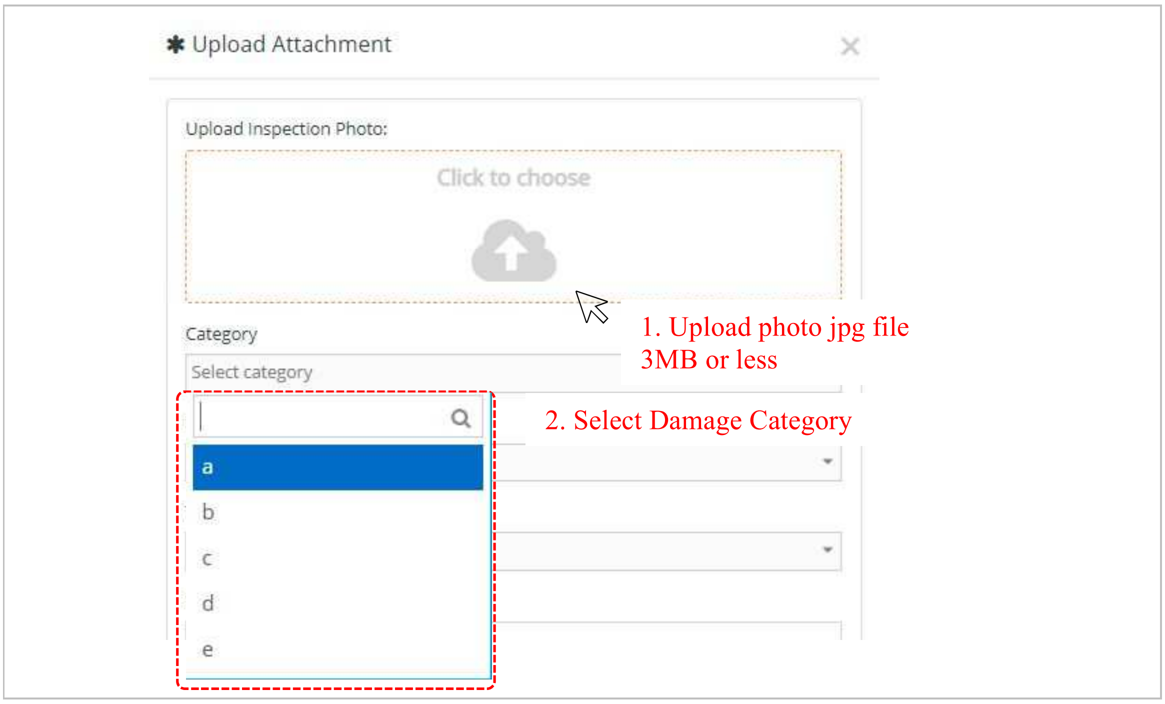
5.



5.Inspection Photo

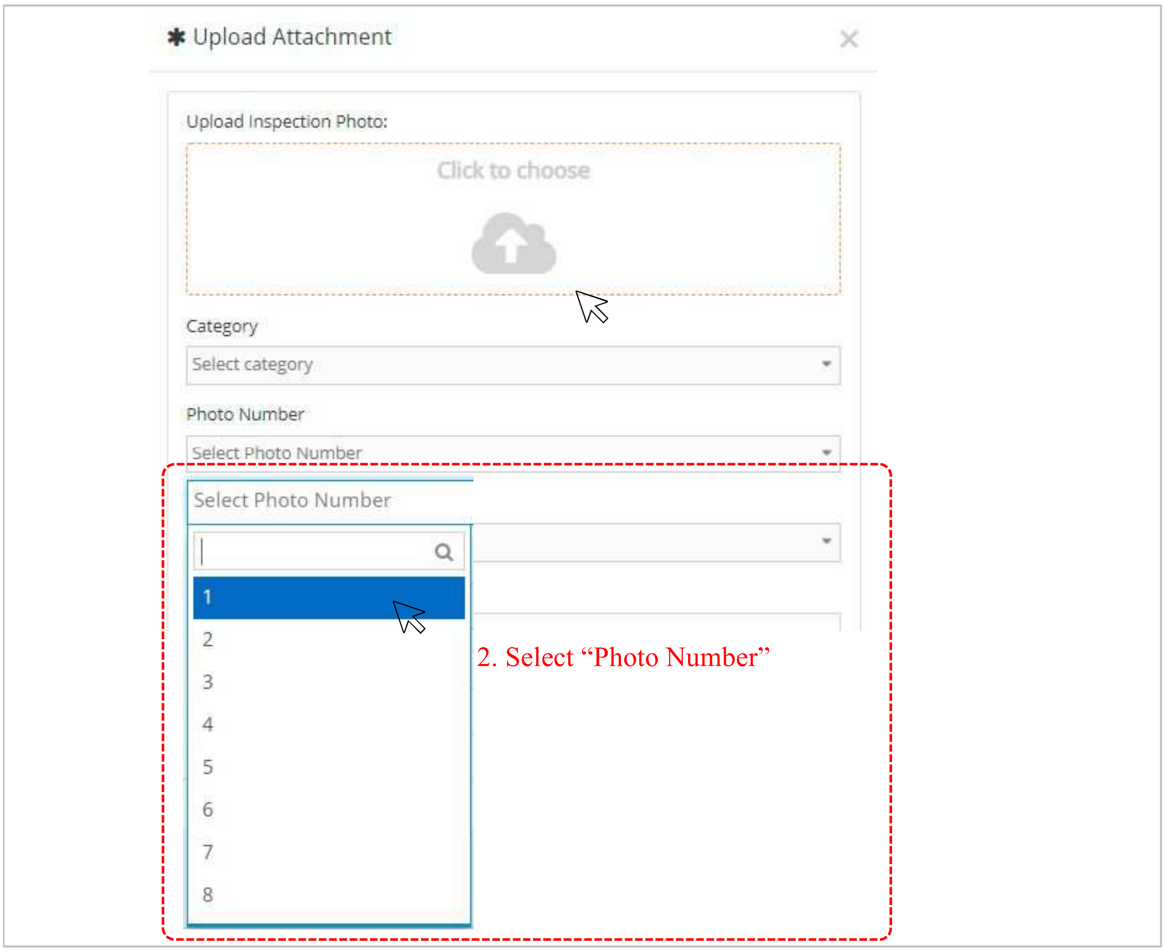


6.



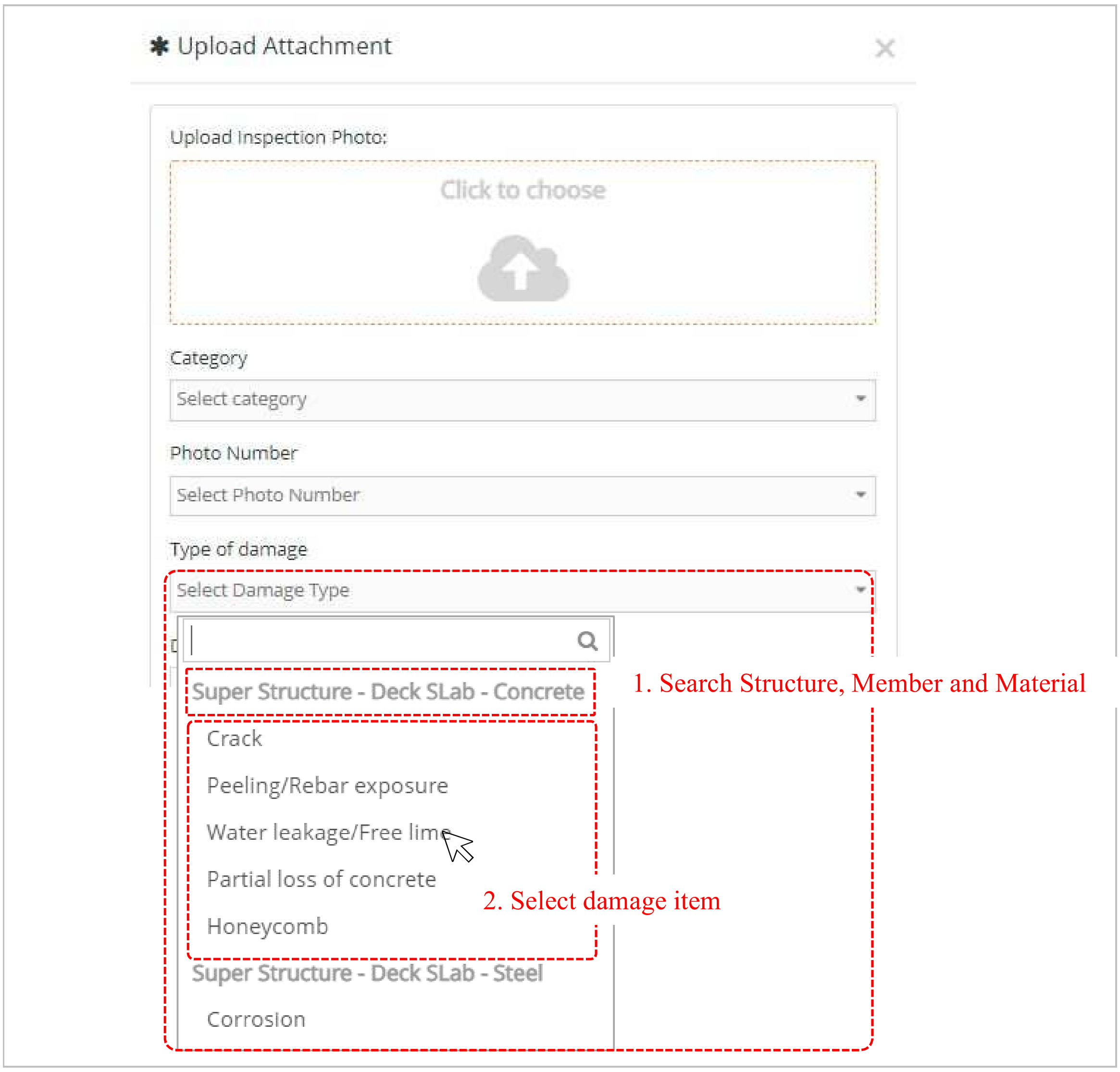
✱ Upload Attachment
Upload Inspection Photo:
Click to choose
Category
Select category
a
b
c
d
e
1. Upload photo jpg file 3MB or less
2. Select Damage Category

7.

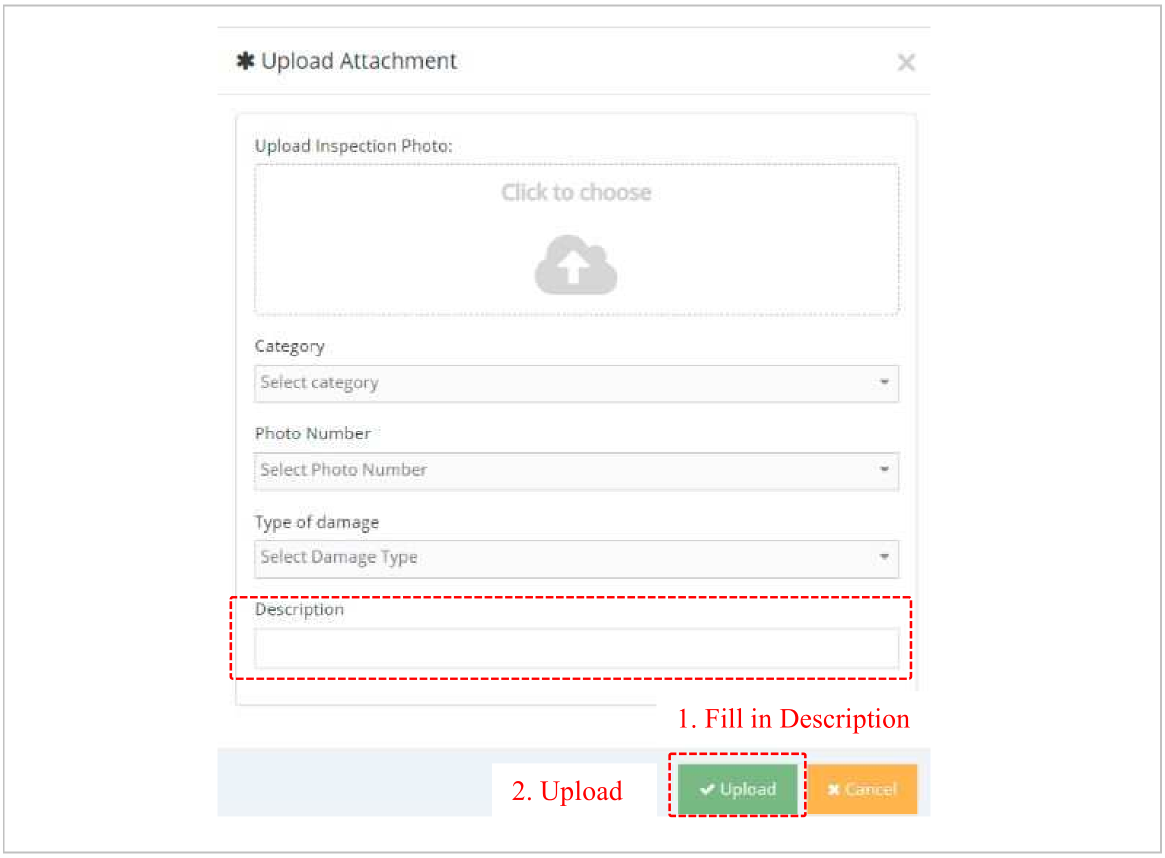


✱ Upload Attachment
Upload Inspection Photo:
Click to choose
Category
Select category
Photo Number
Select Photo Number
Select Photo Number
1
2
3
4
5
6
7
8
2. Select "Photo Number"

8.


Upload Attachment
Upload Inspection Photo:
Click to choose
Category
Select category
Photo Number
Select Photo Number
Type of damage
Select Damage Type
Super Structure - Deck SLab - Concrete
Crack
Peeling/Rebar exposure
Water leakage/Free lime
Partial loss of concrete
Honeycomb
Super Structure - Deck SLab - Steel
Corrosion
1. Search Structure, Member and Material
2. Select damage item

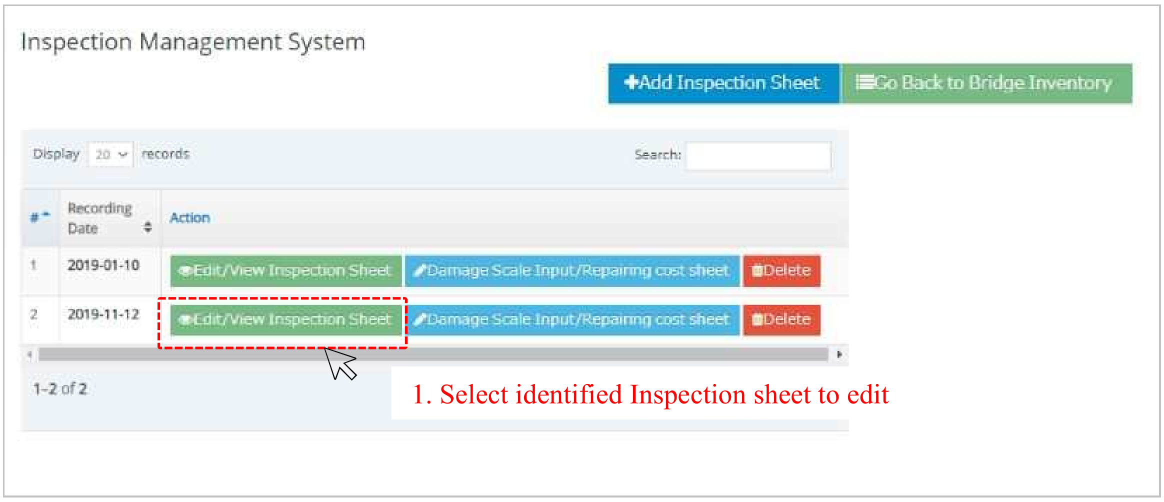
9.



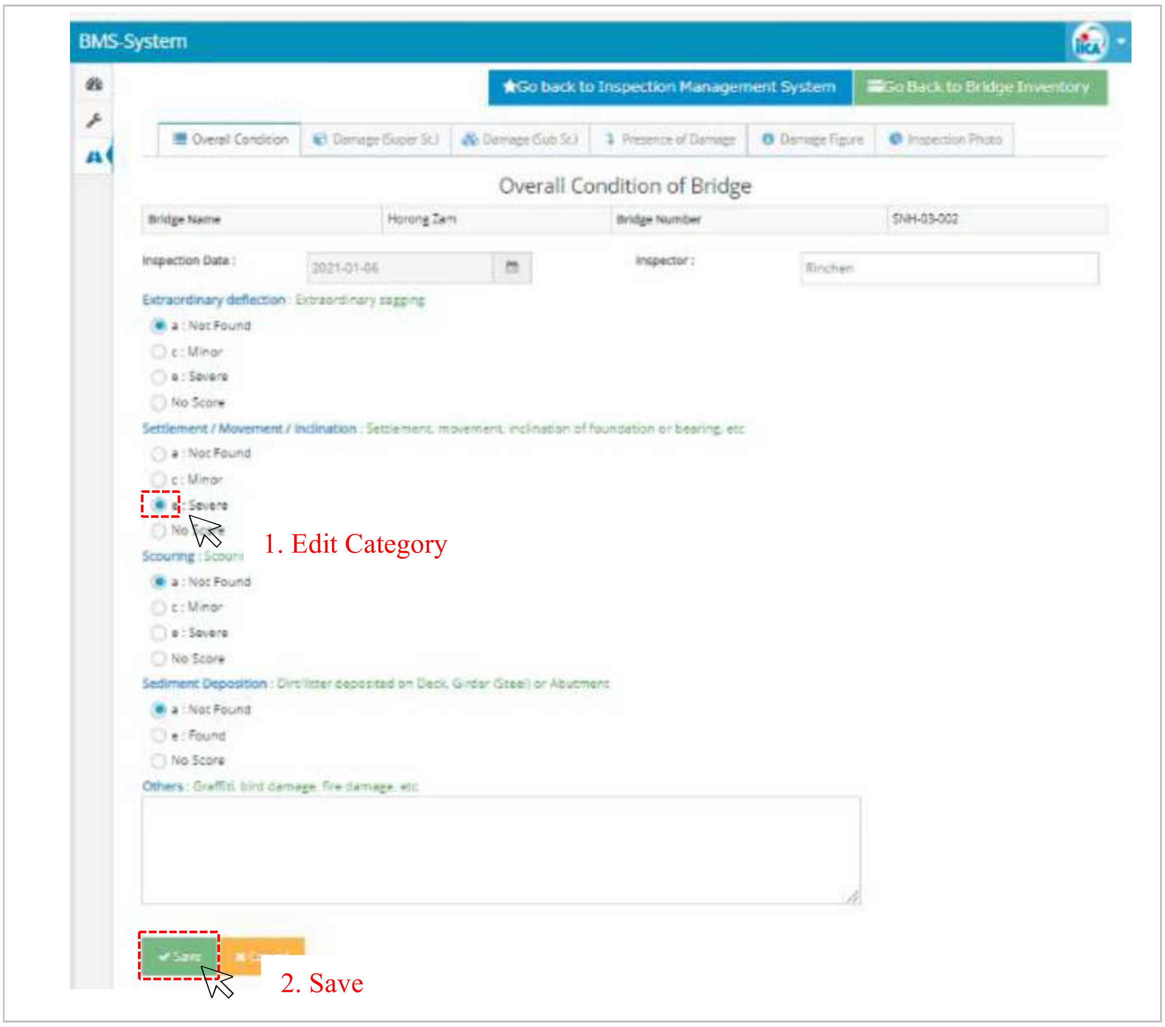
3.3.3 How to edit the existing inspection record

- How to operate in BMS –

1.

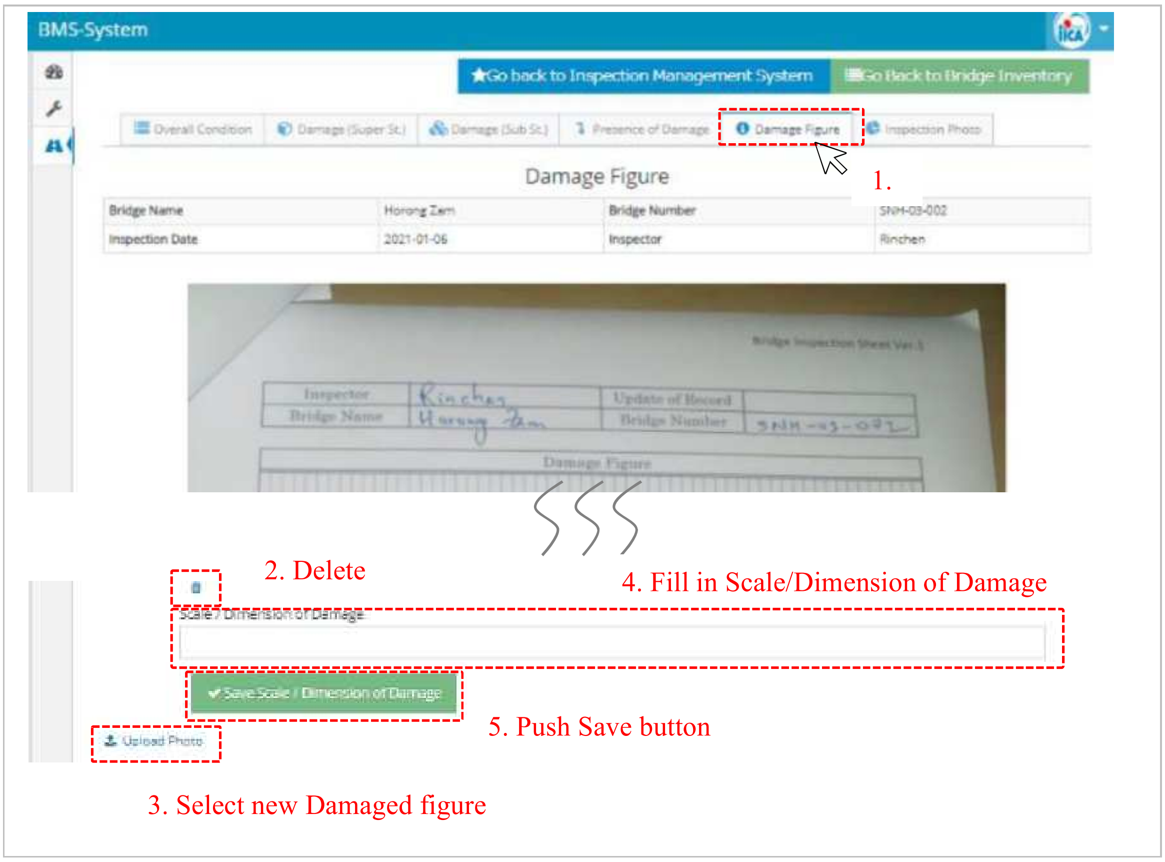


2.



“Damage(Super St)”, “Damage(Sub St)”,”Presence of Damage” are same procedure of “Overall condition”

3.



("Inspection Photo" tab is same procedure of "Damage Figure" tab)

3.4 The Prioritization

The BMS has the function to evaluate repair and reinforcement prioritization by adding weight factor point based on information of bridge ledger and damage category from latest inspection record. Because the weight factor point is defined by administrator, the prioritization point for each bridge is automatically calculated by extracting from Bridge ledger and lates inspection record. All BMS user can know the prioritization point and prioritization order. The general logic to add weight factor point is shown in Figure 3.1.

Weight factor Set by Administrator

Ex. Weight factor point in "Bridge Ledger"

Bridge type

Bailey Bridge	5

Road classification

PNH	20
SNH	4
Dzongkhag	3
GC	3
Feeder Road	2
Urban Road(Thimphu)	6

Abutment type

RRM	7
Gabion wall	7

Loading capacity (no range to fix)

8	-	11	7
12	-	17	5
18	-	23	4
24	-	39	3
40	-	69	2
70	-		0

Total traffic volume (msa)

0	-	49	0
50	-	99	3
100	-		6

⋮

Ex. Weight factor point in "Bridge Inspection record"

Extraordinary deflection

a	0
b	-
c	-
d	-
e	20

Settlement Movement Inclination

a	0
b	-
c	-
d	-
e	20

Scouring

a	0
b	-
c	10
d	-
e	20

⋮

Weight factor distribution to each Bridge

Bridge Detail			Bridge Ledger							
#	Bridge Name	Bridge....No....	Bridge Type	Road Classification	Abutment Type	Loading Capacity	Total Traffic Volume	Rainfall Condition	Alternate Route	Age of bridge
1	Babzur Zam	GCR-0102-001	0	2	7	2	3	2	5	0
2	Tyelegangchu Zam	PNH-04-001	0	20	7	0	6	5	5	0

Total point of "Bridge Ledger" and "Inspection"

Deck Surface (Expansion joint)		Drainage facilities		Total Points	Action
Abnormity	Unevenness	Clogging	Water Leakage/Bearing		
0	0	0	10	31	
10	0	0	10	130	

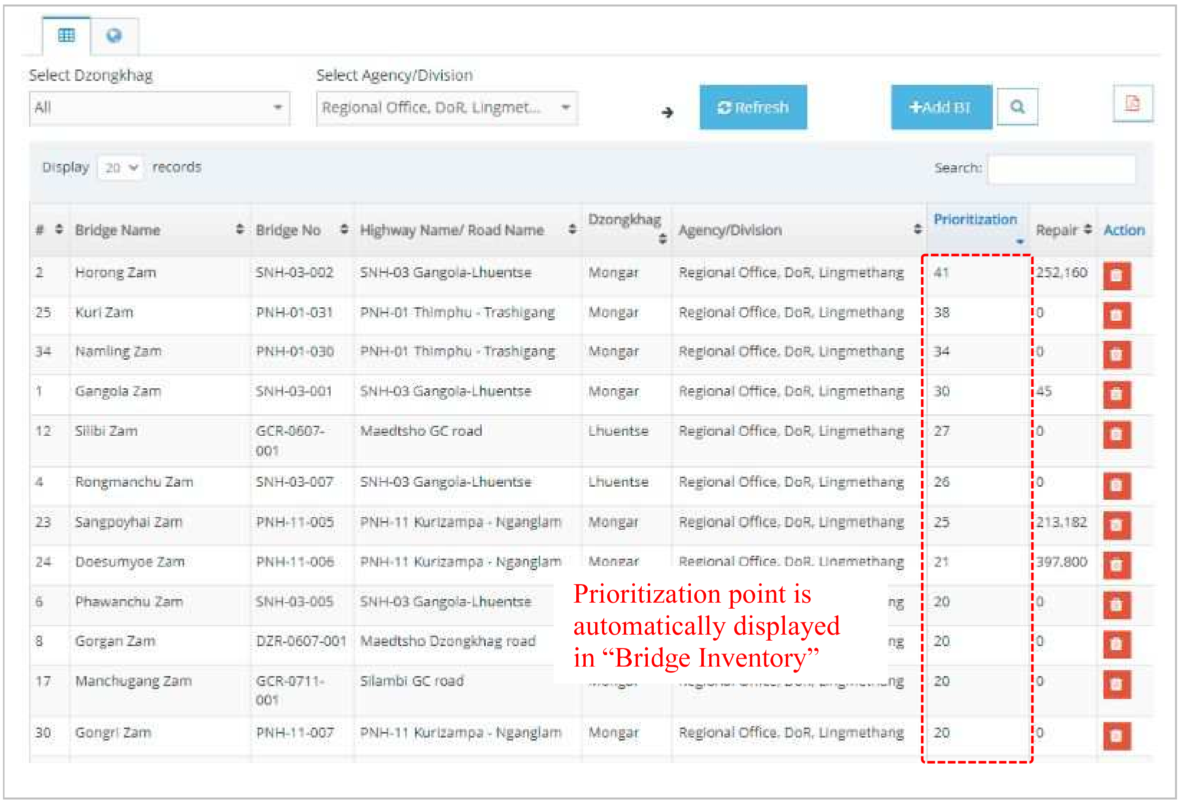
Prioritization point for each item is distributed

Reference: "Bridge Prioritization Summary" in BMS

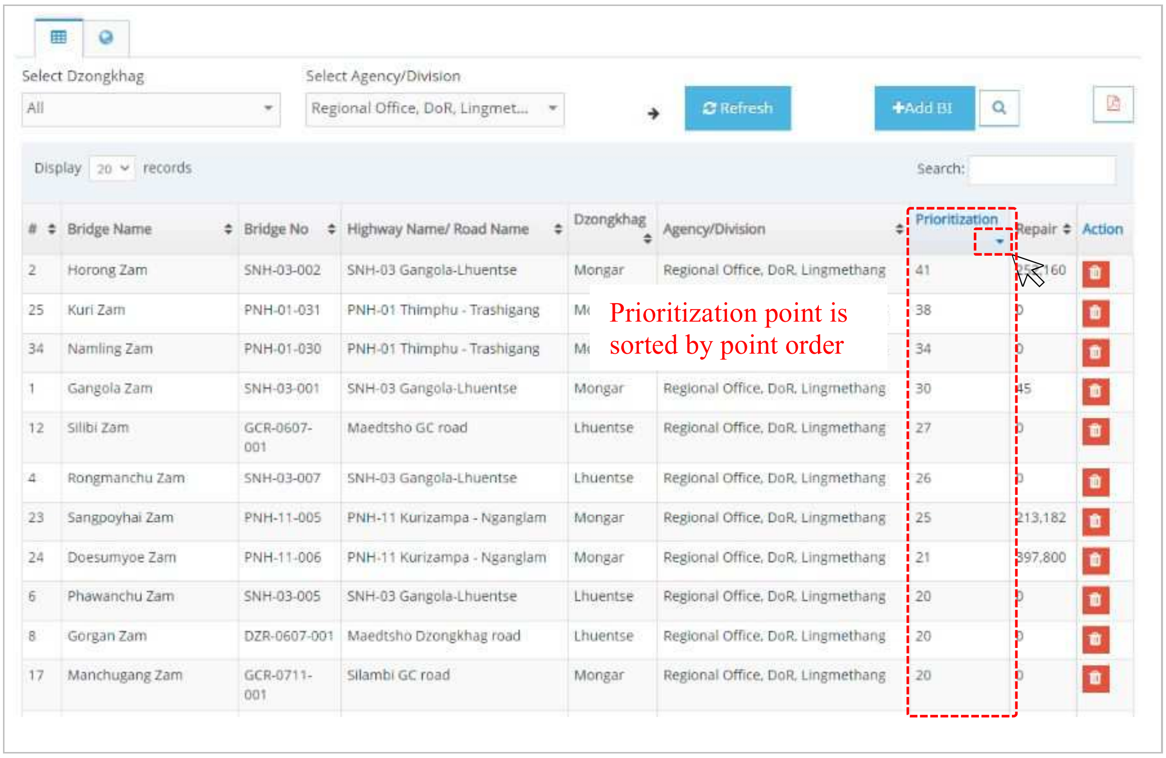
Figure 3.1 The general logic to add weight factor point

-How to operate in BMS-

1.In Bridge Inventory



2.



3.5 The repairing cost estimation

The repairing cost estimation system is to roughly estimate repairing cost based on damage scale multiply by unit cost for repairing. The necessary items for calculation are systematically linked with each module. The system linkage in BMS is shown in Figure 3.2.

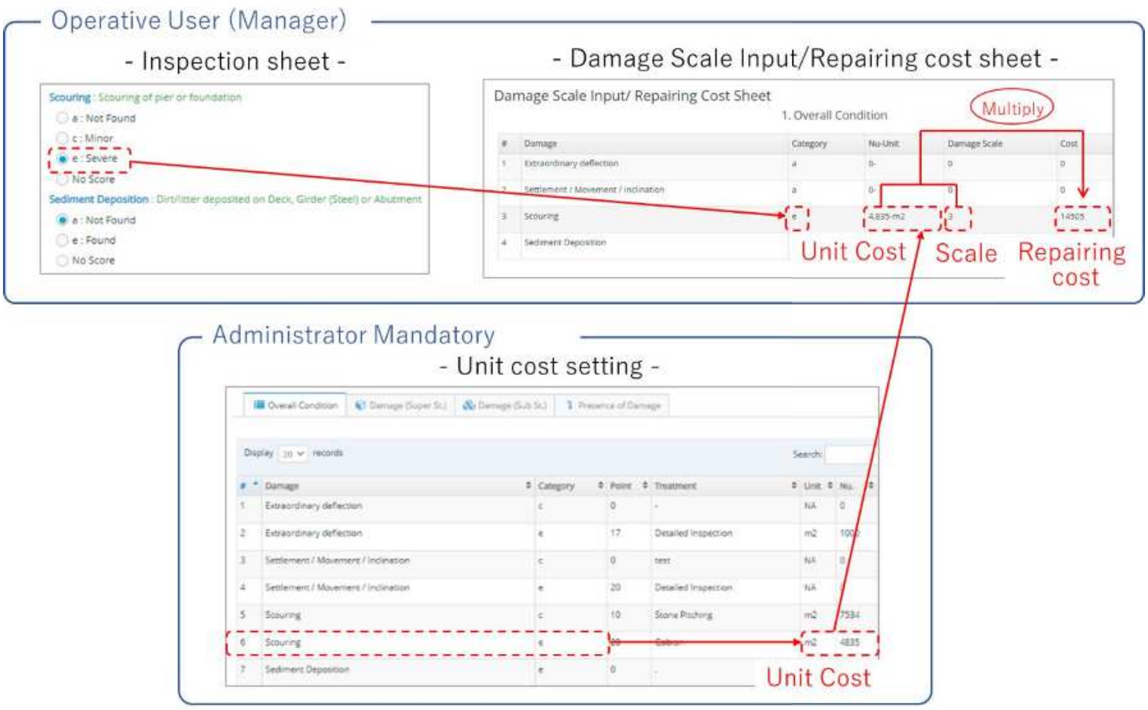
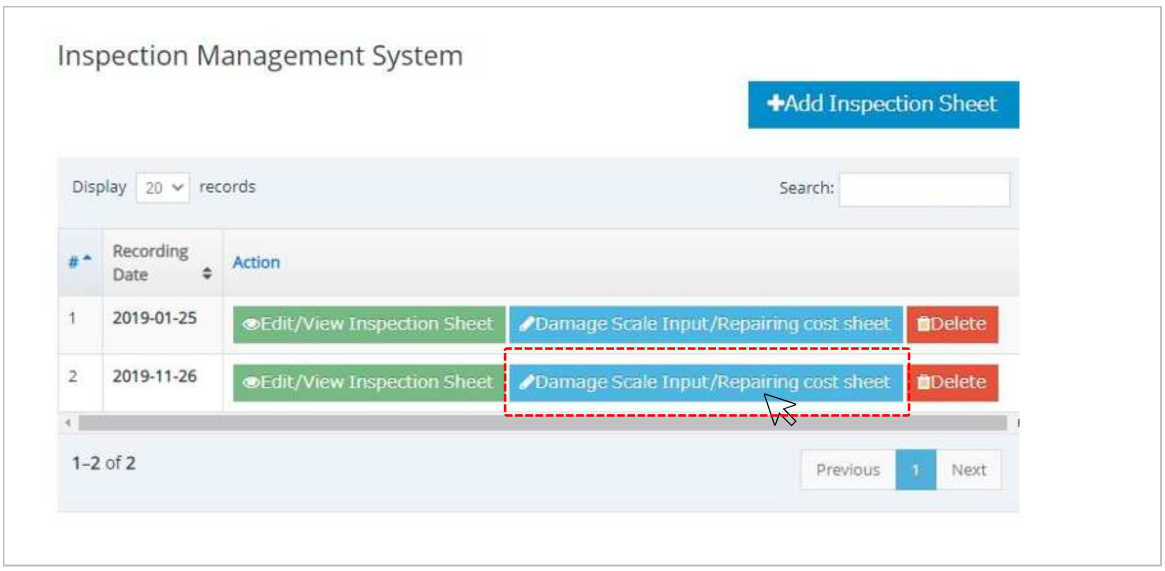


Fig 3.2 System linkage for repairing cost calculation

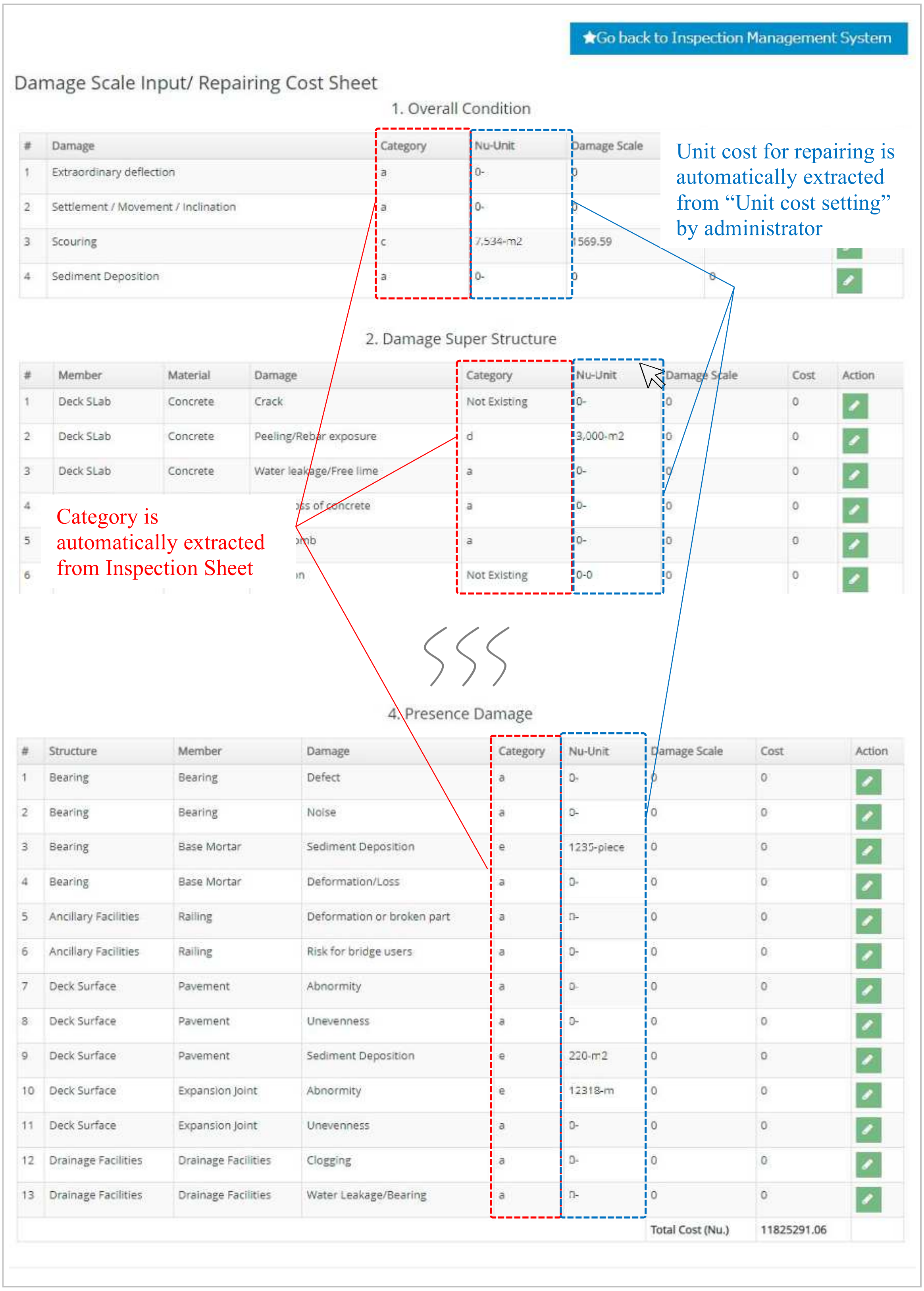
The operational user (Manager) is only to set damage scale in “Damage Scale Input/Repairing cost sheet”. The procedure to operate in BMS is as follows.

-How to operate in BMS-

1. Access to “Inspection Management System”



2.



★Go back to Inspection Management System

Damage Scale Input/ Repairing Cost Sheet

1. Overall Condition

#	Damage	Category	Nu-Unit	Damage Scale		
1	Extraordinary deflection	a	0-	0		
2	Settlement / Movement / Inclination	a	0-	0		
3	Scouring	c	7,534-m2	1569.59		
4	Sediment Deposition	a	0-	0	0	

Unit cost for repairing is automatically extracted from "Unit cost setting" by administrator

2. Damage Super Structure

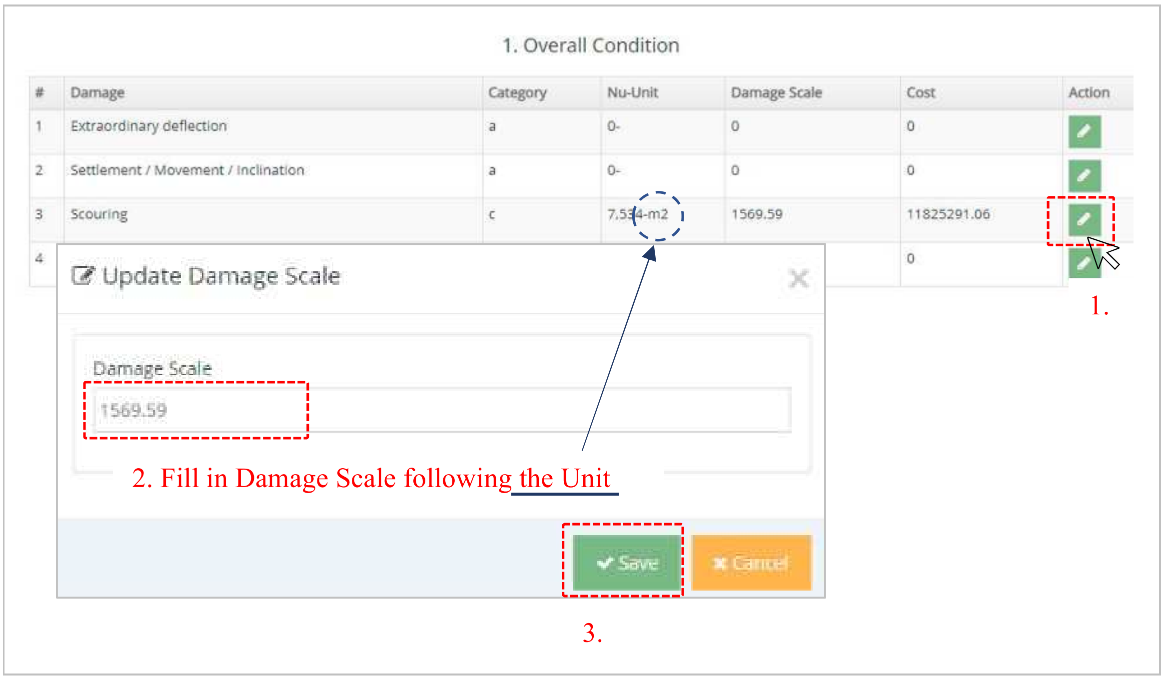
#	Member	Material	Damage	Category	Nu-Unit	Damage Scale	Cost	Action
1	Deck SLab	Concrete	Crack	Not Existing	0-	0	0	
2	Deck SLab	Concrete	Peeling/Rebar exposure	d	3,000-m2	0	0	
3	Deck SLab	Concrete	Water leakage/Free lime	a	0-	0	0	
4			...ss of concrete	a	0-	0	0	
5			...mb	a	0-	0	0	
6			...n	Not Existing	0-0	0	0	

Category is automatically extracted from Inspection Sheet

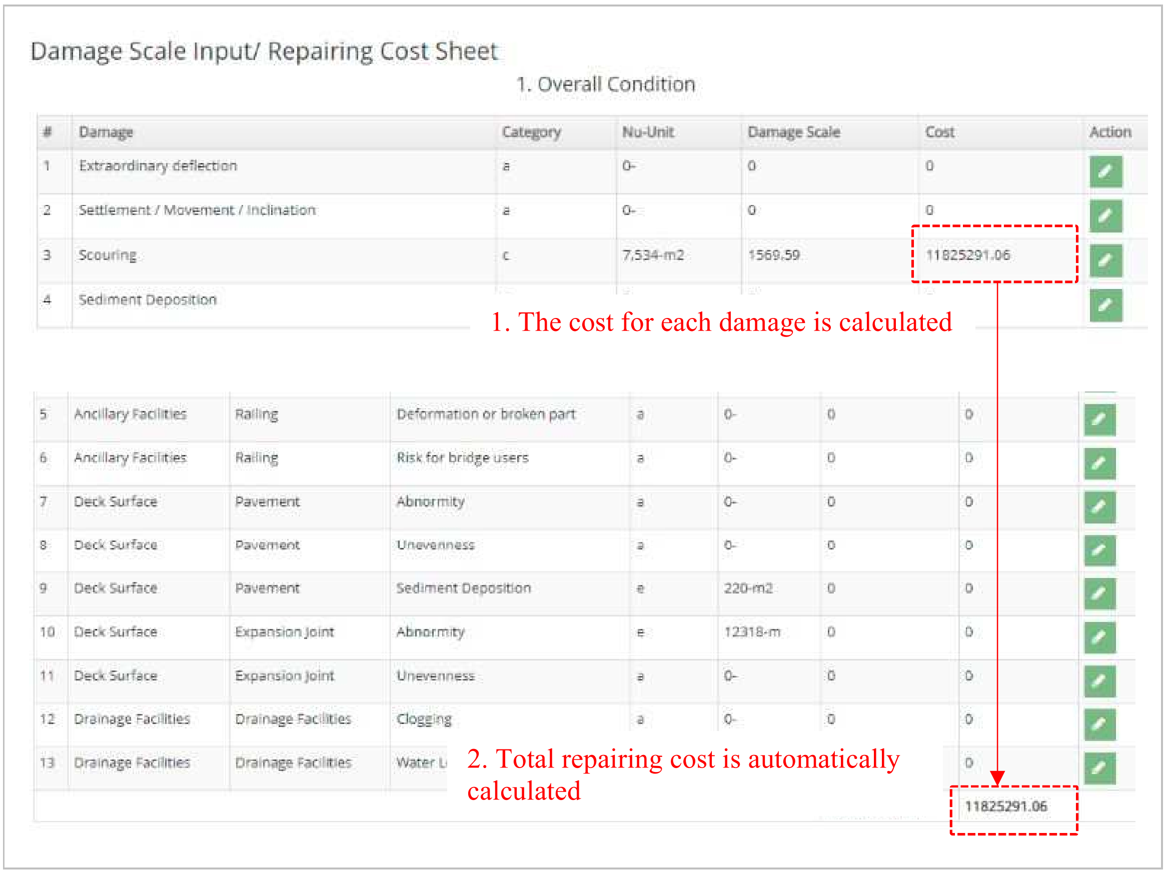
4. Presence Damage

#	Structure	Member	Damage	Category	Nu-Unit	Damage Scale	Cost	Action
1	Bearing	Bearing	Defect	a	0-	0	0	
2	Bearing	Bearing	Noise	a	0-	0	0	
3	Bearing	Base Mortar	Sediment Deposition	e	1235-piece	0	0	
4	Bearing	Base Mortar	Deformation/Loss	a	0-	0	0	
5	Ancillary Facilities	Railing	Deformation or broken part	a	0-	0	0	
6	Ancillary Facilities	Railing	Risk for bridge users	a	0-	0	0	
7	Deck Surface	Pavement	Abnormity	a	0-	0	0	
8	Deck Surface	Pavement	Unevenness	a	0-	0	0	
9	Deck Surface	Pavement	Sediment Deposition	e	220-m2	0	0	
10	Deck Surface	Expansion Joint	Abnormity	e	12318-m	0	0	
11	Deck Surface	Expansion Joint	Unevenness	a	0-	0	0	
12	Drainage Facilities	Drainage Facilities	Clogging	a	0-	0	0	
13	Drainage Facilities	Drainage Facilities	Water Leakage/Bearing	a	0-	0	0	
						Total Cost (Nu.)	11825291.06	

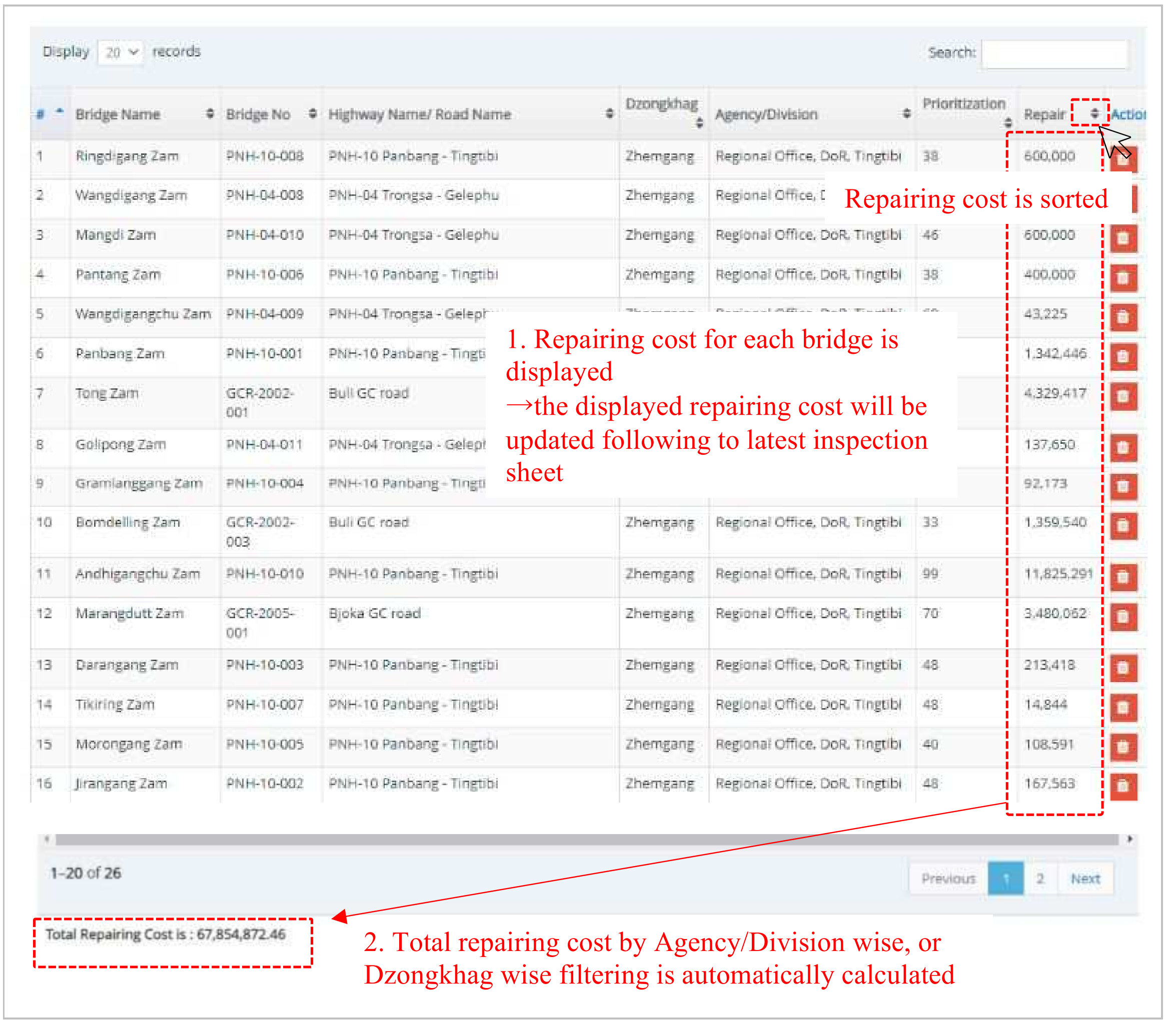
3.


1. Overall Condition
Damage Category Nu-Unit Damage Scale Cost Action
1 Extraordinary deflection a 0- 0 0
2 Settlement / Movement / Inclination a 0- 0 0
3 Scouring c 7,534-m2 1569.59 11825291.06
4
Update Damage Scale
Damage Scale
1569.59
2. Fill in Damage Scale following the Unit
Save
Cancel
1.
3.

4.


Damage Scale Input/ Repairing Cost Sheet
1. Overall Condition
Damage Category Nu-Unit Damage Scale Cost Action
1 Extraordinary deflection a 0- 0 0
2 Settlement / Movement / Inclination a 0- 0 0
3 Scouring c 7,534-m2 1569.59 11825291.06
4 Sediment Deposition
1. The cost for each damage is calculated
5 Ancillary Facilities Railing Deformation or broken part a 0- 0 0
6 Ancillary Facilities Railing Risk for bridge users a 0- 0 0
7 Deck Surface Pavement Abnormity a 0- 0 0
8 Deck Surface Pavement Unevenness a 0- 0 0
9 Deck Surface Pavement Sediment Deposition e 220-m2 0 0
10 Deck Surface Expansion Joint Abnormity e 12318-m 0 0
11 Deck Surface Expansion Joint Unevenness a 0- 0 0
12 Drainage Facilities Drainage Facilities Clogging a 0- 0 0
13 Drainage Facilities Drainage Facilities Water L 0
2. Total repairing cost is automatically calculated
11825291.06

5. Display in Bridge Inventory



Display 20 records Search:

#	Bridge Name	Bridge No	Highway Name/ Road Name	Dzongkhag	Agency/Division	Prioritization	Repair	Action
1	Ringdigang Zam	PNH-10-008	PNH-10 Panbang - Tingtibi	Zhemgang	Regional Office, DoR, Tingtibi	38	600,000	
2	Wangdigang Zam	PNH-04-008	PNH-04 Trongsa - Gelephu	Zhemgang	Regional Office, [illegible]			
3	Mangdi Zam	PNH-04-010	PNH-04 Trongsa - Gelephu	Zhemgang	Regional Office, DoR, Tingtibi	46	600,000	
4	Pantang Zam	PNH-10-006	PNH-10 Panbang - Tingtibi	Zhemgang	Regional Office, DoR, Tingtibi	38	400,000	
5	Wangdigangchu Zam	PNH-04-009	PNH-04 Trongsa - Geleph[illegible]				43,225	
6	Panbang Zam	PNH-10-001	PNH-10 Panbang - Tingti[illegible]				1,342,446	
7	Tong Zam	GCR-2002-001	Buli GC road				4,329,417	
8	Golipong Zam	PNH-04-011	PNH-04 Trongsa - Geleph[illegible]				137,650	
9	Gramlanggang Zam	PNH-10-004	PNH-10 Panbang - Tingti[illegible]				92,173	
10	Bomdelling Zam	GCR-2002-003	Buli GC road	Zhemgang	Regional Office, DoR, Tingtibi	33	1,359,540	
11	Andhigangchu Zam	PNH-10-010	PNH-10 Panbang - Tingtibi	Zhemgang	Regional Office, DoR, Tingtibi	99	11,825,291	
12	Marangdutt Zam	GCR-2005-001	Bjoka GC road	Zhemgang	Regional Office, DoR, Tingtibi	70	3,480,062	
13	Darangang Zam	PNH-10-003	PNH-10 Panbang - Tingtibi	Zhemgang	Regional Office, DoR, Tingtibi	48	213,418	
14	Tikiring Zam	PNH-10-007	PNH-10 Panbang - Tingtibi	Zhemgang	Regional Office, DoR, Tingtibi	48	14,844	
15	Morongang Zam	PNH-10-005	PNH-10 Panbang - Tingtibi	Zhemgang	Regional Office, DoR, Tingtibi	40	108,591	
16	Jirangang Zam	PNH-10-002	PNH-10 Panbang - Tingtibi	Zhemgang	Regional Office, DoR, Tingtibi	48	167,563	

1-20 of 26 Previous 1 2 Next

Total Repairing Cost is : 67,854,872.46

MANUAL 7 : Operation Manual on Bridge Management System (For Administrator)

CAMBRIDGE

Technical Cooperation Project for Capacity Development in Construction and Maintenance of Bridges in the Kingdom of Bhutan

Operation Manual on Bridge Management System (For Administrator)

April 2022

Department of Road
Ministry of Works & Human Settlement
Royal Government of Bhutan

Japan International Cooperation Agency

Table of Contents

1 General

The BMS supposed to be utilized by not only head quarter officer but also regional office in DoR though the web-based database system. Due to all users access in one database system, the mandatory in DoR should be set in BMS system. Following to the accessibility and permission in system, the BMS will be utilized as DoR mandatory systematical structure.

The target users for this user’s manual are for administrator in DoR expect for the target who is developer and system engineer to deal with programing structure.

➢ **System feature and structure**

I. Web-based System

By accessing BMS via Web, the System that can be used not only by DoR headquarters bridge division staff but also by regional office staff was developed.

II. Software Structure

The Zend Framework (ZF) application which is an open-source web application framework implemented on PHP. It is also managed using phpMyAdmin as a client tool for managing a MySQL server with a web browser which is also implemented in PHP.

III. Server PC Setting

The server PC for BMS is managed by ICT division MoWHS in the server room. The server management environment is prepared 24 hours a day with air conditions and blackout curtains.

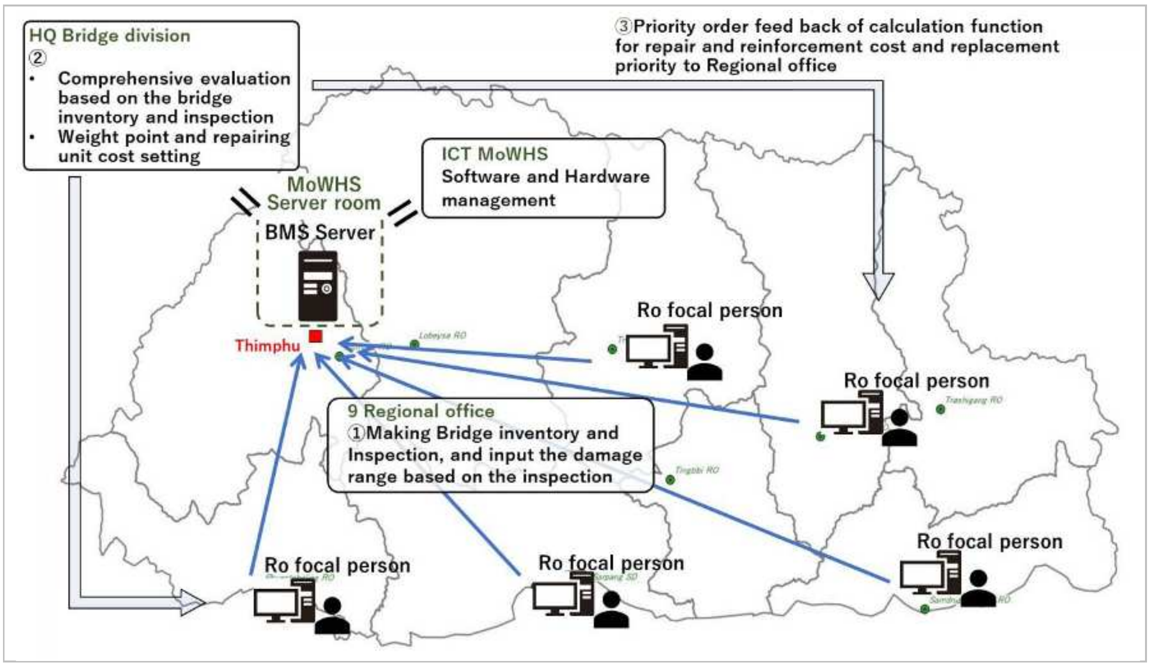


Figure 1.1 Cooperation between HQ and Regional office

➢ Definition of Administrator

The role of BMS administrator is as follows,

a) Management of System including system access permissions, user setting and database backup

- Detailed interface setting
- Definition and management of User setting for all user

b) Management of BMS utilization

- Accessibility and permission of Bridge Inventory, Bridge inspection and Repairing cost estimation
- Definition of weight factor setting for prioritization
- Definition of unit cost for repairing

2 Access permission system

In the BMS system, interface and accessibility can be set in the "set privileges" function. The definition level is categorized by five levels as "Administrator", "Manager", "Dealing Officer", "Report viewer", and "Public". In the existing setting, it is utilized only in "Administrator", "Manager", "Dealing Officer". The existing setting is shown in Table 2.1.

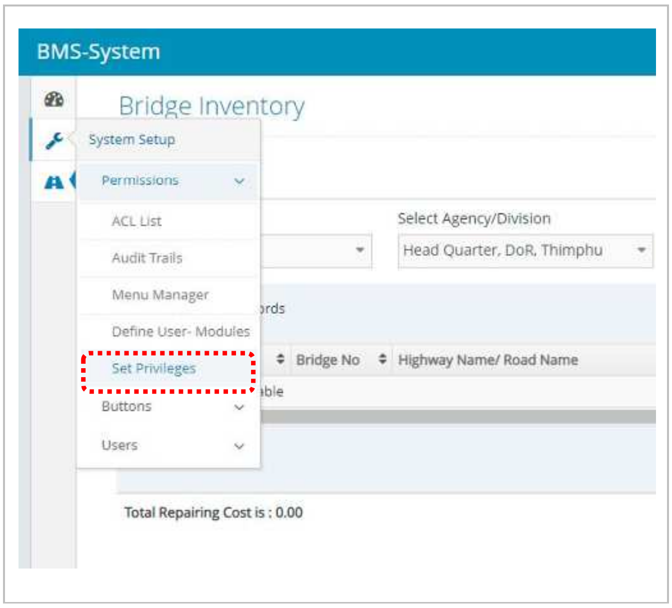
Table 2.1 Sample of accessibility setting (Set Privileges)

Module & function			Available Type	Set Privileges※		
				Dealing Officer	Manager	Administrator
System Setup	Permissions	ACL List	View & Edit			✓
		Audit Trails	View & Edit			✓
		Menu Manager	View & Edit			✓
		Define User	All account setting			✓
			Own account setting		✓	
		Set Privileges	View & Edit			✓
	Database Backup		View & Edit			✓
Bridge Master	Bridge Ledger Item setting		View & Edit			✓
	Prioritization Setting		View & Edit			✓
	Unit Cost Setting		View & Edit			✓
BMS Module	Bridge Inventory		View	✓	✓	✓
			Edit		✓	✓
			Restore Bridge Data			✓
	Bridge Inspection		View	✓	✓	✓
			Edit		✓	✓
	Repairing Cost Estimation System		View	✓	✓	✓
			Edit		✓	✓
Summary Sheet	Bridge Evaluation Summary		View	✓	✓	✓
	Bridge Prioritization Summary		View	✓	✓	✓

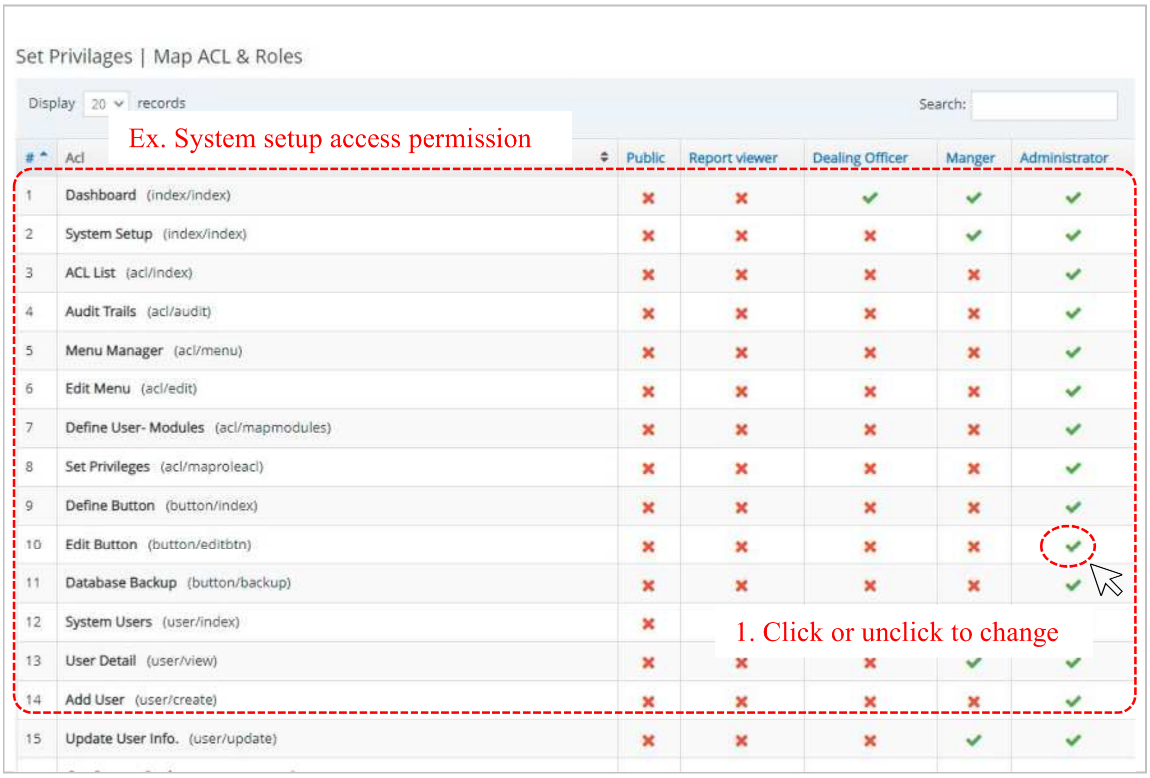
※Privileges level (Manager or Administrator) is defined in user setting on "System User"

- How to operate in BMS -

1. Access to the "Set Privileges"



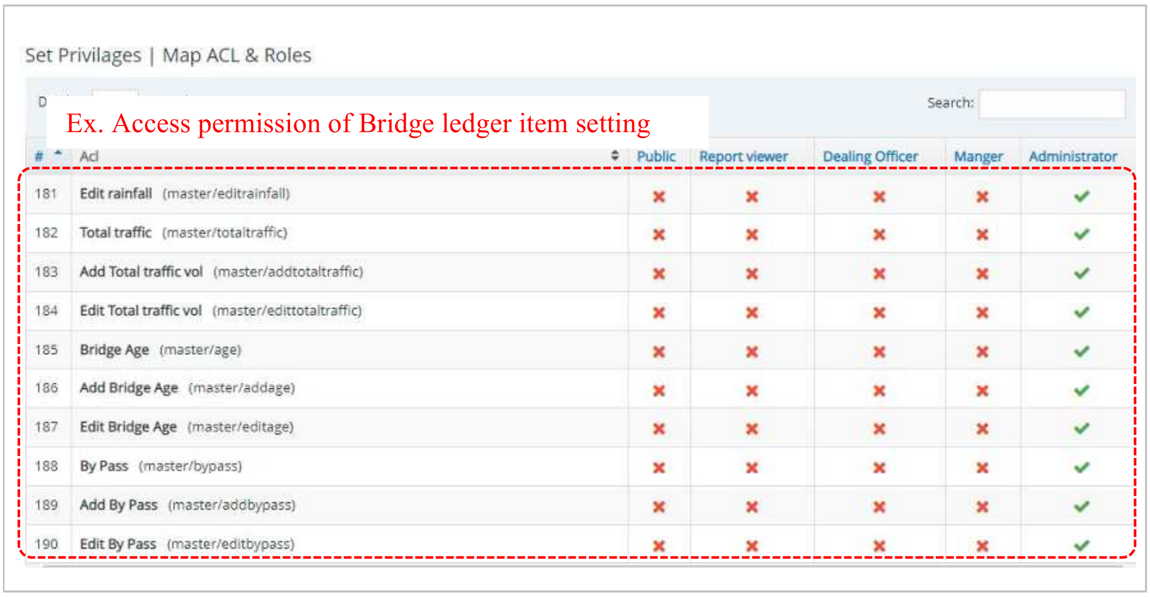
2. Set the access permission



Set Privilages | Map ACL & Roles

Display 20 records Search:

#	Acl	Public	Report viewer	Dealing Officer	Manger	Administrator
1	Dashboard (index/index)	✗	✗	✓	✓	✓
2	System Setup (index/index)	✗	✗	✗	✓	✓
3	ACL List (acl/index)	✗	✗	✗	✗	✓
4	Audit Trails (acl/audit)	✗	✗	✗	✗	✓
5	Menu Manager (acl/menu)	✗	✗	✗	✗	✓
6	Edit Menu (acl/edit)	✗	✗	✗	✗	✓
7	Define User- Modules (acl/mapmodules)	✗	✗	✗	✗	✓
8	Set Privileges (acl/maproleacl)	✗	✗	✗	✗	✓
9	Define Button (button/index)	✗	✗	✗	✗	✓
10	Edit Button (button/editbtn)	✗	✗	✗	✗	✓
11	Database Backup (button/backup)	✗	✗	✗	✗	✓
12	System Users (user/index)	✗				
13	User Detail (user/view)	✗	✗	✗	✓	✓
14	Add User (user/create)	✗	✗	✗	✗	✓
15	Update User Info. (user/update)	✗	✗	✗	✓	✓



Set Privilages | Map ACL & Roles

Search:

#	Acl	Public	Report viewer	Dealing Officer	Manger	Administrator
181	Edit rainfall (master/editrainfall)	✗	✗	✗	✗	✓
182	Total traffic (master/totaltraffic)	✗	✗	✗	✗	✓
183	Add Total traffic vol (master/addtotaltraffic)	✗	✗	✗	✗	✓
184	Edit Total traffic vol (master/edittotaltraffic)	✗	✗	✗	✗	✓
185	Bridge Age (master/age)	✗	✗	✗	✗	✓
186	Add Bridge Age (master/addage)	✗	✗	✗	✗	✓
187	Edit Bridge Age (master/editage)	✗	✗	✗	✗	✓
188	By Pass (master/bypass)	✗	✗	✗	✗	✓
189	Add By Pass (master/addbypass)	✗	✗	✗	✗	✓
190	Edit By Pass (master/editbypass)	✗	✗	✗	✗	✓

Set Privilages | Map ACL & Roles

Ex. Access permission of View or Editing setting for Bridge Ledger and Inspection sheet

#	Acl	Public	Report viewer	Dealing Officer	Manger	Administrator
101	Bridge Management (index/index)	✗	✗	✓	✓	✓
102	Bridge Inventory (bridgeinv/index)	✗	✗	✓	✓	✓
103	Bridge Inventory List (bridgeinv/index)	✗	✗	✓	✓	✓
104	Bridge Inventory Map (bridgeinv/bmap)	✗	✗	✓	✓	✓
105	Add Bridge & Geographic Data (bridgeinv/addbridge)	✗	✗	✗	✓	✓
106	Edit Bridge & Geographic Data (bridgeinv/editbridge)	✗	✗	✗	✓	✓
107	Bridge Data (bridgeinv/bridgedata)	✗	✗	✓	✓	✓
108	Add Bridge Data (bridgeinv/addbridgedata)	✗	✗	✗	✓	✓
109	Edit Bridge Data (bridgeinv/editbridgedata)	✗	✗	✗	✓	✓
110	Bridge Photo Sheet (bridgeinv/photosheet)	✗	✗	✓	✓	✓
111	Bridge Photosheet add (bridgeinv/photosheetadd)	✗	✗	✗	✓	✓
112	Restore Bridge Data (bridgeinv/restorebridge)	✗	✗	✗	✗	✓
113	Inspection Sheet (inspection/)	✗	✗	✓	✓	✓
114	Damage Inspection (inspection/index)	✗	✗	✓	✓	✓
115	Add Condition of Damage (inspection/addcondition)	✗	✗	✗	✓	✓
116	Add Presence of Damage (inspection/addpresence)	✗	✗	✗	✓	✓
117	Add Damage Figure (inspection/adddamagefigure)	✗	✗	✗	✓	✓

------------- Reference how to set privilege in DoR Mandatory---------------

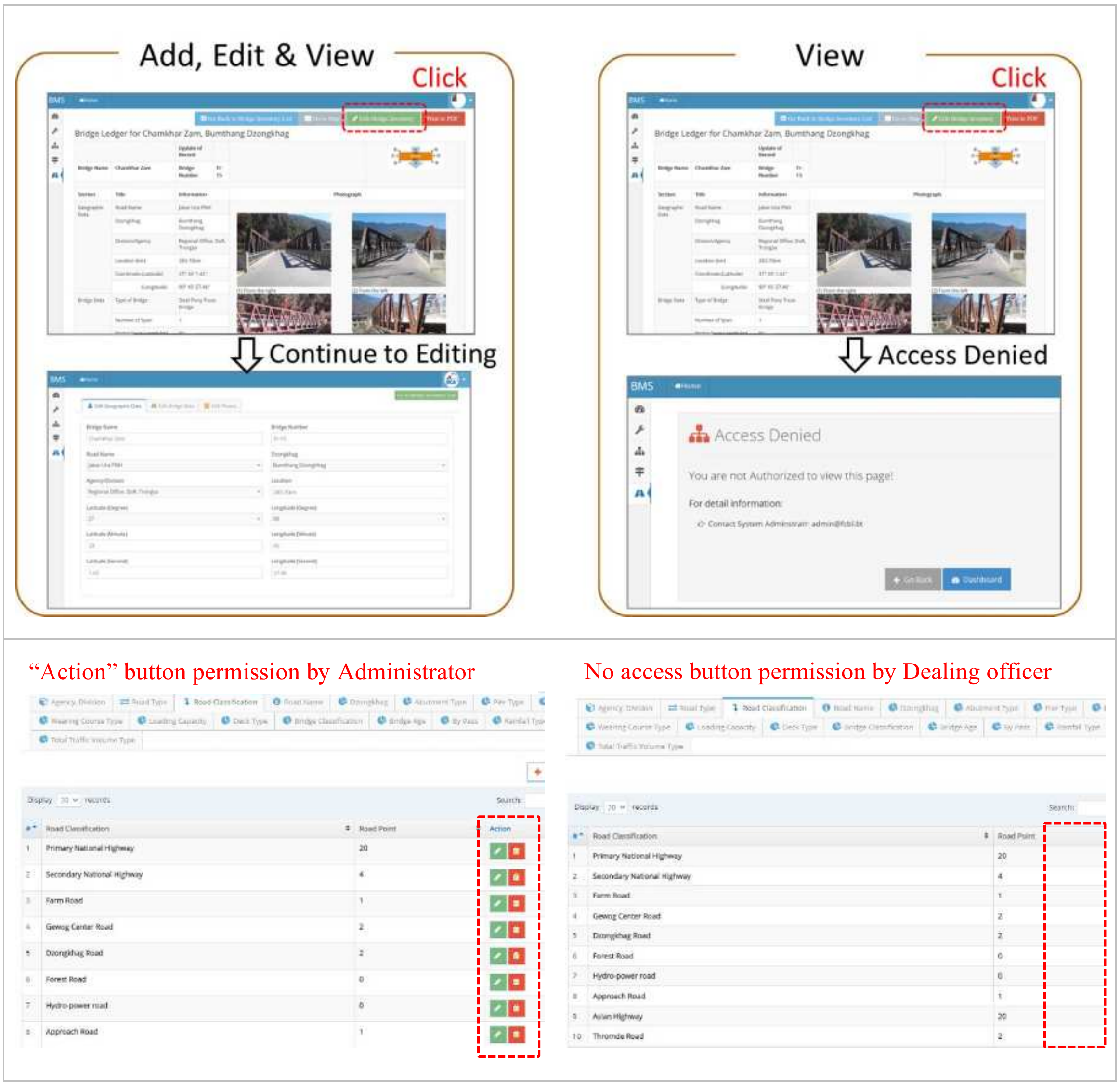
- **Existing Setting in DoR Jurisdiction Structure**

In the BMS system, the user privilege level is categorized by "Administrator", "Manager", and "Dealing officer", and set the access permission by each level. The DoR mandatory arrangement should be set to connect with the level of BMS in system. The existing setting as the sample is shown in Table 2.2. the setting should be changed by following DoR mandatory as required.

Table 2.2 The sample of DoR mandatory arrangement

DoR Mandatory			Privilege Level		
			Administrator	Manager	Dealing Officer
Head Quarter, Bridge Division	Chief Engineer		✓		
	Executive Engineer	D section	✓		
		C & M section	✓		
		Trail Bridge section	✓		
	Engineer			✓	
Regional office	Focal Person			✓	
	Engineer				✓

Sample Case of restriction by access permission



3 User Setting

3.1 System Users

Administrator can manage all BMS user setting as follows, all setting will be managed in “System Users” function.

a. Confirming all user configuration

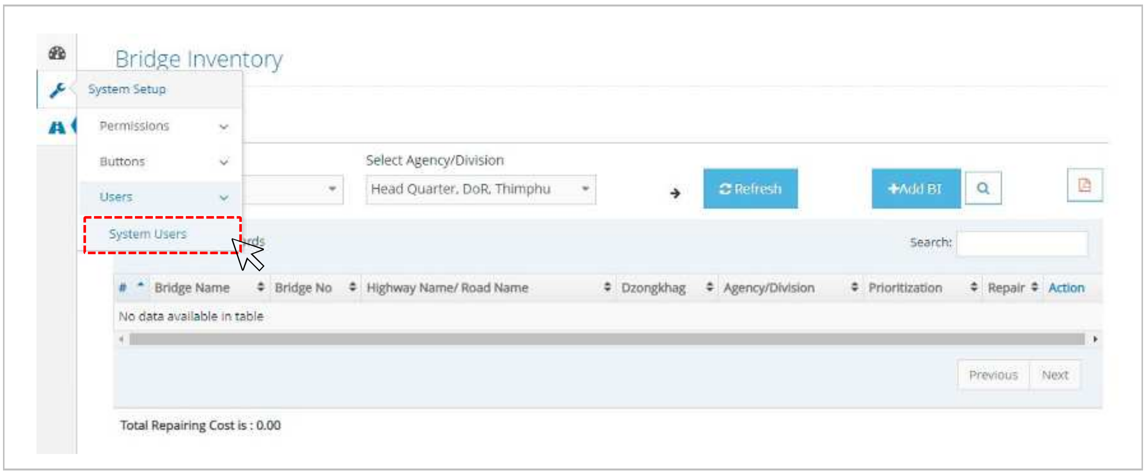
b. Confirming all users last login and logout time, date, count of Login

c. Active or no active setting for all users

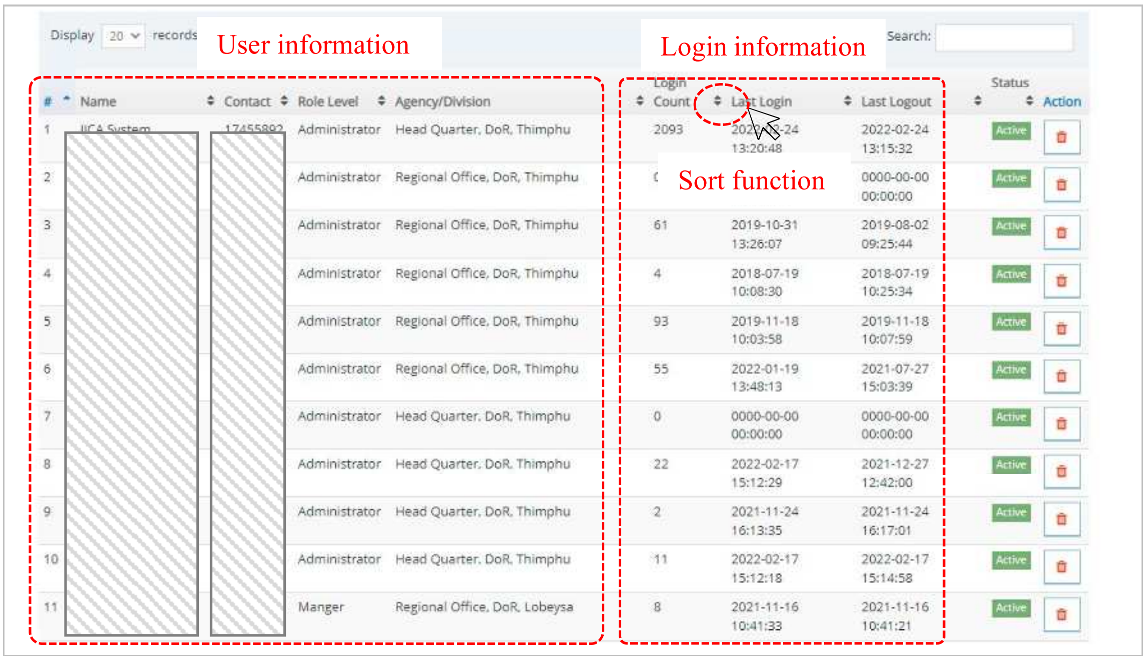
d. Add and delete user with mandatory and jurisdiction (role level) in DoR

- How to operate in BMS -

1.



2.

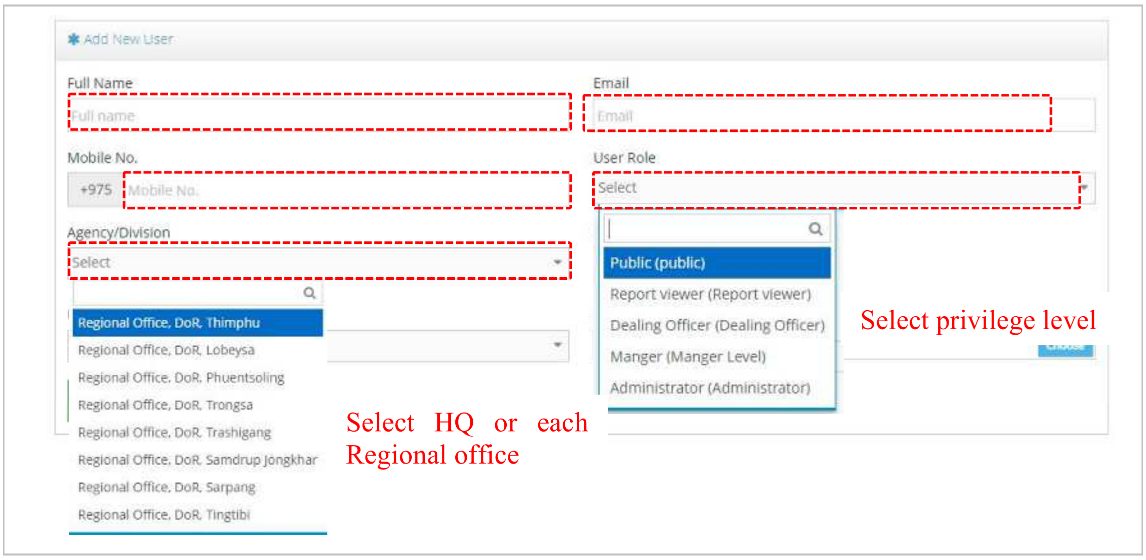


3.1.1 Add new User Setting

- How to operate in BMS –

1.

2.



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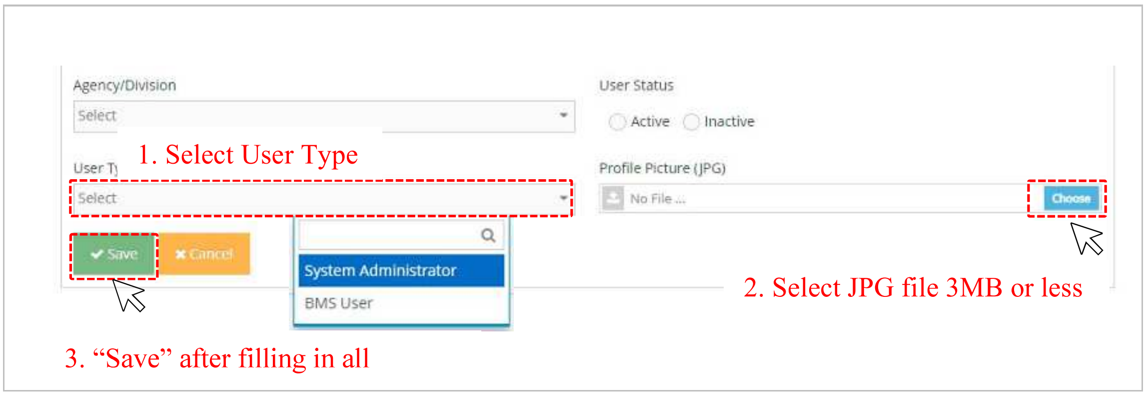
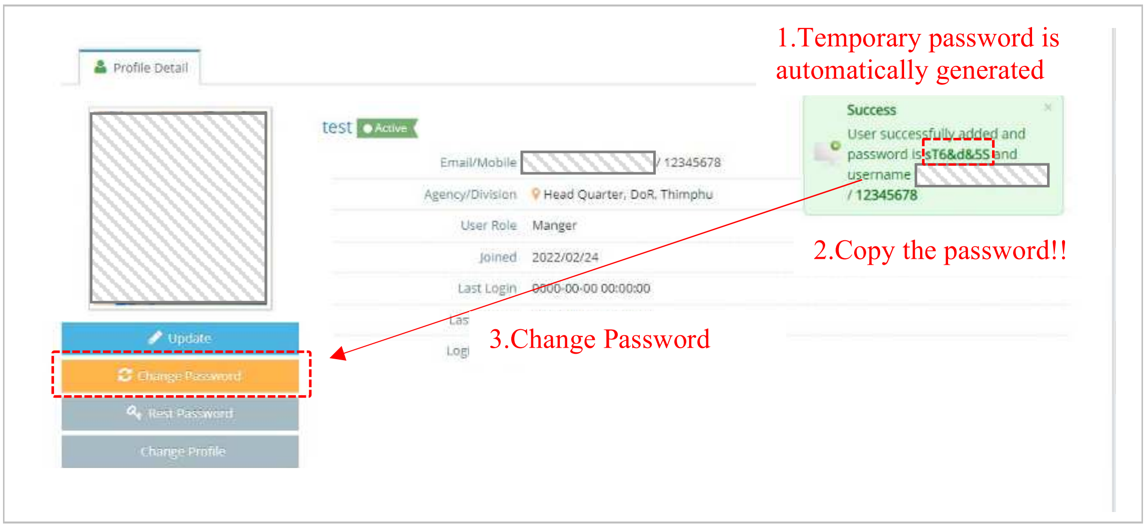
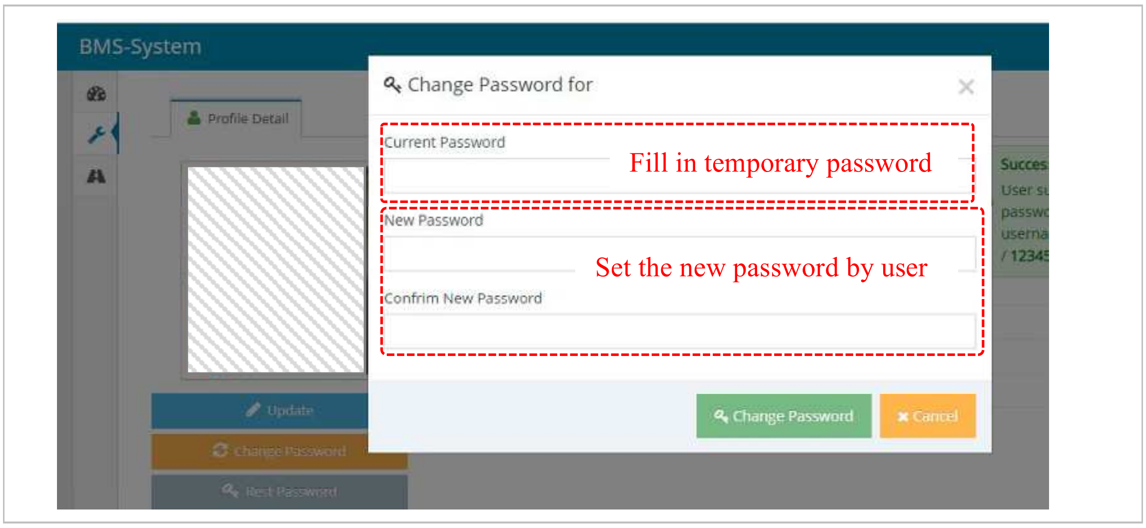


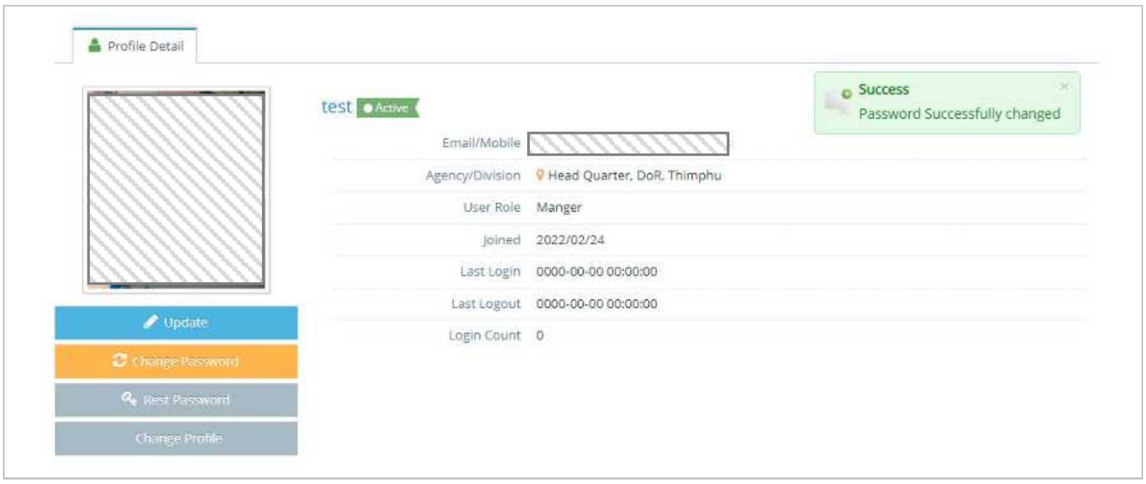
4.


1.Temporary password is automatically generated
Profile Detail
test
Active
Email/Mobile
/ 12345678
Agency/Division
Head Quarter, DoR, Thimphu
User Role
Manger
Joined
2022/02/24
Last Login
0000-00-00 00:00:00
Success
User successfully added and password is sT6&d&5S and username
/ 12345678
2.Copy the password!!
3.Change Password
Update
Change Password
Rest Password
Change Profile

5.


BMS-System
Profile Detail
Change Password for
Current Password
Fill in temporary password
New Password
Set the new password by user
Confrim New Password
Change Password
Cancel
Update
Change Password
Rest Password

6.

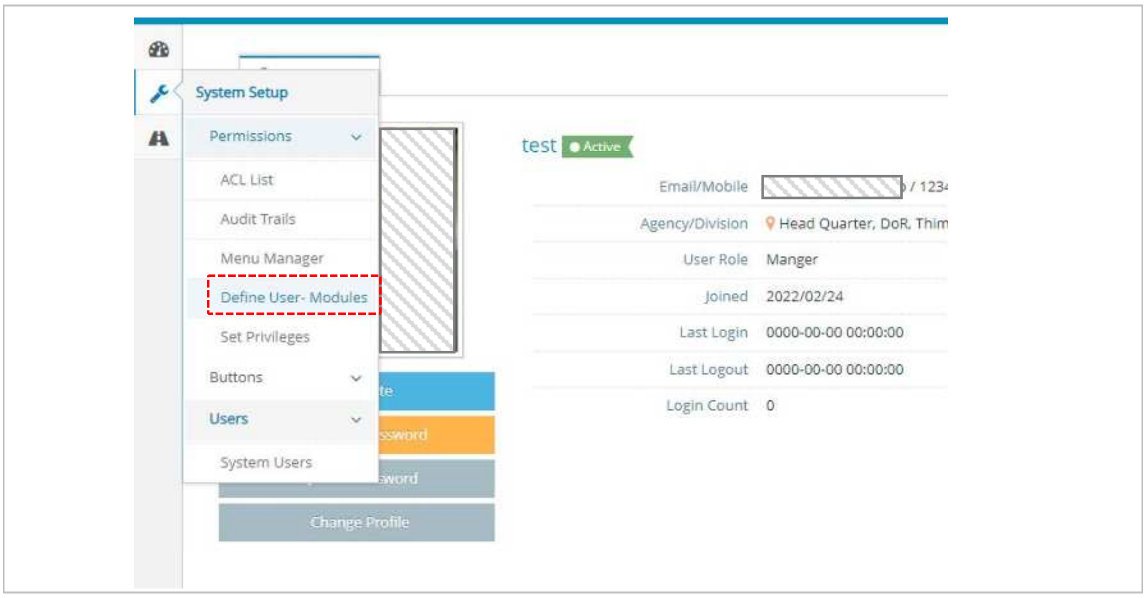

Profile Detail
test
Active
Success
Password Successfully changed
Email/Mobile
Agency/Division
Head Quarter, DoR, Thimphu
User Role
Manger
Joined
2022/02/24
Last Login
0000-00-00 00:00:00
Last Logout
0000-00-00 00:00:00
Login Count
0
Update
Change Password
Rest Password
Change Profile

3.1.2 Define User- Modules

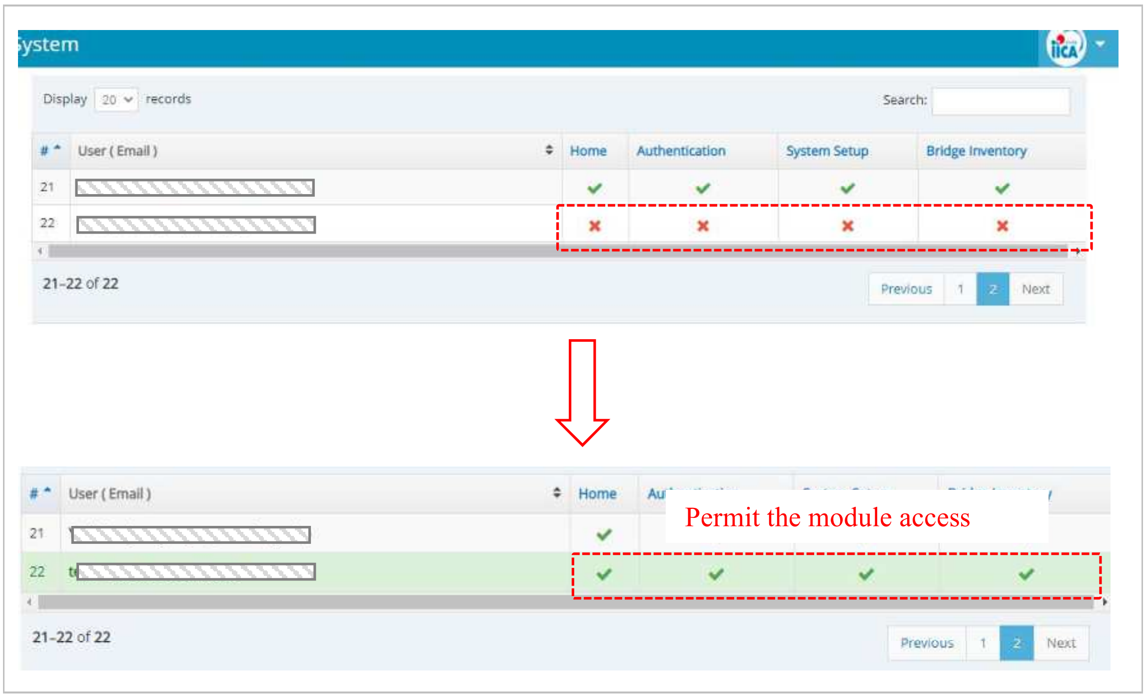
After setting the new user, administrator permit the module access to the new user as follows.

- How to operate in BMS -

1.



2.



4 Bridge Master Setting

4.1 Definition of Bridge Ledger Items

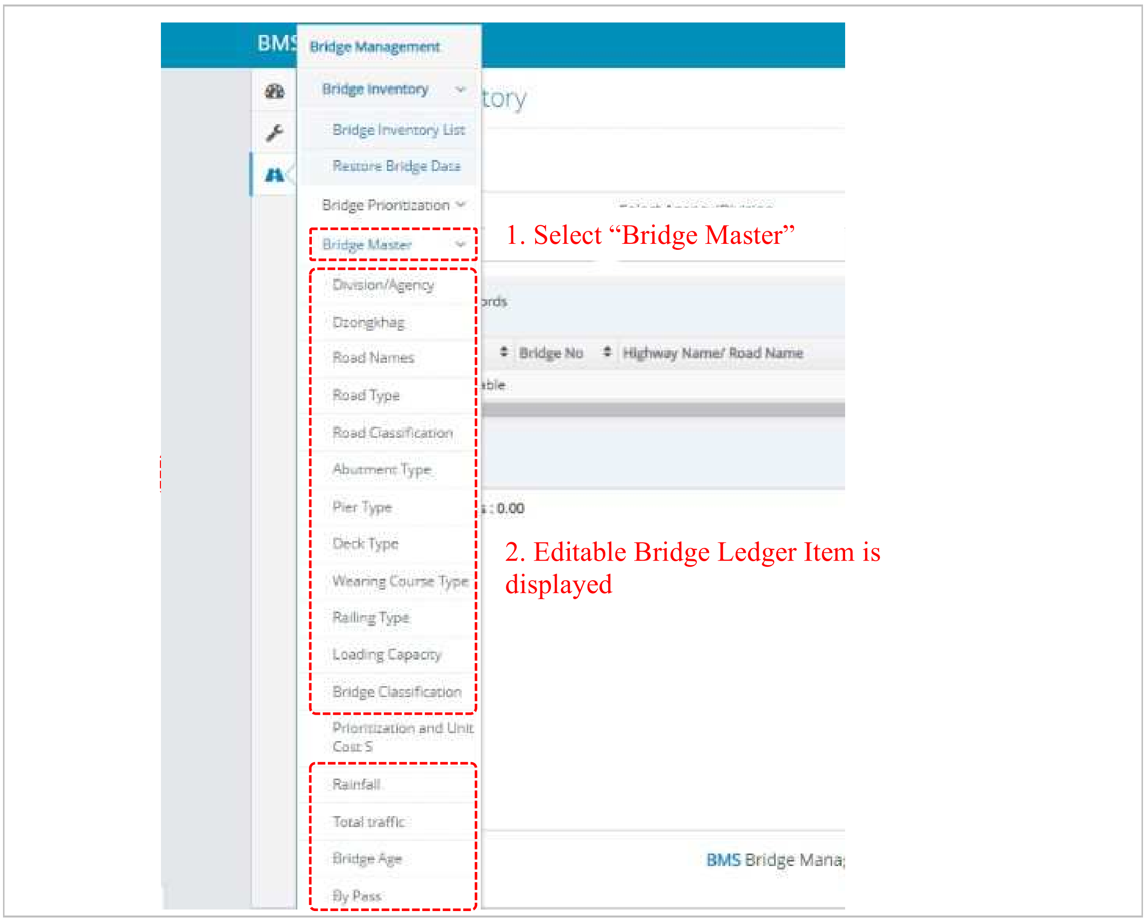
Administrator can manage the information of some Bridge Ledger Item in "Bridge Master" for BMS user to input information as fixed and format by pulling down selection. In the existing setting, administrator can only manage function and it should be customized as it necessary. The existing setting as the sample case is shown in Table 4.1.

Table 4.1 The sample case of fixed Item setting

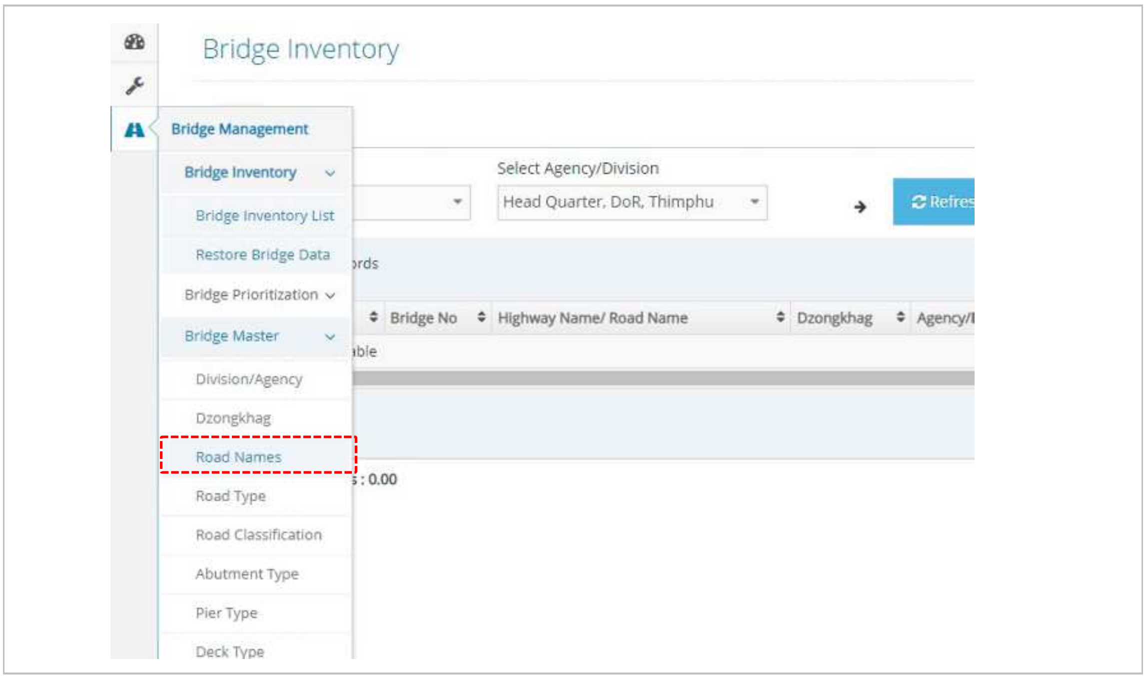
Section	Item of Bridge Ledger	Information (Pull down selection)
Geographic Data	Highway Name/ Road Name (Definition of "Road Name", "Road Type", "Road Classification")	Road Name ・PNH-01 Thimphu - Trashigang ・PNH-02 Samtse – Deothang ・SNH-04 Sunkosh - Dagana ・SNH-07 Samtse – Sipsu ・Maedtsho Dzongkhag road ・Tsirang Toed GC road ・Khoma GC road Road Type ・Flexible Pavement ・Rigid Pavement Road Classification ・Asian Highway ・Primary National Highway ・Secondary National Highway etc
	Dzongkhag	Dzongkhag
	Division/Agency	・Head Quarter, DoR, Thimphu ・Regional office, DoR, "Region"
	Alternate route (Bypass near bridge)	Yes, No
	Rainfall	Heavy, Moderate, Light
Bridge Data	Bridge Classification	Concrete, Steel, Composite, Bailey, Bailey Suspension
	Deck Type	RCC, Steel, Wooden, Embankment, Rigid frame
	Wearing Course Type	Asphalt, Premix Bitumen Carpet (Asphalt), Concrete, Steel, Wooden, Embankment, Base Course
	Railing Type	Heavy, Moderate, Light
	Abutment Type	RCC, Steel, Wooden, Wooden & Steel, Crash barrier, RRM
	Pier Type	RCC, RCC Column, RCC Wall, RRM
	Loading Capacity	8MT, 12MT, 18MT, 24MT, 40MT, 70MT

- How to operate in BMS –

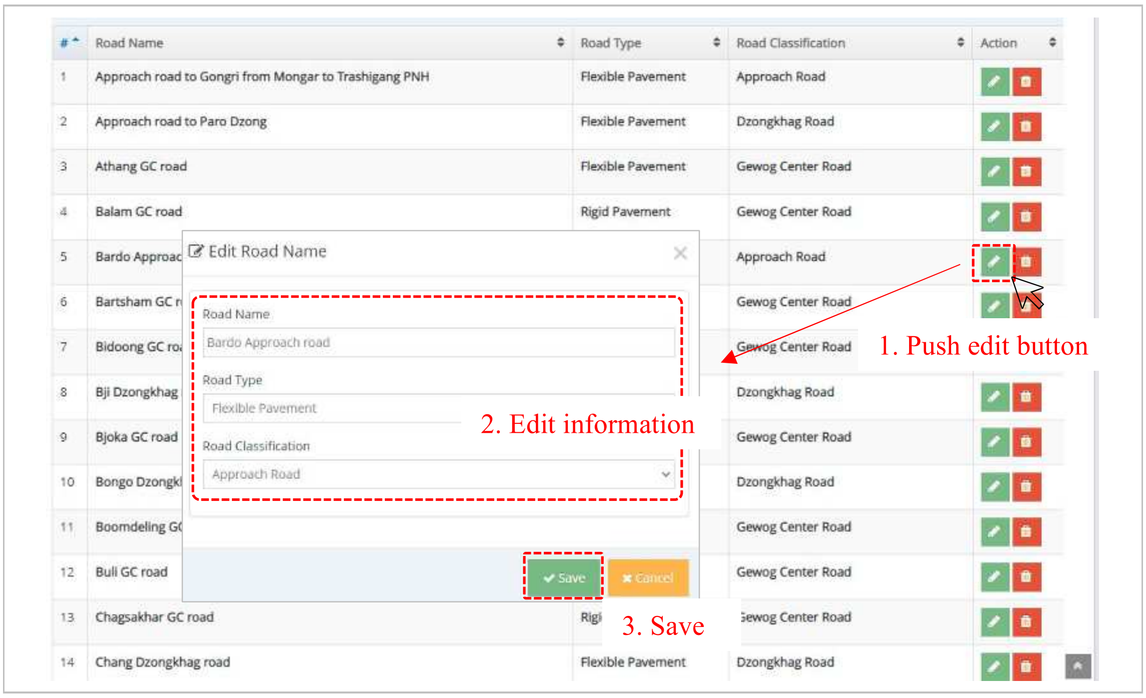
1.



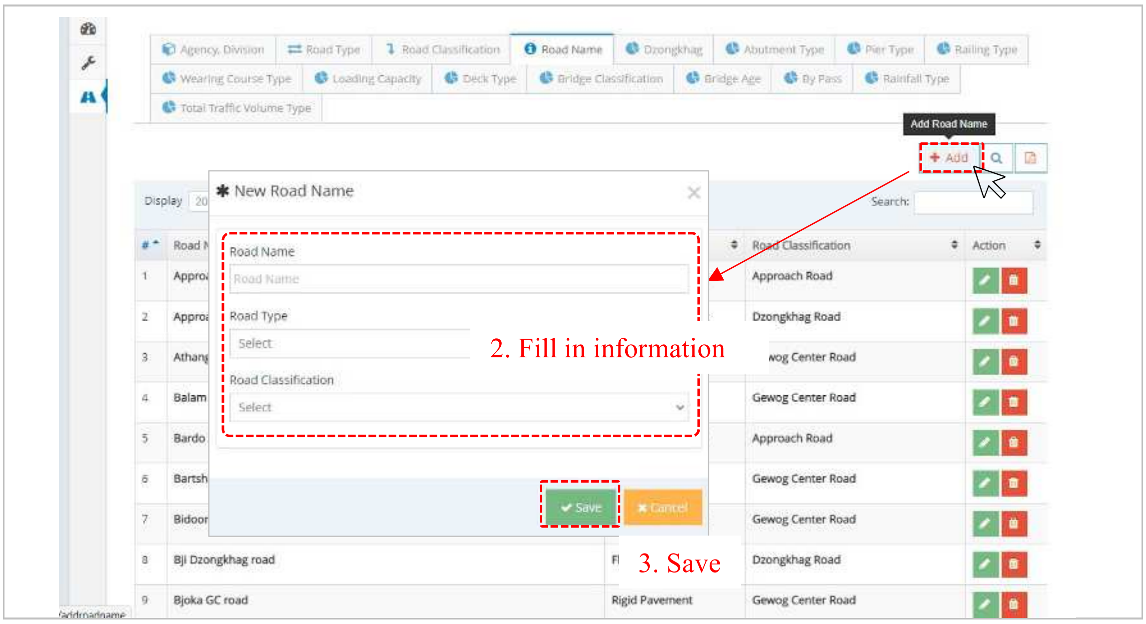
2. Ex. Road Name



3. Edit the existing information



3.Add new information



4.2 Prioritization Setting

The BMS has the function to define the prioritization by weight factor point. The administrator can set the weight factor for each Bridge Ledger Items and Inspection Items. It should be flexibly changed and customized by administrator to properly evaluate prioritization of bridge replacement, repairing and reinforcement.

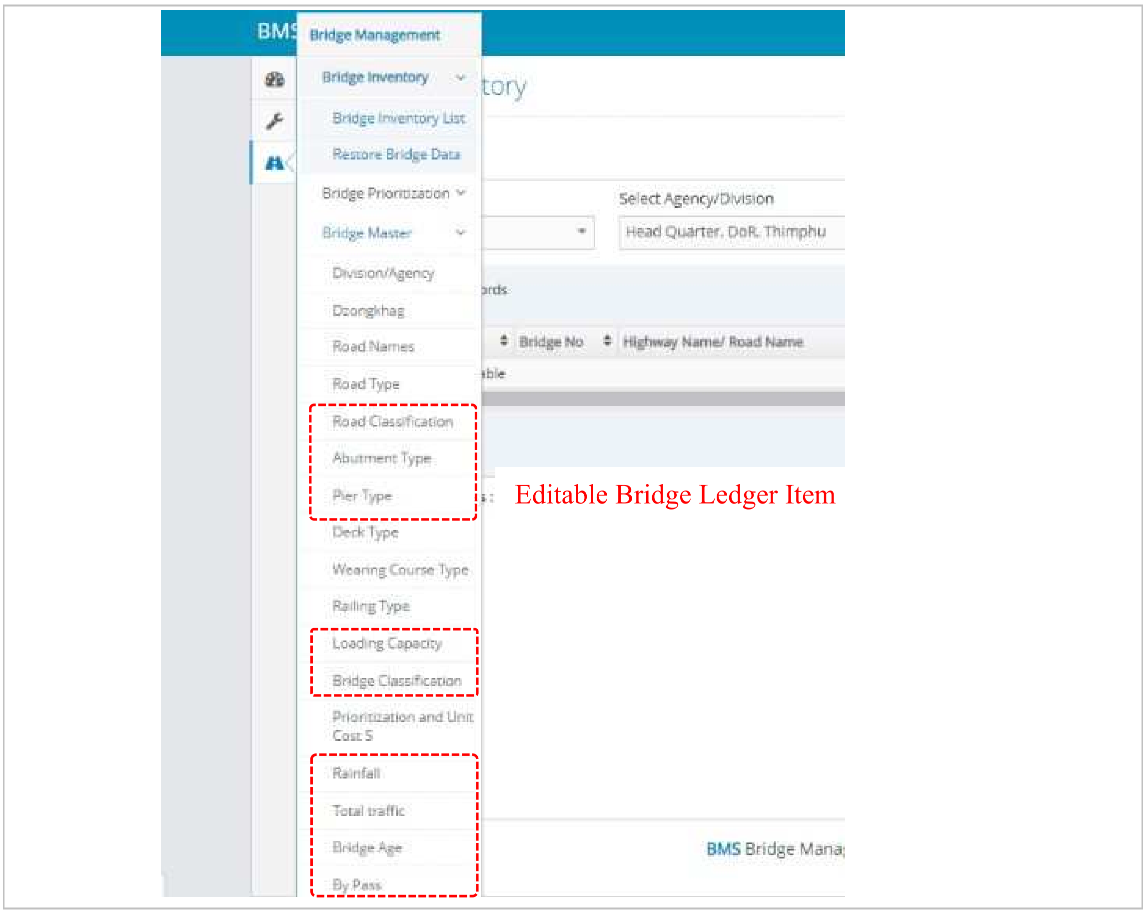
4.2.1 Bridge Ledger Items

Administrator can define the weight factor point for Bridge ledger items. The available item is shown in Table 4.2. The weight factor points and factor items can be edited by administrator.

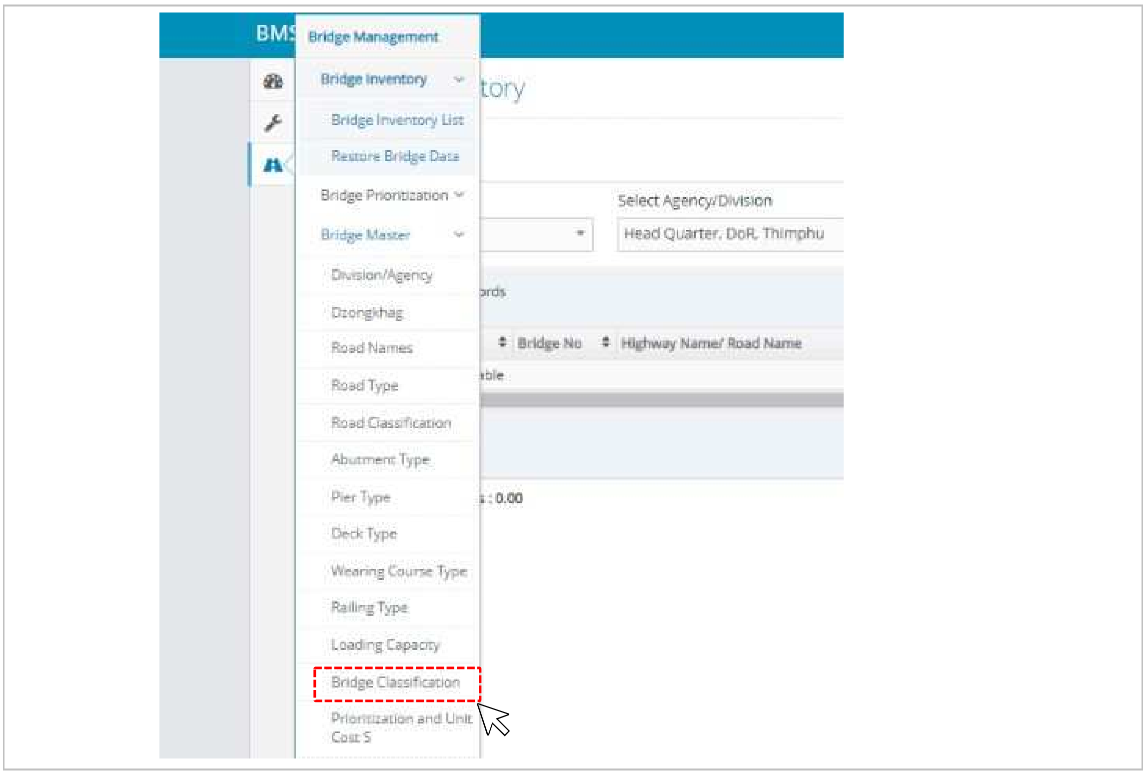
Table 4.2 Available weight factor items for Bridge Ledger

Section	Item of Bridge Ledger	Available weight factor items
Geographic Data	Road Classification	Primary National Highway, Asian Highway, Secondary National Highway, Gewog Center Road, Dzongkhag Road, Thromde Road, Farm Road, Approach Road, Forest Road, Hydro-power Road
	Alternate route (Bypass near bridge)	Yes, No
	Rainfall	Heavy, Moderate, Light
Bridge Data	Bridge Classification	Concrete, Steel, Composite, Bailey, Bailey Suspension
	Abutment Type	RCC, Steel, Wooden, Wooden & Steel, Crash barrier, RRM
	Pier Type	RCC, RCC Column, RCC Wall, RRM
	Bridge Age	10 years distance weight
	Loading Capacity	8MT, 12MT, 18MT, 24MT, 40MT, 70MT
	Total Traffic Volume Type	"Over 100", "50 - 100", "Under 50"

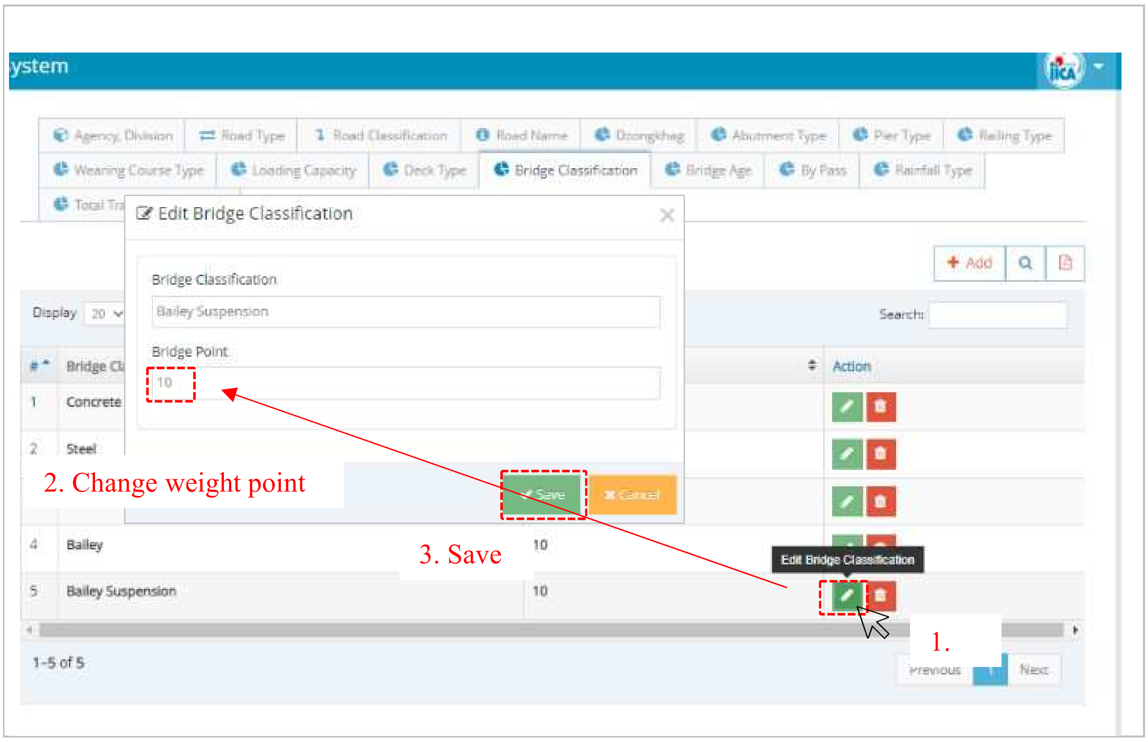
- How to operate BMS –



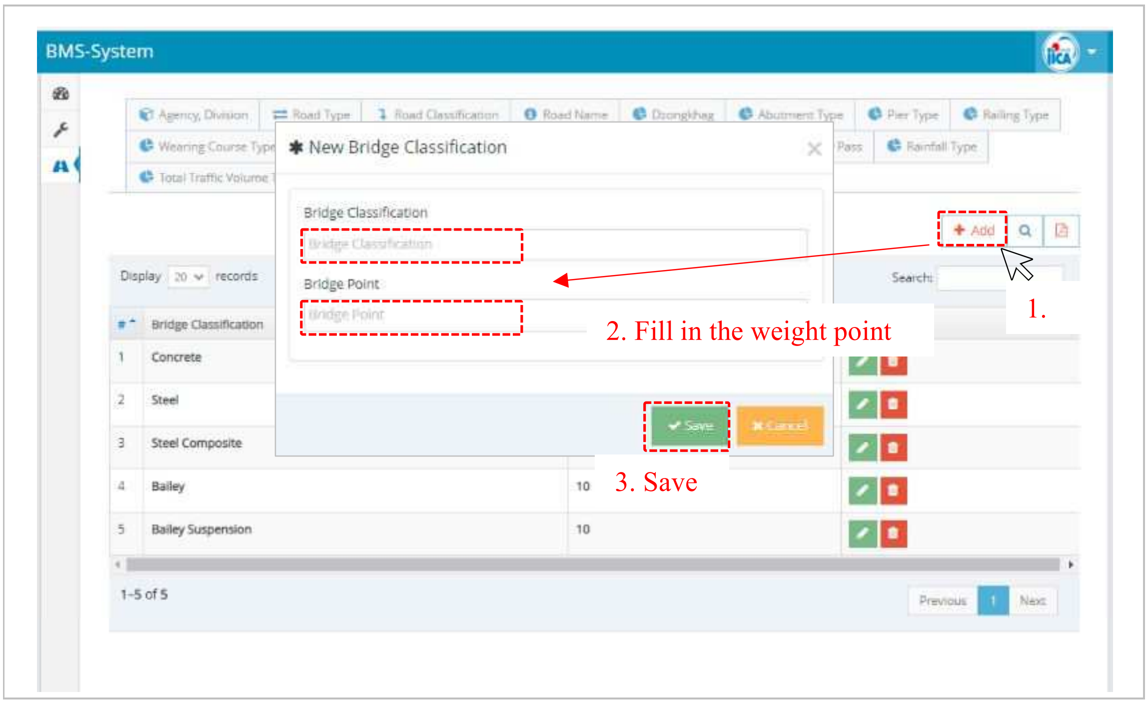
1. ex. Bridge Classification



2. Edit the existing information



3. Add new items and weight point



4.2.2 Bridge Inspection Items

Administrator can define weight factor point of each evaluation category for each damage items. The available items and category are shown in Table 4.3.

Table 4.3 Available weight factor items for Bridge Inspection

- Overall Condition

Damage	Category
Extraordinary deflection	c,e
Settlement/Movement/Inclination	c,e
Scouring	c,e
Sediment Deposition	e

- Damage (Super Structure)

Member	Material	Damage	Category
Deck Slab	Concrete	Crack	b,c,d,e
		Peeling/Rebar exposure	c,d,e
		Water leakage/Free lime	c,d,e
		Partial loss of concrete	e
		Honeycomb	b,c,d,e
	Steel	Corrosion	b,c,d,e
		Crack	c,e
		Looseness/Omission	c,e
		Fracture	e

Member	Material	Damage	Category
		Deterioration of Painting	c,d,e
Main Girder	Concrete	Crack	b,c,d,e
		Peeling/Rebar exposure	c,d,e
		Water leakage/Free lime	c,d,e
		Honeycomb	c,d,e
	Steel	Corrosion	b,c,d,e
		Crack	c,e
		Looseness/Omission	c,e
		Fracture	e
		Deterioration of Painting	c,d,e

· Damage (Sub Structure)

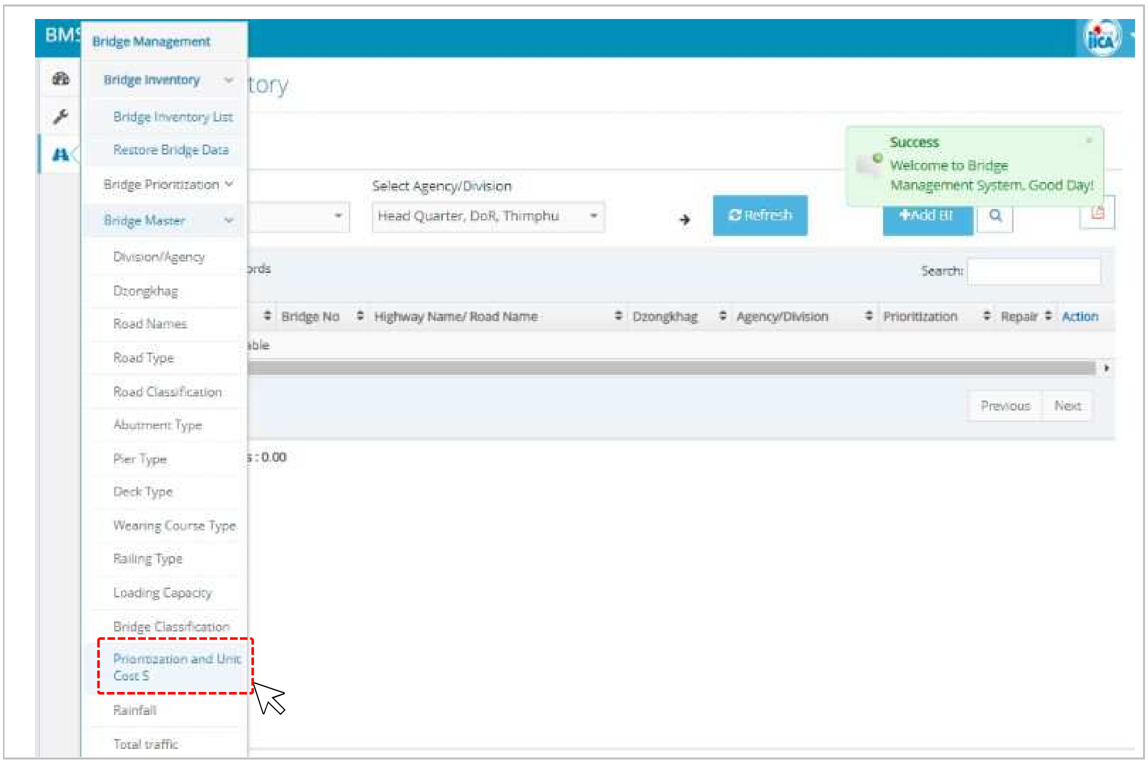
Member	Material	Damage	Category
Body	Concrete	Crack	c,d,e
		Peeling/Rebar exposure	c,d,e
		Water leakage/Free lime	c,d,e
		Honeycomb	c,d,e
	Concrete/Masonry	Damage/Deformation	c,e

· Presence of Damage

Structure	Member	Damage	Category
Bearing	Bearing	Defect (Severe corrosion, defect / hardening / missing parts)	c,e
		Noise (Extraordinary noise during passing vehicle)	c,e
	Base Mortar	Deformation/Loss (Crack of mortar, partial defect)	c,e
Ancillary Facilities	Railing	Deformation/Damage (Deformation or broken part)	c,e
		Deformation/Damage (Risk for bridge users)	c,e
Deck Surface	Pavement	Abnormity (Hole, big pothole, crack)	c,e
		Unevenness (Dangerous parts for bridge users)	c,e
		Sediment Deposition (Dirt/litter deposited on pavement)	e
	Expansion Joint	Abnormity (Broken)	c,e
		Unevenness (Level Difference)	c,e
Drainage Facilities	Drainage Facilities	Clogging (Clogging with soil and overlay)	c,e
		Water Leakage/Bearing (Broken or drained water affected to girder or other member)	c,e

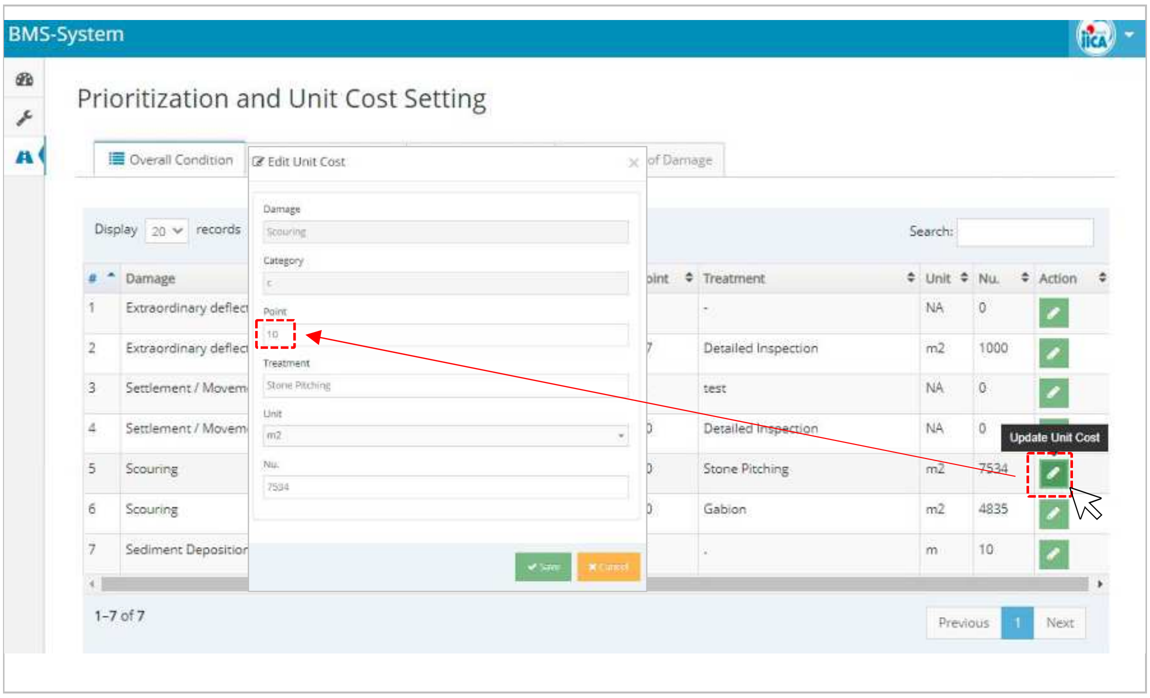
- How to operate BMS –

1.



2.

3.Edit weight factor point



4.3 Unit Cost Setting

The repairing cost estimation system is to roughly estimate repairing cost based on damage scale multiply by unit cost for repairing. The necessary items for calculation are systematically linked with each module. The system linkage in BMS is shown in Figure 4.1.

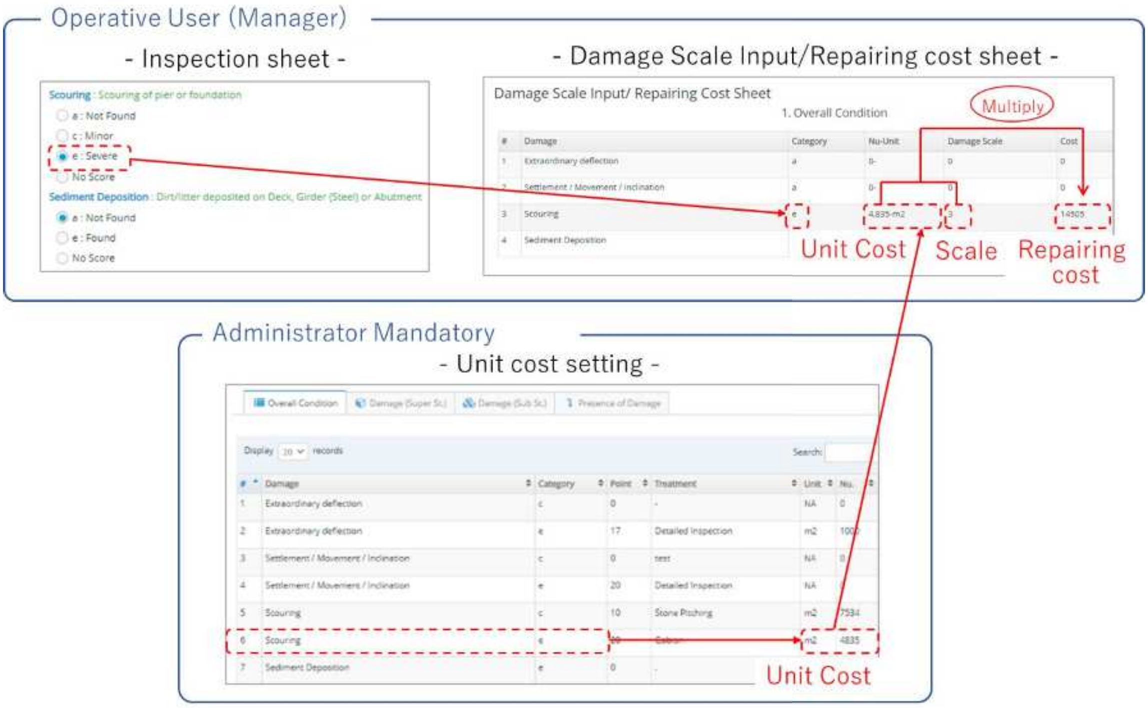
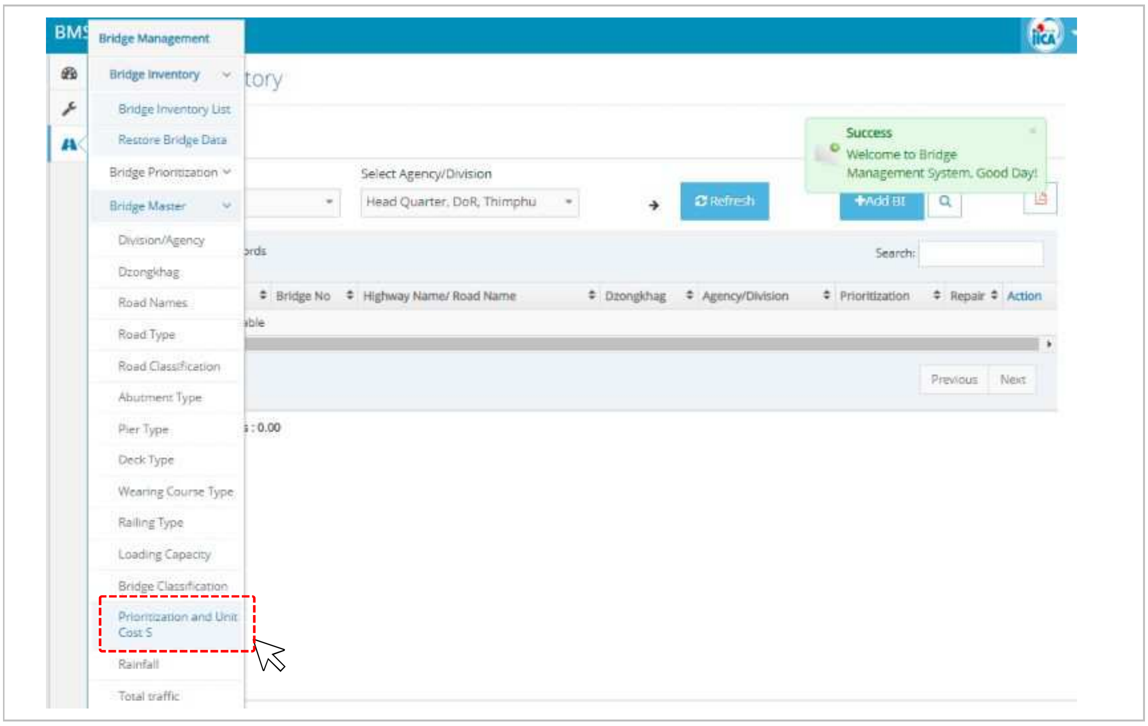


Fig 4.1 System linkage for repairing cost calculation

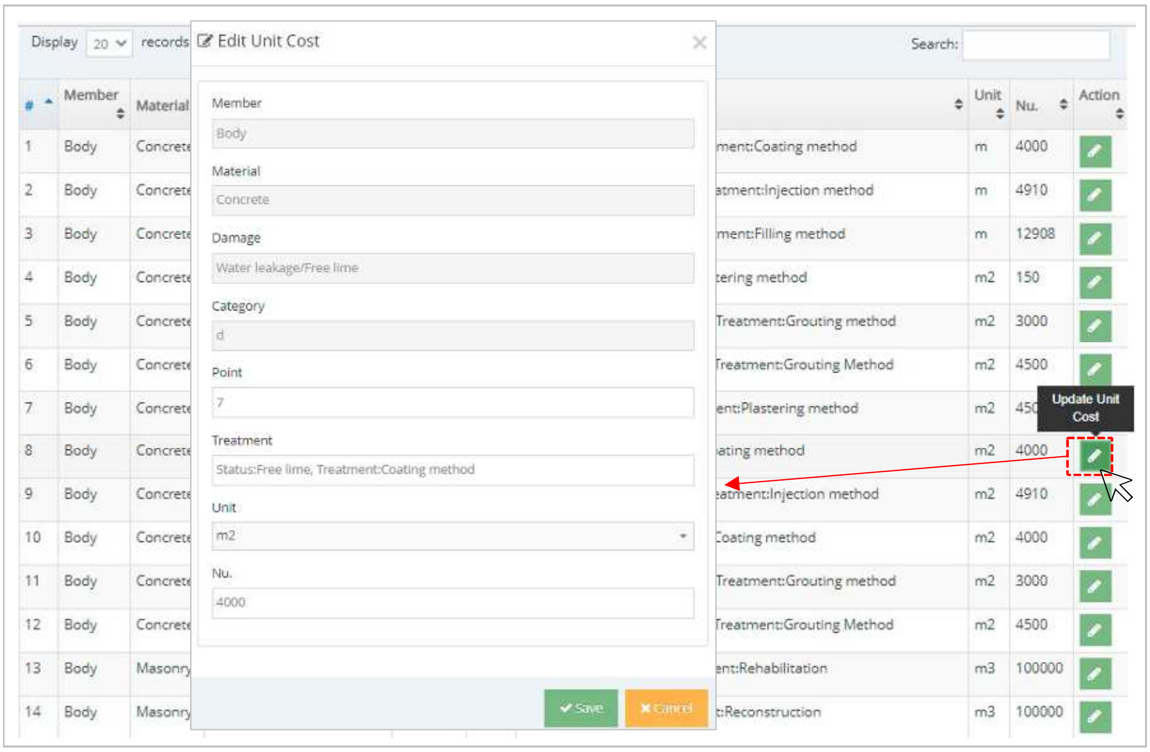
Administrator can define the unit cost for repair, unit for damaged scale and treatment. The available items for setting are same as items of prioritization.

- How to operate in BMS -

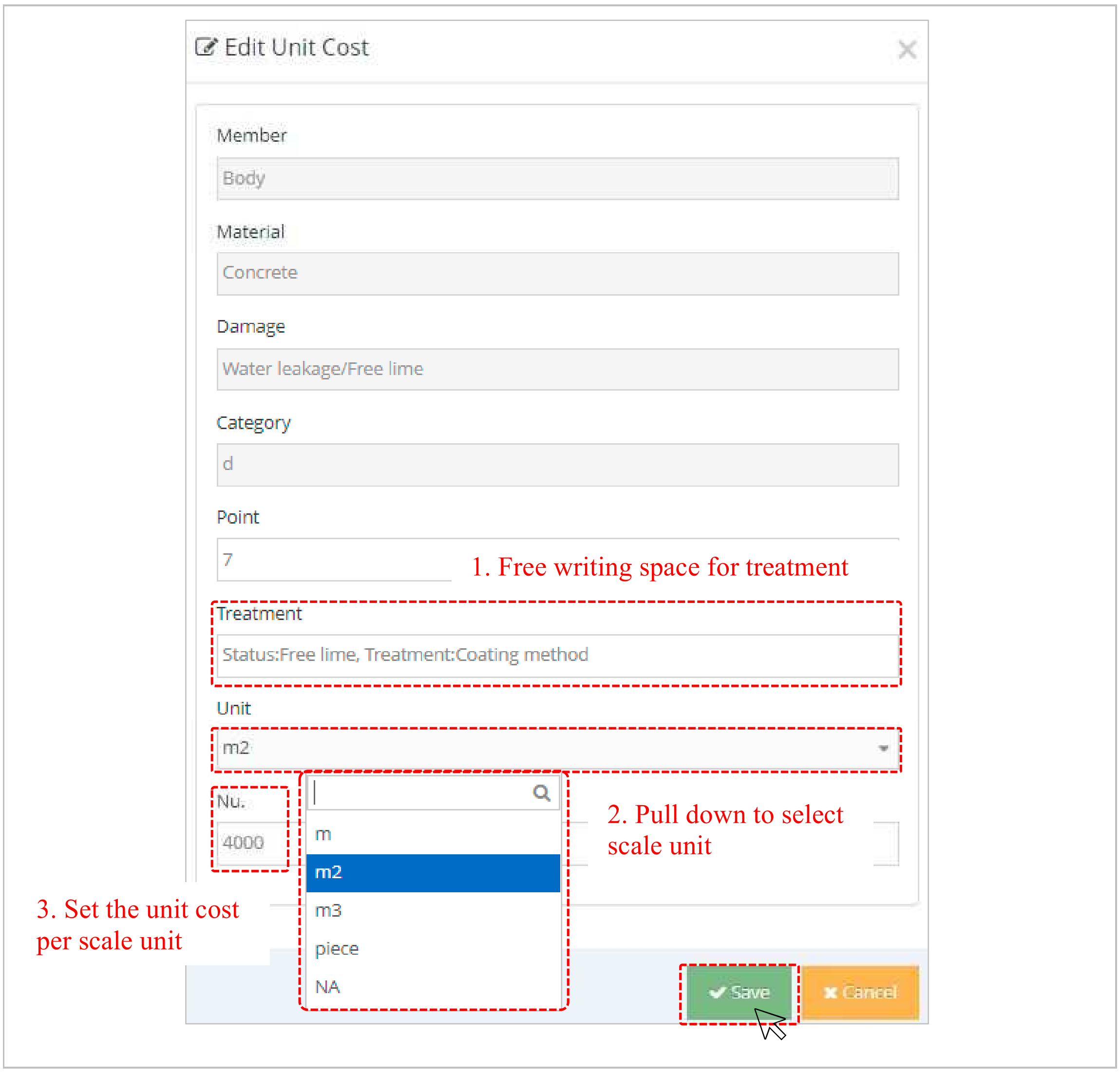
1.



2.



3.


Edit Unit Cost
Member
Body
Material
Concrete
Damage
Water leakage/Free lime
Category
d
Point
7
1. Free writing space for treatment
Treatment
Status:Free lime, Treatment:Coating method
Unit
m2
Nu.
4000
m
m2
m3
piece
NA
2. Pull down to select scale unit
3. Set the unit cost per scale unit
Save
Cancel

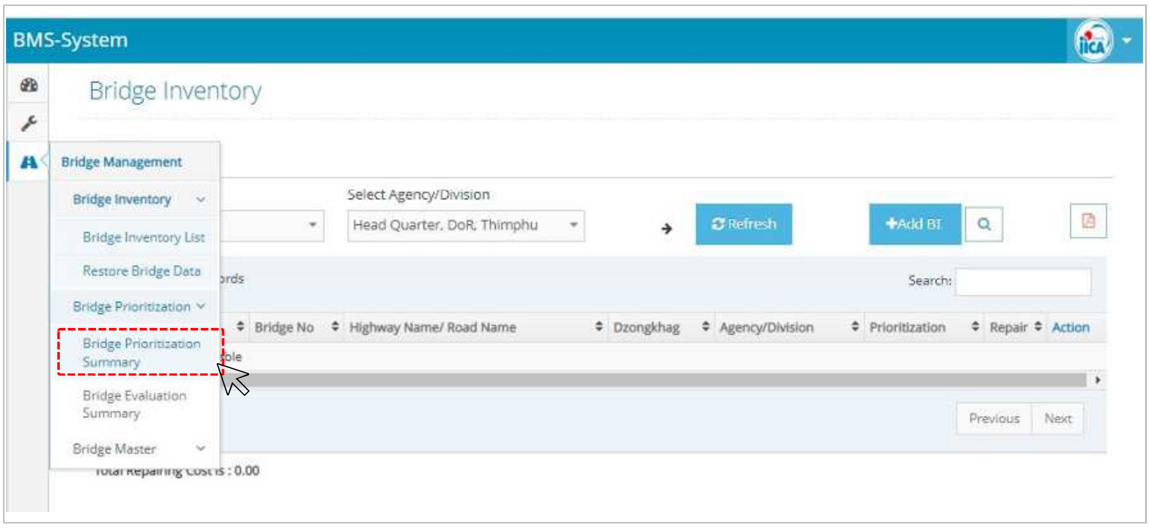
4.4 Summary Sheets

The users can view the distribution of weight point and evaluation criteria for all or regional wise bridges by Summary Sheet. The latest result will be reflected in the summary sheet soon after changing and updating information of Bridge Ledger and Inspection sheet.

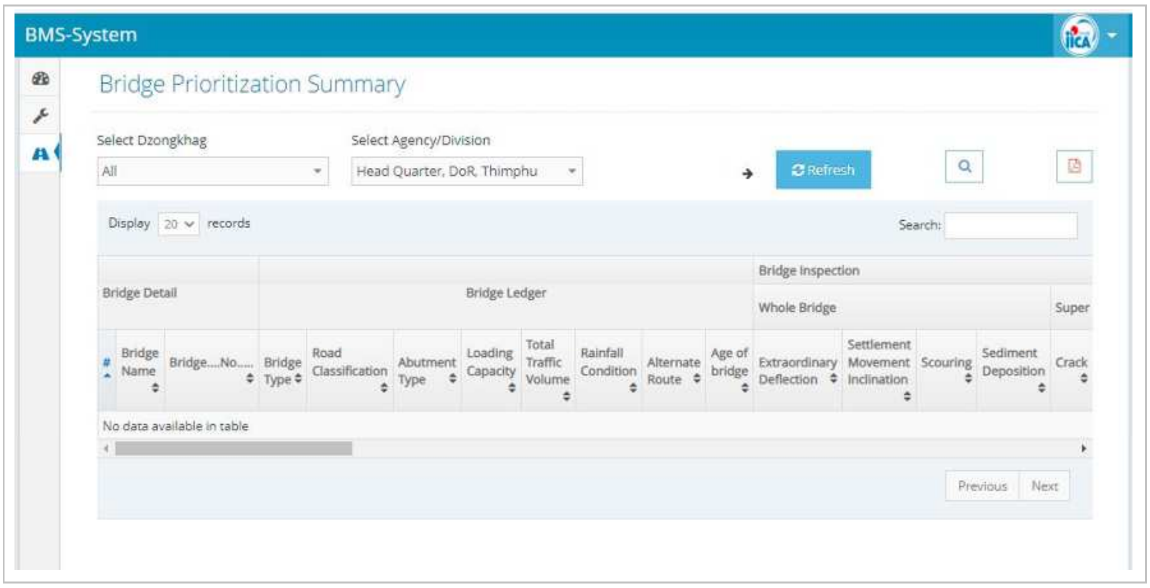
4.4.1 Bridge Prioritization Summary

- How to operate in BMS –

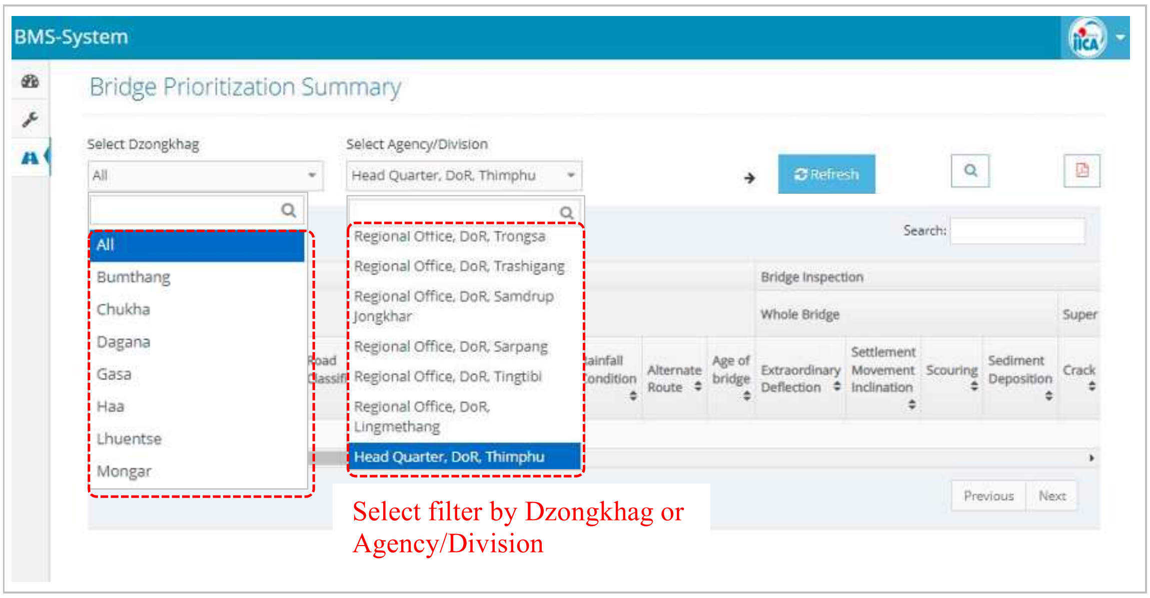
1.



2.



3.


BMS-System
Bridge Prioritization Summary
Select Dzongkhag
All
Select Agency/Division
Head Quarter, DoR, Thimphu
Refresh
All
Bumthang
Chukha
Dagana
Gasa
Haa
Lhuentse
Mongar
Regional Office, DoR, Trongsa
Regional Office, DoR, Trashigang
Regional Office, DoR, Samdrup Jongkhar
Regional Office, DoR, Sarpang
Regional Office, DoR, Tingtibi
Regional Office, DoR, Lingmethang
Head Quarter, DoR, Thimphu
Search:
Bridge Inspection
Whole Bridge
Super
Alternate Route
Age of bridge
Extraordinary Deflection
Settlement Movement Inclination
Scouring
Sediment Deposition
Crack
Previous
Next
Select filter by Dzongkhag or Agency/Division

4.Evaluated weight factor point distribution will be displayed

Display 20 records   Search:

Bridge Detail			Bridge Ledger								Bridge Inspection			
											Whole Bridge			
#	Bridge Name	Bridge_No	Bridge Type	Road Classification	Abutment Type	Loading Capacity	Total Traffic Volume	Rainfall Condition	Alternate Route	Age of bridge	Extraordinary Deflection	Settlement Movement Inclination	Scouring	Sedimen Deposit
3	Tashiling Zam	PNH-01-018	0	20	1	2	6	2	5	0	17	0	20	0
2	Tyelegangchu Zam	PNH-04-001	0	20	7	0	6	5	5	0	0	0	10	0
10	Bong Zam	PNH-01-020	0	20	7	2	3	2	5	0	0	0	0	0
35	Yurmo Zam	SNH-16-001	10	4	1	2	3	2	0	0	0	0	0	0
22	Hurjoe Zam	PNH-01-023	0	20	7	2	3	2	5	0	0	0	10	0
27	Rootala zam	GCR-1702-002	0	2	1	2	0	2	5	0	17	0	0	0
7	Sayzamchu Zam	PNH-01-029	0	20	7	4	6	2	0	0	0	0	0	0
15	Saytsa Zam	PNH-01-021	0	20	7	2	3	2	5	0	0	0	0	0
11	Nyola Zam	PNH-01-013	0	20	7	2	6	2	0	0	0	0	0	0
23	Rubor Zam	PNH-01-024	0	20	7		3	2	5	0	0	0	10	0
5	Yeshoygangchu Zam	PNH-04-003	0	20	1	2	6	5	0	4	0	0	0	0
8	Gaktong Zam	PNH-01-027	10	20	1	0	3	2	5	4	0	0	0	0
18	Chamdhogang Zam	GCR-1704-001	10	2	7	3	0	5	5	0	0	0	0	0
37	Dzongkhalum Zam	PNH-04-002	0	20	1	0	6	5	5	0	0	0	0	0
12	Chela Zam	GCR-1704-003	0	2	7		0	5	5	0	17	0	0	0
17	Kaba Doba Zam	GCR-1704-004	10	2	1		0	5	5	0	0	0	0	0
29	Kartigang Zam	PNH-04-006	0	20	1	2	6	2	5	4	0	0	0	0
4	Nagina Zam	PNH-01-017	0	20	1	2	6	2	0	16	0	0	0	0
21	Damkhar Zam	PNH-01-022	0	20	7	2	3	2	5	0	0	0	0	0
25	Rabton Zam	PNH-01-026	0	20	7	2	3	2	0	0	0	0	0	0

Scroll to right end

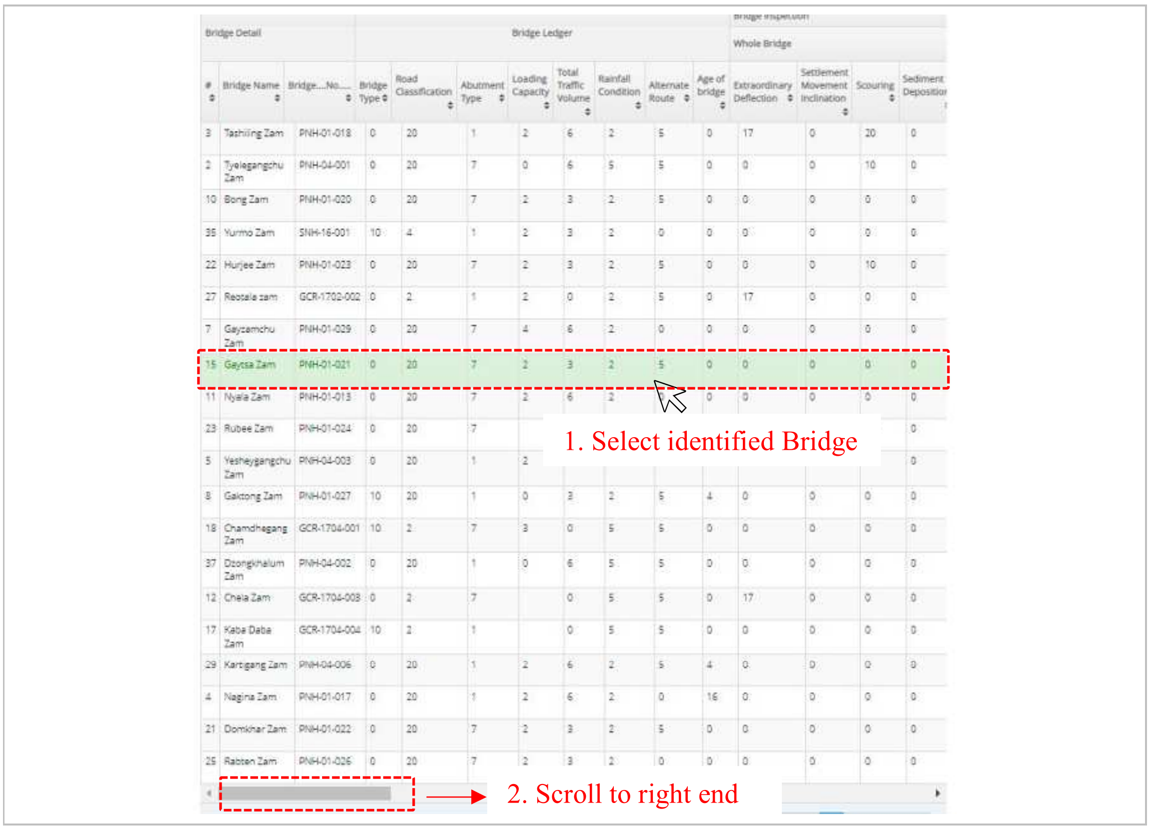
1-20 of 45   Previous 1 2 3 Next

5.

...or, Bearing	Ancillary Facilities		Deck Surface (Pavement)			Deck Surface (Expansion joint)		Drainage facilities		Total Points	Action
...mation/Loss	Deformation/Damage : Deformation or broken part	Deformation/Damage : Risk for bridge users	Abnormity	Unevenness	Sediment Deposition	Abnormity	Unevenness	Clogging	Water Leakage/Bearing		
	0	0	0	0	0	0	1			150	
	0	0	0	0	0	10	0	0	10	130	
	10	0	0	0	0	10	0	10	10	99	
	0	10	10	0	0	0	0	0	10	94	
	0	0	0	0	0	10	0	0	10	84	
	0	0	0	0	0	0	0	0	10	84	
	0	0	0	0	0	10	0	0	10	79	
	0	0	0	0	0	10	0	0	0	79	
	0	10	10	0	0	10	0	0	10	77	
	0	0	0	0	0	0	0	0	10	77	
	0	0	0	0	0	10	0	0	10	76	
	0	0	0	0	0	0	0	0	10	75	
	0	0	0	0	0	0	0	0	10	68	
	0	0	0	0	0	10	0	0	10	67	
	10	0	10	0	0	0	0	0	10	66	
	0	0	0	0	0	0	0	0	10	66	
	0	0	0	0	0	10	0	0	10	65	
	0	0	0	0	0	0	0	10	0	64	
	0	0	0	0	0	0	0	0	10	64	
	0	0	0	0	0	0	0	0	10	64	

Sorted by point order

6.

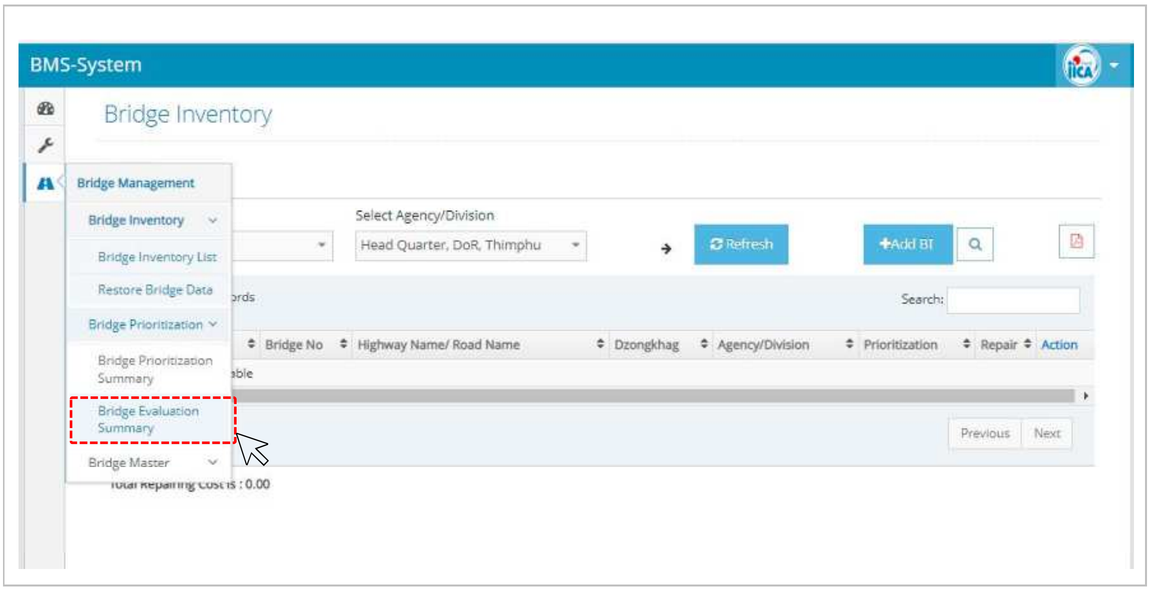

1. Select identified Bridge
2. Scroll to right end

7.

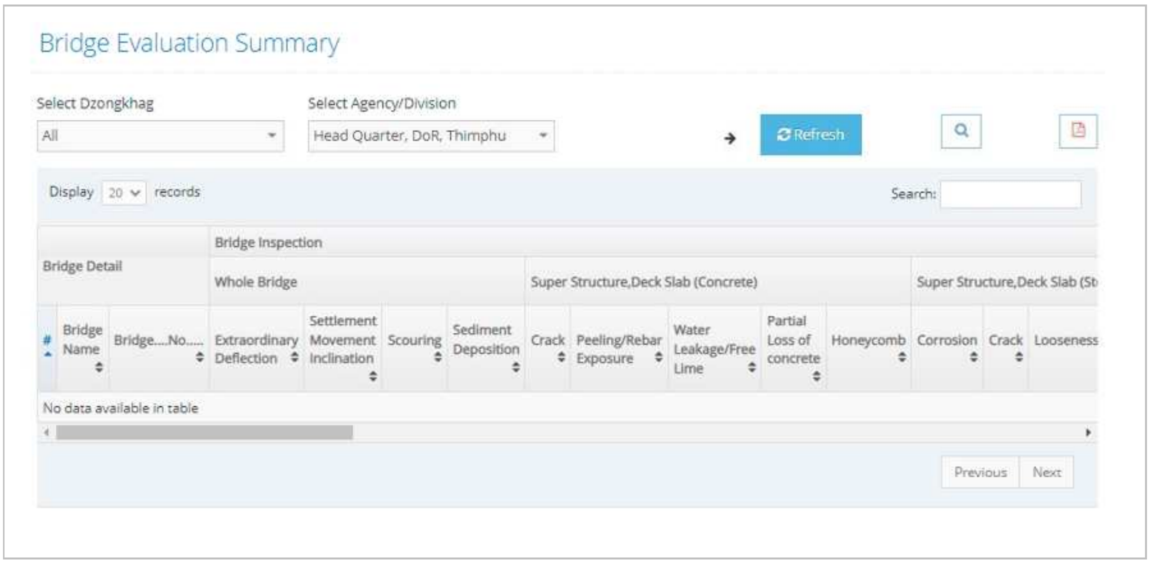

3. The user can view the distribution of point and total point for identified bridge

4.4.2 Bridge Evaluation Summary

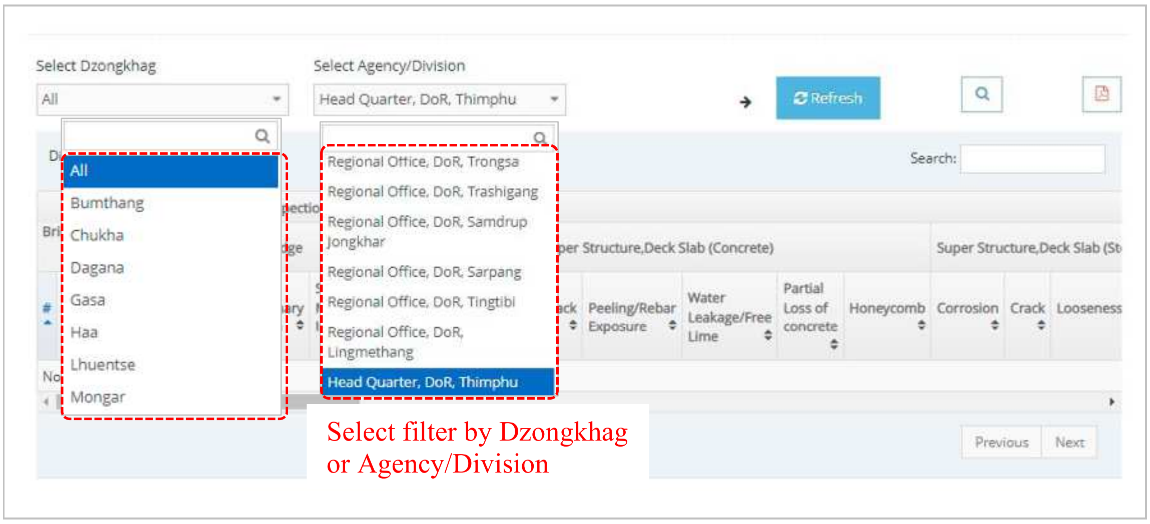
1.



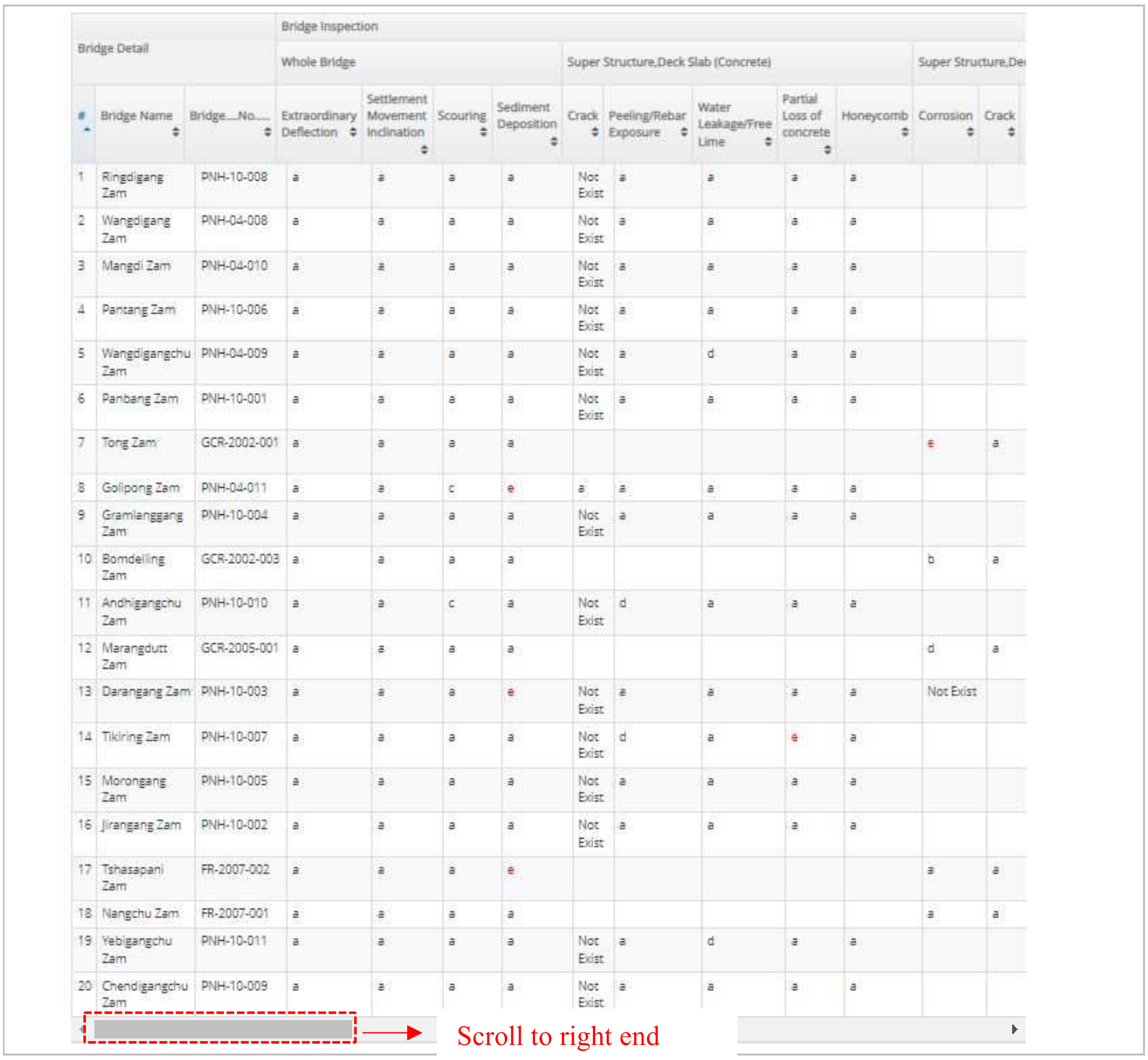
2.



3.

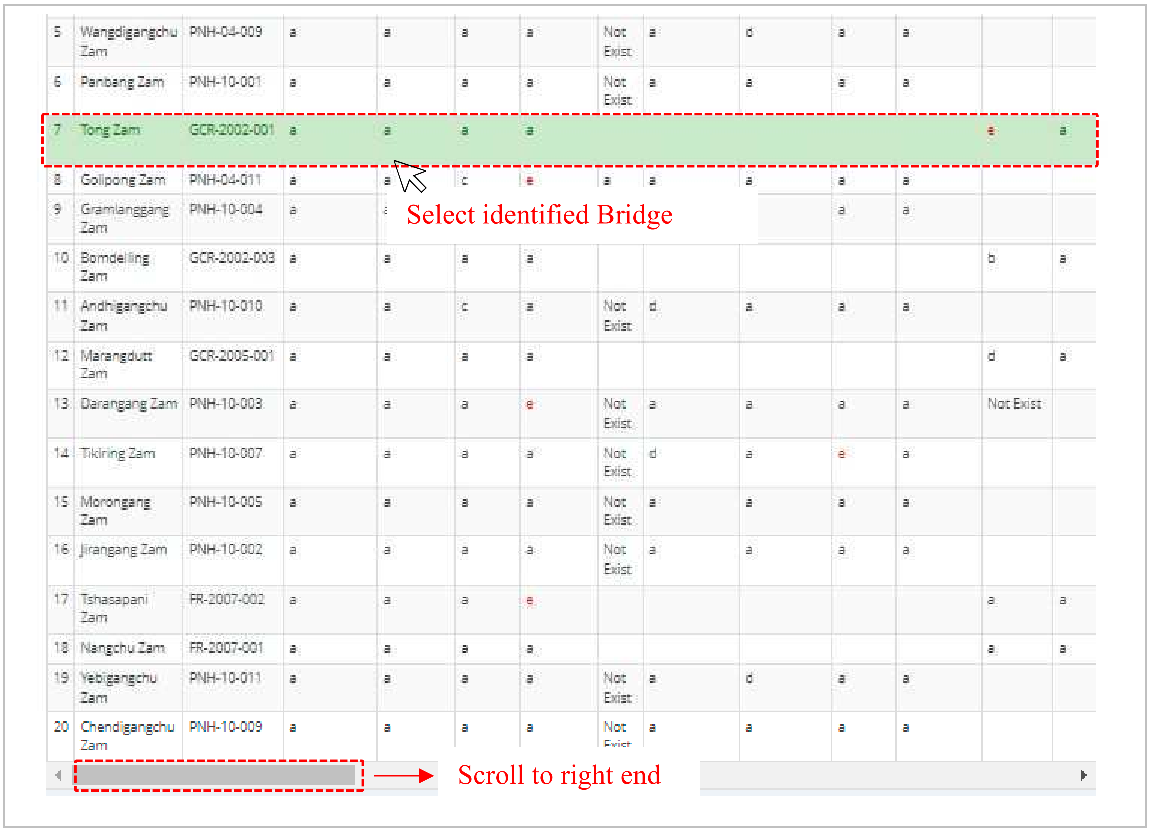


4. Distribution of Evaluated category for damage will be displayed



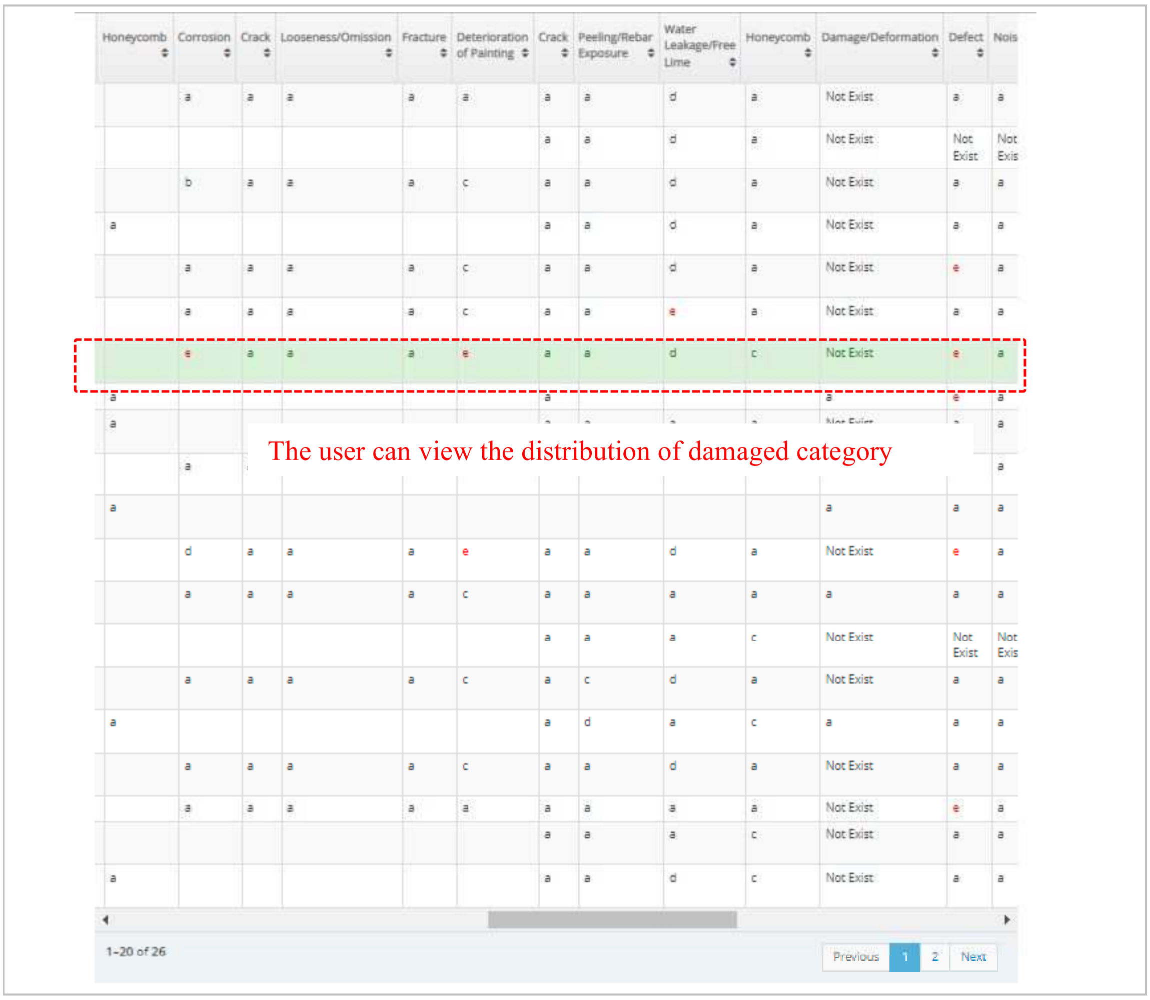
Bridge Detail			Bridge Inspection										
			Whole Bridge				Super Structure,Deck Slab (Concrete)					Super Structure,De	
#	Bridge Name	Bridge....No....	Extraordinary Deflection	Settlement Movement Inclination	Scouring	Sediment Deposition	Crack	Peeling/Rebar Exposure	Water Leakage/Free Lime	Partial Loss of concrete	Honeycomb	Corrosion	Crack
1	Ringdigang Zam	PNH-10-008	a	a	a	a	Not Exist	a	a	a	a		
2	Wangdigang Zam	PNH-04-008	a	a	a	a	Not Exist	a	a	a	a		
3	Mangdi Zam	PNH-04-010	a	a	a	a	Not Exist	a	a	a	a		
4	Pantang Zam	PNH-10-006	a	a	a	a	Not Exist	a	a	a	a		
5	Wangdigangchu Zam	PNH-04-009	a	a	a	a	Not Exist	a	d	a	a		
6	Panbang Zam	PNH-10-001	a	a	a	a	Not Exist	a	a	a	a		
7	Tong Zam	GCR-2002-001	a	a	a	a						e	a
8	Golipong Zam	PNH-04-011	a	a	c	e	a	a	a	a	a		
9	Gramlanggang Zam	PNH-10-004	a	a	a	a	Not Exist	a	a	a	a		
10	Bomdelling Zam	GCR-2002-003	a	a	a	a						b	a
11	Andhigangchu Zam	PNH-10-010	a	a	c	a	Not Exist	d	a	a	a		
12	Marangdutt Zam	GCR-2005-001	a	a	a	a						d	a
13	Darangang Zam	PNH-10-003	a	a	a	e	Not Exist	a	a	a	a	Not Exist	
14	Tikiring Zam	PNH-10-007	a	a	a	a	Not Exist	d	a	e	a		
15	Morongang Zam	PNH-10-005	a	a	a	a	Not Exist	a	a	a	a		
16	Jirangang Zam	PNH-10-002	a	a	a	a	Not Exist	a	a	a	a		
17	Tshasapani Zam	FR-2007-002	a	a	a	e						a	a
18	Nangchu Zam	FR-2007-001	a	a	a	a						a	a
19	Yebigangchu Zam	PNH-10-011	a	a	a	a	Not Exist	a	d	a	a		
20	Chendigangchu Zam	PNH-10-009	a	a	a	a	Not Exist	a	a	a	a		

5.



5	Wangdigangchu Zam	PNH-04-009	a	a	a	a	Not Exist	a	d	a	a		
6	Panbang Zam	PNH-10-001	a	a	a	a	Not Exist	a	a	a	a		
7	Tong Zam	GCR-2002-001	a	a	a	a						e	a
8	Golipong Zam	PNH-04-011	a	a	c	e	a	a	a	a	a		
9	Gramlanggang Zam	PNH-10-004	a	a						a	a		
10	Bomdelling Zam	GCR-2002-003	a	a	a	a						b	a
11	Andhigangchu Zam	PNH-10-010	a	a	c	a	Not Exist	d	a	a	a		
12	Marangdutt Zam	GCR-2005-001	a	a	a	a						d	a
13	Darangang Zam	PNH-10-003	a	a	a	e	Not Exist	a	a	a	a	Not Exist	
14	Tikiring Zam	PNH-10-007	a	a	a	a	Not Exist	d	a	e	a		
15	Morongang Zam	PNH-10-005	a	a	a	a	Not Exist	a	a	a	a		
16	Jirangang Zam	PNH-10-002	a	a	a	a	Not Exist	a	a	a	a		
17	Tshasapani Zam	FR-2007-002	a	a	a	e						a	a
18	Nangchu Zam	FR-2007-001	a	a	a	a						a	a
19	Yebigangchu Zam	PNH-10-011	a	a	a	a	Not Exist	a	d	a	a		
20	Chendigangchu Zam	PNH-10-009	a	a	a	a	Not Exist	a	a	a	a		

6.

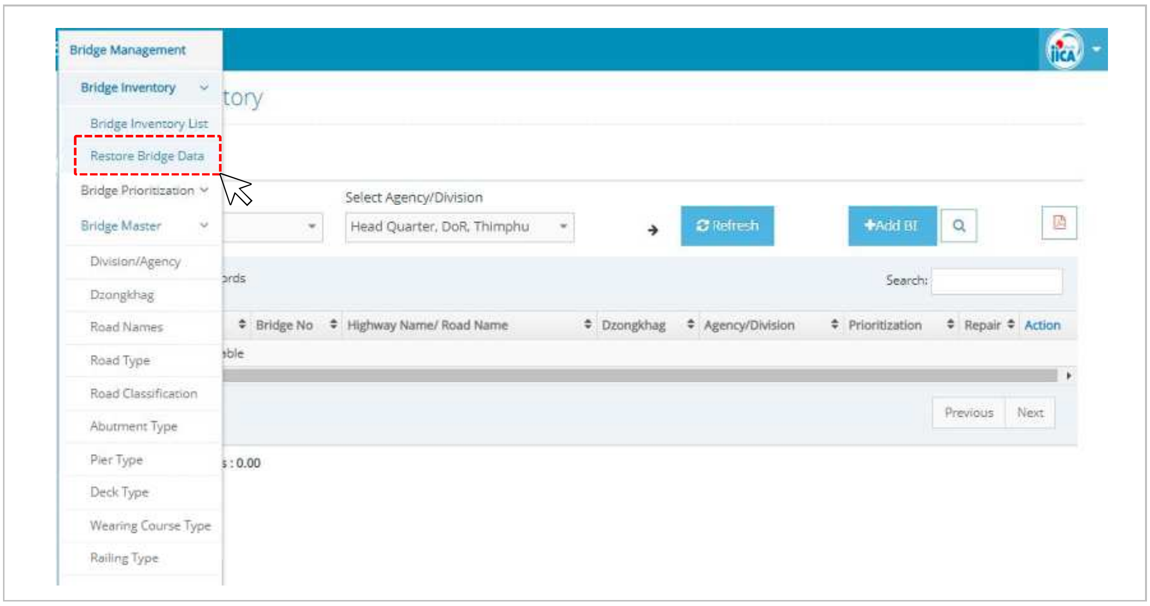

Honeycomb
Corrosion
Crack
Looseness/Omission
Fracture
Deterioration of Painting
Crack
Peeling/Rebar Exposure
Water Leakage/Free Lime
Honeycomb
Damage/Deformation
Defect
Nois
The user can view the distribution of damaged category
1-20 of 26
Previous
1
2
Next

5 Restore Bridge Data

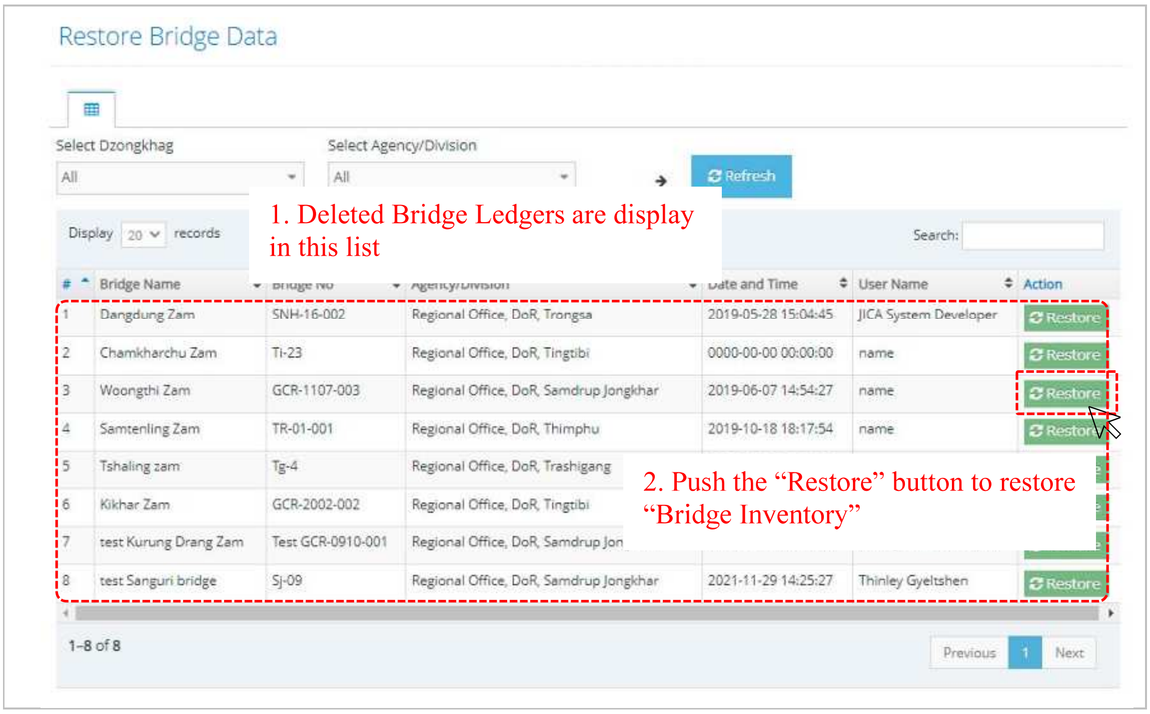
Although Bridge ledger can be deleted by user, to countermeasure for unintended operation by user, the deleted bridge ledger will be stocked in the list of Restore Bridge Data function. Only administrator can restore Bridge Ledger and corresponded Inspection sheet.

- How to operate in BMS –

1.



2.

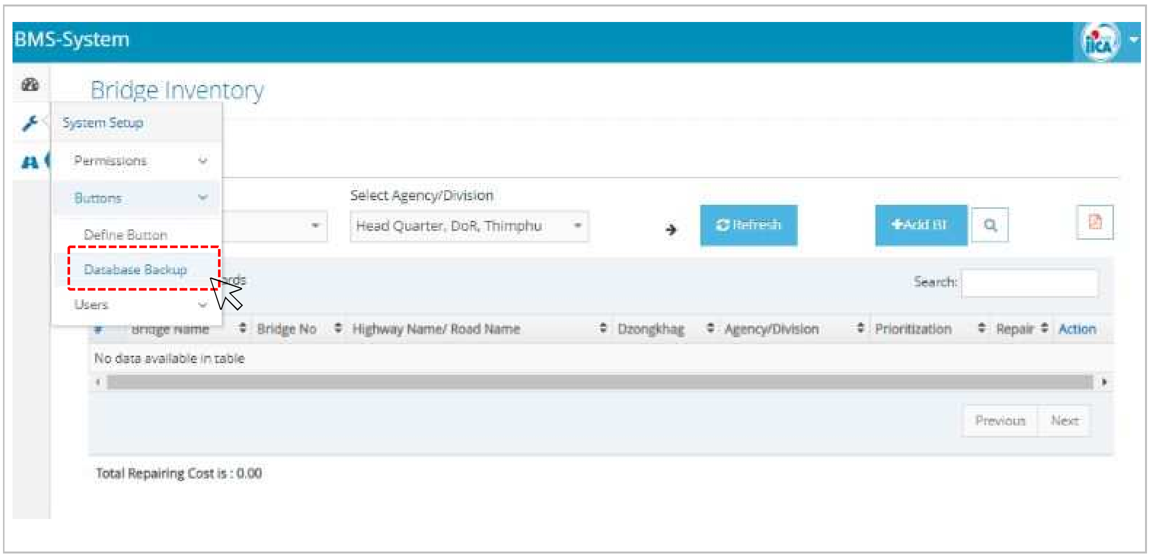


6 Database Backup

The total BMS is stocked in Server for BMS located in Sever room operated by ICT division MoWHS. In case that server will crash and need to recover BMS, the administrator must backup the Database information to recover the status before server crash. The database backup file must be manually taken by administrator, and the administrator and system engineer can recover the existing status before server crash. this manual shows the operational guideline how to take backup data file as follows,

- How to operate BMS –

1.



2.

Automatically save SQL Database backup file to “BMS server” and “Local PC”