

**THE PROJECT FOR CAPACITY  
DEVELOPMENT ON BRIDGE  
MAINTENANCE AND MANAGEMENT  
IN  
LAO PEOPLE'S DEMOCRATIC  
REPUBLIC**

**BRIDGE REPAIR  
AND  
RETROFITTING MANUAL  
(DRAFT VERSION JANUARY 2024)**

**VERION 1.0**

**JAPAN INTERNATIONAL COOPERATION AGENCY**

**INTERNATIONAL DEVELOPMENT CENTER OF JAPAN  
INC.**

**NAGASAKI UNIVERSITY**

**ORIENTAL CONSULTANTS GLOBAL CO., LTD.**

**KATAHIRA ENGINEERING INTERNATIONAL CO., LTD.**

## **FOREWORD**

This manual was prepared under the JICA sponsored Project for Capacity Development on Bridge Maintenance and Management in Lao PDR for the purpose of mainstreaming preventive bridge maintenance and management in Laos. The manual was designed and adopted fully referring to Bridge Repair and Retrofitting Manual developed by Nagasaki Prefecture and the other Japanese Bridge Maintenance Manual.

For any reasons, Nagasaki Prefectural Government and JICA shall not be liable for any disputes or damages caused to the users, persons concerned and/or third parties arising from the use of the information contained in this manual.

## TABLE OF CONTENTS

Table of Contents

List of Figures

List of Tables

List of Abbreviations

	Page
<b>1. INTRODUCTION AND OVERVIEW .....</b>	<b>1-1</b>
1.1 Background .....	1-1
1.1.1 Current Condition of Road Bridges in Lao PDR .....	1-1
1.1.2 Bridge Maintenance Issues .....	1-2
1.2 Purpose .....	1-2
1.3 Scope .....	1-2
1.4 Overview .....	1-2
1.4.1 Composition .....	1-2
1.4.2 Bridge Maintenance Process .....	1-2
<b>2. ORGANIZATION RELATED TO BRIDGE REPAIR AND RETROFITTING.....</b>	<b>2-1</b>
2.1 Outline .....	2-1
2.2 Jurisdiction .....	2-2
2.2.1 Bridge Maintenance .....	2-2
2.2.2 Seminar and Workshop .....	2-5
<b>3. SAFETY AND MAINTENANCE WORK.....</b>	<b>3-1</b>
3.1 Safety Work .....	3-1
3.2 Routine Maintenance .....	3-4
3.3 Working Clearance for Repair .....	3-6
<b>4. SURVEY FOR BRIDGE REPAIR AND RETROFITTING.....</b>	<b>4-1</b>
4.1 Outline .....	4-1
4.1.1 Purpose of Survey .....	4-1
4.1.2 Common Rules in Bridge Survey .....	4-2
4.2 Preliminary Survey .....	4-2
4.2.1 Document Survey.....	4-2
4.2.2 Site Investigation.....	4-3
4.2.3 Judgement of Necessity for Detailed Investigation.....	4-4
4.3 Detailed Investigation.....	4-7
4.3.1 Planning .....	4-7
4.3.2 Detailed Investigation Method.....	4-7
4.3.3 Organization of Detailed Investigation Results.....	4-7
4.4 Defect Causes and Soundness Evaluation .....	4-8
4.4.1 Concrete Structure.....	4-8
4.4.2 Steel Structure .....	4-13
4.4.3 Foundation .....	4-14
4.4.4 Bearing.....	4-15
4.4.5 Expansion Joint.....	4-15
4.4.6 Others.....	4-16
<b>5. BRIDGE REPAIR DESIGN .....</b>	<b>5-1</b>
5.1 Repair Design Procedure.....	5-1
5.2 Concept for Bridge Repair.....	5-3

## BRIDGE REPAIR AND RETROFITTING MANUAL

---

5.3	Concrete structure.....	5-9
5.3.1	Outline.....	5-9
5.3.2	Selection of Repair Methods.....	5-10
5.4	Steel Structure .....	5-17
5.4.1	Outline.....	5-17
5.4.2	Selection of Repair Method .....	5-17
5.5	Foundation.....	5-22
5.5.1	Outline.....	5-22
5.5.2	Selection of Repair Methods.....	5-22
5.6	Bearing .....	5-23
5.6.1	Outline.....	5-23
5.6.2	Selection of Repair Methods.....	5-24
5.7	Expansion Joint .....	5-25
5.7.1	Outline.....	5-25
5.7.2	Selection of Repair Methods.....	5-25
5.8	Protection around Substructure .....	5-26
5.8.1	Outline.....	5-26
5.8.2	Selection of Repair Method .....	5-26
5.9	Other Bridge Accessories .....	5-28
5.9.1	Outline.....	5-28
5.9.2	Selection of Repair Method .....	5-28
5.10	Preventive Measures against Re-Deterioration .....	5-30
5.10.1	Main Causes of Re-Deterioration after Repair.....	5-30
5.10.2	Selection of Preventive Measures against Re-Deterioration.....	5-31
5.10.3	Follow-up.....	5-33
<b>6.</b>	<b>BRIDGE RETROFITTING DESIGN .....</b>	<b>6-1</b>
6.1	Bridge Retrofitting Policy .....	6-1
6.1.1	Purpose and Target of Retrofitting .....	6-1
6.1.2	Applicable Standard and Points of Note .....	6-1
6.1.3	Procedure of Retrofitting Design .....	6-3
6.2	Retrofitting of Steel Bridge .....	6-5
6.3	Retrofitting of Concrete Bridge .....	6-7
6.4	Retrofitting of RC Bridge Deck.....	6-9
6.5	Retrofitting of Substructure .....	6-12
6.6	Important Points of Retrofitting Work.....	6-14

## APPENDICES

- Appendix 1 Details of Repair Method
- Appendix 2 Details of Retrofitting Method
- Appendix 3 Example of Bridge Repair
- Appendix 4 Example of Bridge Retrofitting
- Appendix 5 Sample Drawing

## LIST OF FIGURES

	Page
Figure 1.1.1 Number of National Road Bridges by Year of Construction.....	1-1
Figure 1.1.2 Number of National Road Bridges and Percentage by Damage Evaluation Code.....	1-1
Figure 1.4.1 Bridge Maintenance Process.....	1-3
Figure 2.1.1 Bridge Maintenance Cycle.....	2-1
Figure 2.2.1 Organization Chart of DOR.....	2-2
Figure 2.2.2 Budget Appraisal Schedule for Project Type.....	2-4
Figure 2.2.3 Budget Appraisal Schedule for General Expense Type.....	2-4
Figure 3.1.1 Accidents Result in all Industries (In Japan).....	3-1
Figure 3.1.2 Accidents Rate in Death in Construction Site (In Japan).....	3-2
Figure 3.1.3 Scaffoldings.....	3-2
Figure 3.1.4 Signboard.....	3-2
Figure 3.1.5 Hazardous Materials in Site.....	3-3
Figure 3.1.6 Protection Helmet and Safety Shoes.....	3-4
Figure 3.1.7 Fixed Scaffolding.....	3-4
Figure 3.2.1 (Left) Expansion Joint, (Right) Drainage.....	3-5
Figure 3.2.2 Debris and Sand Deposits around Bearing Seat Areas.....	3-6
Figure 3.3.1 Standard Setting of Scaffolding.....	3-6
Figure 3.3.2 Detail of Working Clearance.....	3-6
Figure 4.1.1 Survey and Design Work Flow for Bridge Repair.....	4-1
Figure 4.2.1 Judgement Flowchart of Necessity for Detailed Investigation.....	4-4
Figure 4.2.2 Areas Where Crack is Likely to Occur.....	4-6
Figure 4.4.1 An Example of a Conceptual Diagram of the Deterioration Progress Process due to Carbonation.....	4-10
Figure 4.4.2 A Conceptual Diagram of the Deterioration Progress Process due to ASR.....	4-11
Figure 4.4.3 An Example of a Conceptual Diagram of the Deterioration Progress Process due to Fatigue of Deck Slab.....	4-12
Figure 5.1.1 Basic Idea of the Proper Maintenance Works.....	5-1
Figure 5.1.2 Repair Flow.....	5-2
Figure 5.2.1 Progress of Cracks on bottom of Bridge Deck.....	5-4
Figure 5.3.1 Selection Flow of Repair Methods of Concrete Members according to Kind of Defects.....	5-10
Figure 5.3.2 Major Defects of PC, RC Superstructures and a Flow to Select Repair Methods.....	5-12
Figure 5.3.3 Major Defects of RC Substructures and a Flow to Select Repair Methods.....	5-13
Figure 5.4.1 Selection Flow of Repair Methods of Steel Structure according to Kind of Defects.....	5-17
Figure 5.7.1 Selection Flow of Repair Methods of Expansion Joint.....	5-25
Figure 5.8.1 Selection Flow of Repair Methods of Protection around Substructure.....	5-27
Figure 5.9.1 Selection Flow of Repair Methods of Bridge Railings, Railing Posts, Curbs.....	5-28
Figure 5.9.2 Selection Flow of Repair Methods of Drainage Facilities.....	5-29
Figure 5.10.1 Selection Flow of Preventive Measures against Re-Deterioration for Alkali-Silica Reaction.....	5-31
Figure 5.10.2 Selection Flow of Preventive Measures against Re-Deterioration for Carbonation.....	5-32
Figure 6.1.1 Reinforcement Design Flow.....	6-4
Figure 6.2.1 Examples of Steel Bonding Method.....	6-5
Figure 6.2.2 Example of Bonding Continuous Fiber Plates.....	6-5
Figure 6.2.3 Example of Span Reduction by Additional Pier.....	6-6
Figure 6.2.4 Example of Redistribution of Superstructure Reaction Force.....	6-6
Figure 6.2.5 Examples of Main Girder Reinforcement.....	6-6
Figure 6.3.1 Examples of Steel Plate Bonding Method.....	6-7

Figure 6.3.2 Example of Shear Strength Reinforcement.....6-7  
Figure 6.3.3 Example of Continuous Fiber Plate Bonding Method .....6-8  
Figure 6.3.4 Replacement of the Main Girder End .....6-8  
Figure 6.3.5 Example of Outer Cable Method .....6-8  
Figure 6.3.6 Example of Additional Pier.....6-8  
Figure 6.4.1 Example of Steel Plate Bonding Method.....6-10  
Figure 6.4.2 Example of Continuous Fiber Sheets Bonding Method.....6-10  
Figure 6.4.3 Example of Continuous Fiber Plates Bonding Method.....6-11  
Figure 6.4.4 Example of Partial Re-concreting .....6-11  
Figure 6.4.5 Example of Upper Surface Thickness Increasing Method.....6-11  
Figure 6.4.6 Example of Lower Surface Thickness Increasing Method .....6-12  
Figure 6.5.1 Example of Steel Plate Wrapping Method.....6-13  
Figure 6.5.2 Example of Continuous Fiber Sheet Wrapping Method .....6-13  
Figure 6.5.3 Example of RC Concrete Wrapping Method .....6-13

## LIST OF TABLES

	Page
Table 2.2.1 Main Work in Charge .....	2-2
Table 2.2.2 Implementation Contents of Each Organization.....	2-3
Table 3.3.1 Working Positions and its Space.....	3-7
Table 4.1.1 Common Rules for Bridge Survey .....	4-2
Table 4.2.1 Survey Item for Each Document .....	4-3
Table 4.2.2 Confirmation Item during Site Investigation.....	4-4
Table 4.2.3 Table for the Judgement of Damage Causes of Concrete Member.....	4-5
Table 4.3.1 Examples How to Summarize the Method of Usage.....	4-7
Table 4.4.1 Damage Causes of Concrete Structure .....	4-9
Table 4.4.2 Relation among Deteriorations, Causes, Indicators and Phenomenon .....	4-10
Table 4.4.3 Definition of Deterioration Progress related to Carbonation.....	4-11
Table 4.4.4 Definition of Deterioration Progress related to ASR.....	4-11
Table 4.4.5 Definition of Deterioration Progress related to Fatigue of Deck Slab.....	4-12
Table 4.4.6 Damage Causes of Steel Structure.....	4-13
Table 4.4.7 Definition of Deterioration Progress related to Corrosion of Steel Members Painted by General Painting.....	4-14
Table 4.4.8 Damage Causes of Foundation .....	4-14
Table 4.4.9 Damage Causes of Bearing.....	4-15
Table 4.4.10 Damage Causes of Expansion Joint.....	4-16
Table 4.4.11 Defects of Handrail and Curb .....	4-16
Table 4.4.12 Defects of Drainage Facility.....	4-16
Table 5.2.1 Grade of Deterioration of Carbonation from its Appearance .....	5-3
Table 5.2.2 Grade of Deterioration of ASR from its Appearance.....	5-3
Table 5.2.3 Grade of Deterioration of Concrete Bridge Deck from its Appearance.....	5-4
Table 5.2.4 Selection of Repair Methods against Carbonation .....	5-6
Table 5.2.5 Selection of Repair Methods against ASR (Alkali-Silica Reaction) .....	5-7
Table 5.2.6 Outline of Major Repair Methods .....	5-8
Table 5.2.7 Repair and Reinforcing Methods of Fatigued RC Decks and Expected Effects.....	5-8
Table 5.3.1 Typical Repair Methods of Concrete Structures.....	5-9
Table 5.3.2 Major Defects and their Causes of Concrete Members and Possible Repair Methods for Comparison .....	5-11
Table 5.3.3 List of Repair Methods.....	5-14
Table 5.3.4 List of Repair and Reinforcing Methods .....	5-15
Table 5.3.5 Damage Conditions and Necessary Countermeasures of Bridge Deck Slab.....	5-15
Table 5.3.6 Repair and Reinforcing Methods Corresponding to Category .....	5-16
Table 5.4.1 Judgement of Countermeasures against Corrosion.....	5-19
Table 5.4.2 Judgement of Countermeasures against Deterioration of Corrosion Protection.....	5-19
Table 5.4.3 Judgement of Countermeasures against Cracks .....	5-20
Table 5.4.4 Judgement of Countermeasures against Bolt Loosening or Falling off.....	5-20
Table 5.4.5 Judgement of Countermeasures against Breakage.....	5-20
Table 5.4.6 Major Defects, and Causes, Repair Methods of Steel Structures to Select Repair Methods.....	5-21
Table 5.5.1 Repair Methods of Foundations .....	5-22
Table 5.6.1 Repair Methods of Bearings according to Causes.....	5-24
Table 5.10.1 Follow-Up Inspection Items according to Repair Methods.....	5-33
Table 6.1.1 Classification of Reinforcement Method.....	6-2
Table 6.1.2 Typical Reinforcement Method and Examples of Application Structures.....	6-2

**BRIDGE REPAIR AND RETROFITTING MANUAL**

---

Table 6.4.1 Causes of Defects and Live Load Alleviation Measures .....6-9

Table 6.4.2 Degree of Emergency Reinforcement Countermeasure according to Crack Condition and  
Density .....6-9

Table 6.4.3 Degree of Emergency (A,B,C,D) and Countermeasures .....6-10

**LIST OF ABBREVIATIONS**

ASR	Alkali-Silica-Reaction
ASTM	American Society for Testing and Materials
BMS	Bridge Maintenance System
CCD	Charge Coupled Device
CF	Concrete Failure
DOE	Department of Evaluation
DOP	Department of Planning
DOR	Department of Roads
DPWT	Department of Public Works and Transport
EIRR	Economic Internal Rate of Return
FRP	Fiber Reinforced Plastics
HALS	Hindered Amine Light Stabilizer
JIS	Japanese Industrial Standards
JSCE	Japan Society of Civil Engineers
LCC	Life Cycle Cost
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MPI	Ministry of Planning and Investment
MPWT	Ministry of Public Works and Transport
NEXCO	Nippon Expressway Company Limited
PC	Prestressed Concrete
PCM	Polymer Cement Mortar
PCT	Prestressed Concrete T-shaped
PTTI	Public Works and Transport Training Institute
RAD	Road Administration Division
RBU	Road and Bridge Unit
RC	Reinforced Concrete
RFC	Road Fund Committee
RFS	Road Fund Secretariat
RMS	Road Maintenance System
TED	Technical-Environment Division
UV	Ultra Violet

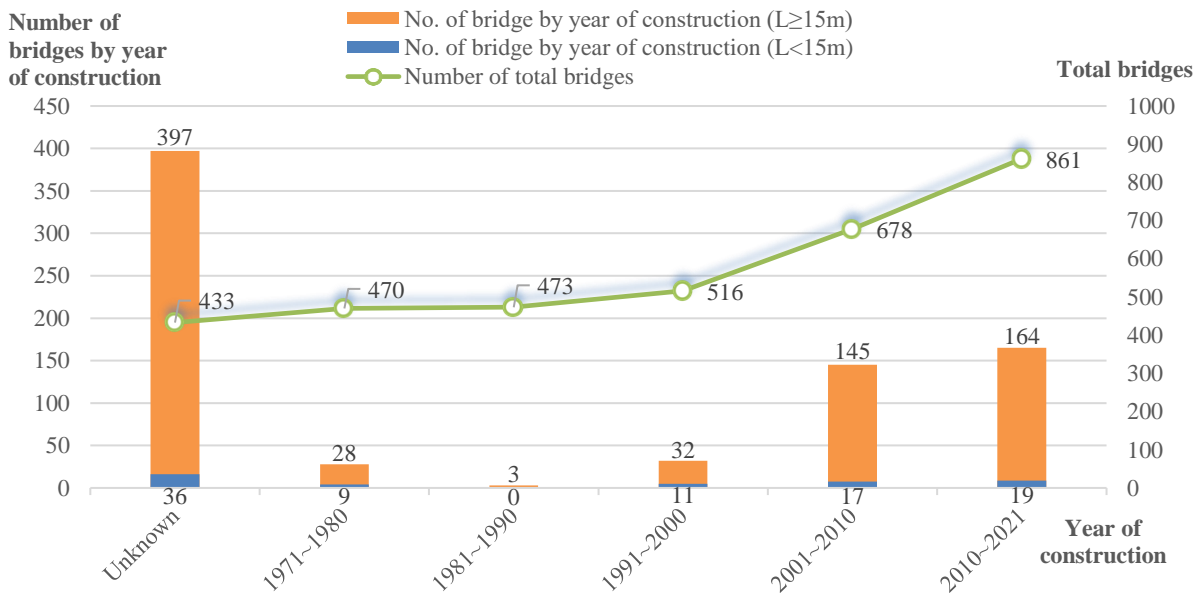
# 1. INTRODUCTION AND OVERVIEW

## 1.1 Background

### 1.1.1 Current Condition of Road Bridges in Lao PDR

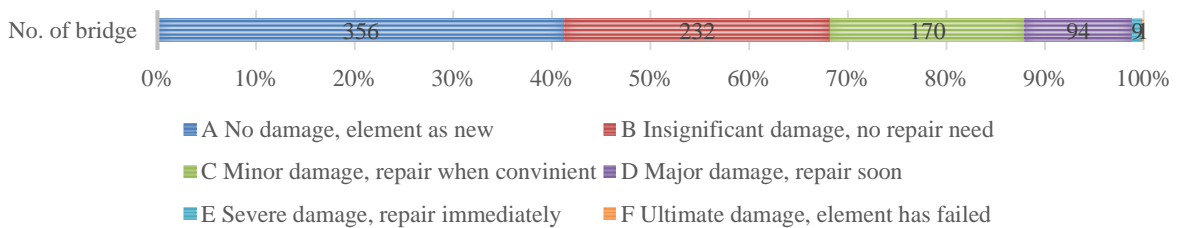
As shown in Figure 1.1.1, there are a total of 862 national road bridges in Lao PDR. After 2000, the number of bridges tends to increase. However, the year of construction of over 50% of them is unknown, and there is no data of bridges constructed before 1970. Besides, 4% of all national road bridges are over 40 years old, and it is expected that the number of bridges to be repaired will increase in the next 10 to 20 years.

On the other hand, according to bridge inventory data related to national road bridges, over 10% of them are required to be repaired soon or immediately (Figure 1.1.2). The cause is the bridge maintenance policy in Lao PDR, which is the break maintenance conducted only after the damages and defect have progressed.



Source: Bridge inventory data of DOR

**Figure 1.1.1 Number of National Road Bridges by Year of Construction**



Source: Bridge inventory data of DOR

**Figure 1.1.2 Number of National Road Bridges and Percentage by Damage Evaluation Code**

### **1.1.2 Bridge Maintenance Issues**

By taking into account the previous section, it is necessary to carry out proper bridge operation and management in Lao PDR. Currently, approximately 10% of bridges located on the national road must be repaired soon and immediately. However, the number of them will gradually increase if the current maintenance policy is applied continuously. To maintain and repair bridges economically and efficiently, it is necessary to formulate a plan to prolong the bridge life preventively from the viewpoint of LCC. Therefore, one of the issues is to promote the repair plan to prolong bridge life.

### **1.2 Purpose**

This manual aims to improve the efficiency of planning and implementation of maintenance works and to select proper countermeasures and materials by taking into account the local conditions of Lao PDR. Therefore, this manual indicates standard repair and retrofitting methods against damages and defects commonly found in bridges managed and maintained by DOR and DPWT.

### **1.3 Scope**

This manual includes the basic knowledge and the procedure to carry out the bridge repair planning and design and bridge retrofitting. Moreover, each institute and organization's jurisdiction is indicated in this manual to specify the role of each institute and organization, which is related to bridge maintenance work.

This manual is intended for;

- DOR and DPWT staff requiring guidance in selecting appropriate measures for bridges;
- The maintenance staff of DOR and DPWT carrying out routine or significant maintenance on bridges;
- Consultant planning and designing bridge repair and retrofitting measures
- Contractor executing bridge repair and retrofitting works.

### **1.4 Overview**

#### **1.4.1 Composition**

The composition of the manual is as follows:

CHAPTER 1. INTRODUCTION AND OVERVIEW

CHAPTER 2. ORGANIZATION RELATED TO BRIDGE REPAIR AND RETROFITTING

CHAPTER 3. SAFETY AND MAINTENANCE WORK

CHAPTER 4. SURVEY FOR BRIDGE REPAIR AND RETROFITTING

CHAPTER 5. BRIDGE REPAIR DESIGN

CHAPTER 6. BRIDGE RETROFITTING DESIGN

The details and examples, sample drawings of bridge repair and retrofitting method are included in this manual as an appendix.

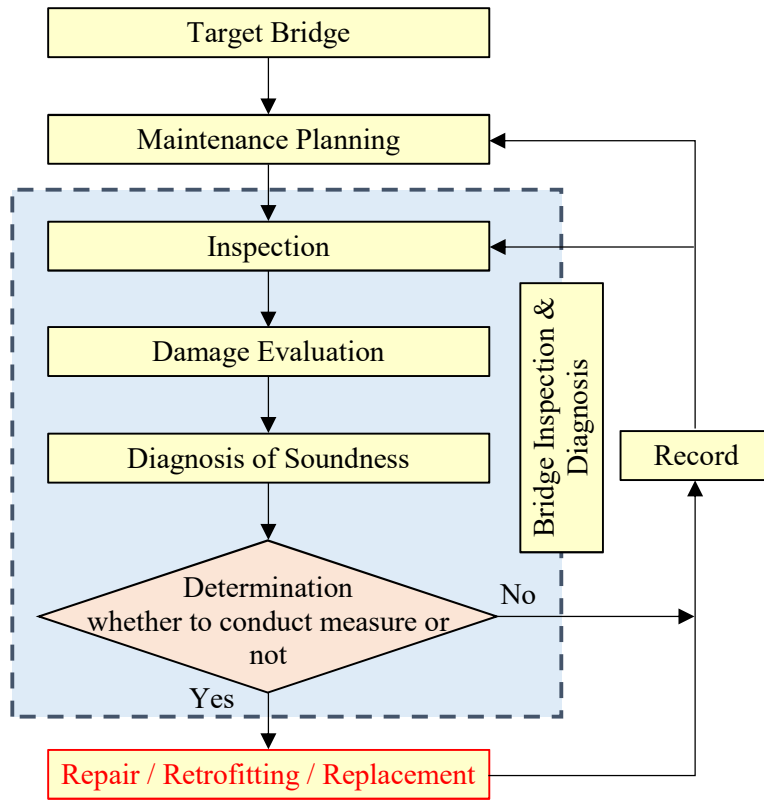
#### **1.4.2 Bridge Maintenance Process**

Figure 1.4.1 shows the basic bridge maintenance process. Bridge Maintenance is divided into 4 phases;

- a) Bridge Maintenance Planning

- b) Bridge Inspection and Diagnosis
- c) Bridge Repair and Retrofitting
- d) Recording.

Therefore, the user should use this manual with Bridge Inspection Manual. This manual is expected to be used by users to understand the bridge maintenance process, required survey, and recording method.



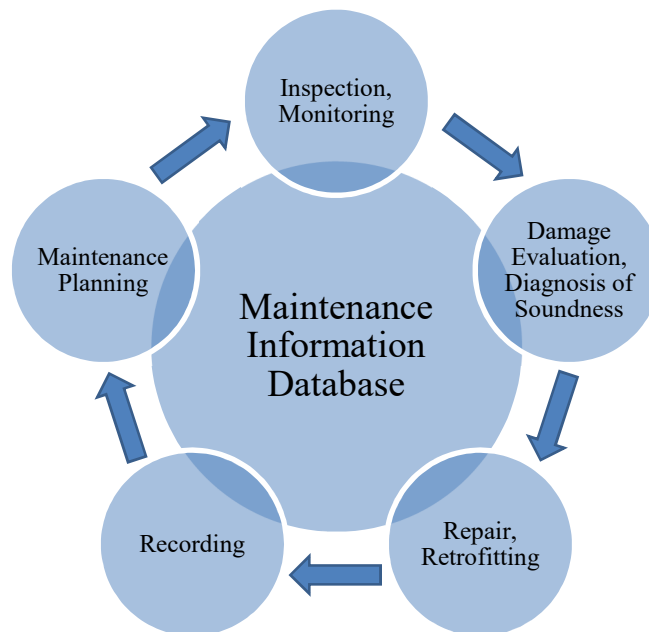
Source: JICA Project Team

**Figure 1.4.1 Bridge Maintenance Process**

## 2. ORGANIZATION RELATED TO BRIDGE REPAIR AND RETROFITTING

### 2.1 Outline

To keep the bridge soundness and to prolong the lifetime, it is essential to conduct routine maintenance of bridge structures. It is necessary to establish a primary and feasible management cycle, as shown in Figure 2.1.1 in the management entity.



**Figure 2.1.1 Bridge Maintenance Cycle**

To continue this bridge maintenance cycle sustainably, it is essential to identify the organization in relevant departments for each cycle segment. The scope of responsibility and the relevant annual schedule should be prescribed in an official document to help share the understandings among organizations.

It should be noted that each organization is not independent from each other, and the cooperation is the key to a smooth flow of the maintenance cycle. Each organization should respond to any request from the other correspondent organizations accordingly and sincerely. Also, the request should be given with the deadline and be as concrete as possible.

It is highly recommended to organize regular joint meetings among relevant organizations to exchange and share the information, to try challenging issues, and to take necessary actions

This chapter clarifies the organization in charge of each maintenance work and its standard procedures.

**2.2 Jurisdiction**

**2.2.1 Bridge Maintenance**

(1) Leading executing organization of bridge maintenance

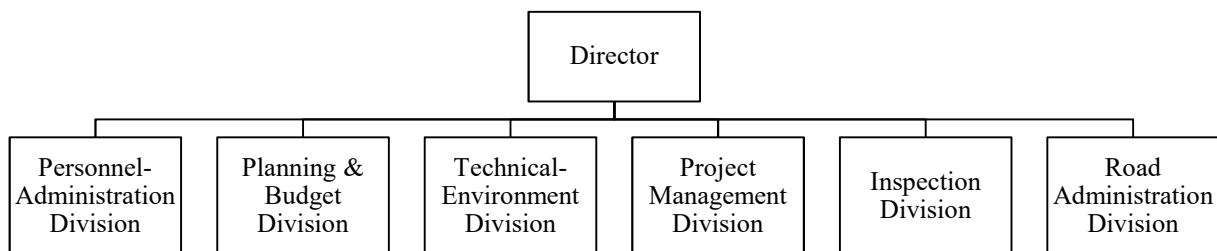
a) DOR

**DOR is the executing organization that mainly plans and designs national roads and bridges, manages construction and maintenance.** Source: DOR

Figure 2.2.1 shows the organization chart of DOR. In particular, RAD (Road Administration Division) and TED (Technical-Environment Division) are in charge of maintenance work shown in Table 2.2.1.

**Table 2.2.1 Main Work in Charge**

	Main Work in charge
RAD:	<ul style="list-style-type: none"> <li>- Various surveys and database updates of national roads</li> <li>- Operation and management of road maintenance system</li> <li>- Road repair, maintenance plan, a budget plan (mainly national roads)</li> <li>- Supervision and monitoring of repair work and maintenance of national road</li> </ul>
TED:	<ul style="list-style-type: none"> <li>- Creation of technical manuals</li> </ul>



Source: DOR

**Figure 2.2.1 Organization Chart of DOR**

b) DPWT

DPWT is the executing organization for public works projects implemented by each prefecture and has a role as an implementing agency for public works projects under the jurisdiction of MPWT.

RBU (Road and Bridge Unit) in DPWT is in charge of maintenance work and the following items in collaboration with DOR.

- Various surveys and database updates of provincial roads
- Road repair, maintenance plan, a budget plan (mainly provincial roads)
- Supervision and monitoring of repair work of national and provincial road
- Supervision and monitoring of daily maintenance of national and provincial road

## (2) Implementation contents of bridge maintenance

Table 2.2.2 shows the implementation contents of each organization.

**Table 2.2.2 Implementation Contents of Each Organization**

		DOR		DPWT
		RAD	TED	RBU
Annual Maintenance Planning		◎	-	○
Inspection	Routine / Daily	◎	-	○
	Periodic	◎	-	○
	Emergency	◎	-	○
Implementation	Routine / Daily Maintenance	◎	-	○
	Repair	◎	△	○
	Retrofitting	◎	△	○
Record	Data Input	○	-	-
	Confirmation of the Data Input	○	-	-
	Database Management	○	-	-

Source: JICA Project Team

Note:

- ◎ : Monitoring Organization
- : Implementation Organization
- △: Assistant if necessary

## (3) The organization involved in the budget application of bridge maintenance

## a) RFS

RFS is an organization that operates the RFC (Road Fund Committee) organized within MPWT and manages and monitors road funds.

## b) MPI

MPI is in charge of the operation and management of the public investment business. All public works projects are appraised by MPI (DOE: Department of Evaluation) based on supporting materials such as cost, design, EIRR, an implementation plan that show the project's validity, and then approved by MPI (DOP: Department of Planning).

## (4) Budget appraisal schedule

There are two types of budget appraisal schedules related to bridge maintenance.

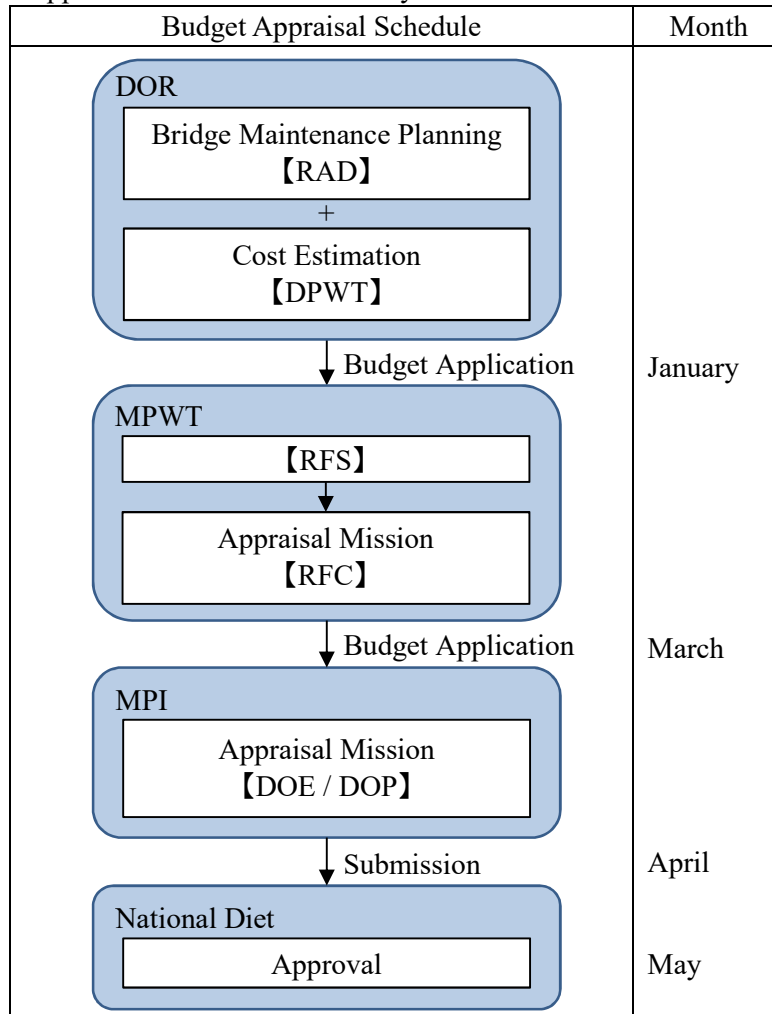
## a) Project type

**The project type budget is targeted to new projects related to the bridge's survey and design and the large-scale rehabilitation of a bridge, which is not included in the Road Maintenance System (RMS). The budget application for these projects is implemented based on the flow shown in** Source: JICA Project Team

Figure 2.2.2.

- A budget application is submitted to RFS by DOR every January
- RFC appraises it in March
- RFC applies it to MPI after approval.
- DOE in MPI appraises it, and then DOP in MPI approves.

- MPI submits it to National Diet.
- National Diet approves and allocates it in May.



Source: JICA Project Team

**Figure 2.2.2 Budget Appraisal Schedule for Project Type**

b) General Expense Type

The general expense type budget is targeted to the bridge maintenance work based on RMS. For this case, it is not necessary to apply it to MPI because the budget allocated for RMS is applicable. The figure shows the budget application schedule of the general expense type.

	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
Survey	■							
Analysis and Evaluation		■						
Repair Design			■	■				
Document Preparation for Budget Application					■			
Approval by Minister of MPWT						■		
Implementation								■

Source: JICA Project Team

**Figure 2.2.3 Budget Appraisal Schedule for General Expense Type**

### 2.2.2 Seminar and Workshop

It is very beneficial to share information on new know-how and technologies and damage patterns through seminars and workshops nationwide. Seminars and workshops should be held regularly to build partnerships and networks among RAD and TED in DOR, RBU in DPWT staff.

(1) Related organization

a) PTTI

PTTI is an organization under MPWT and is a training institution to improve the technical level of MPWT staff.

(2) Implementation contents of seminar and workshop

PTTI is in charge of the following contents;

- The organization and implementation of national seminars and workshops
- To carry out local workshop and information sharing

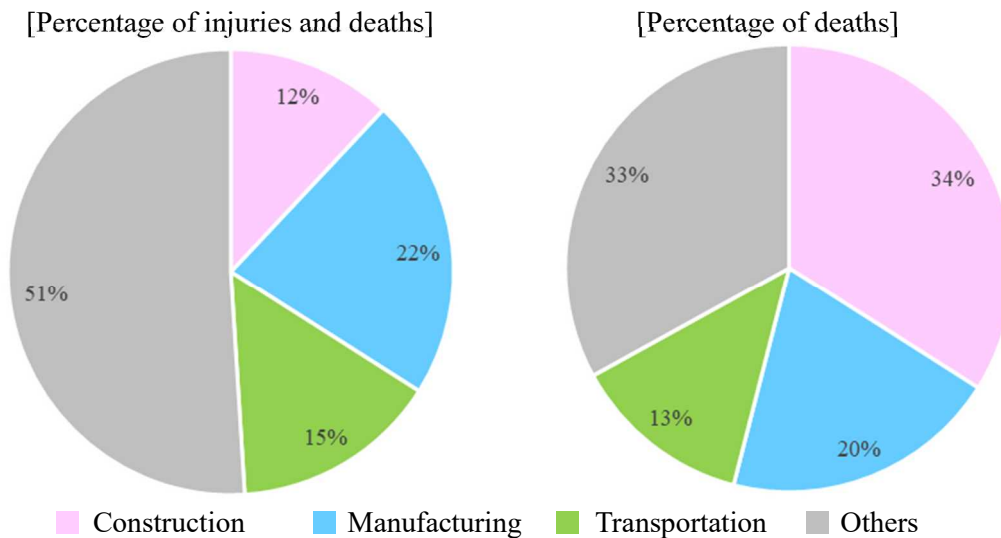
### 3. SAFETY AND MAINTENANCE WORK

#### 3.1 Safety Work

##### (1) Introduction

Construction sites have some risks of life compared to other industries.

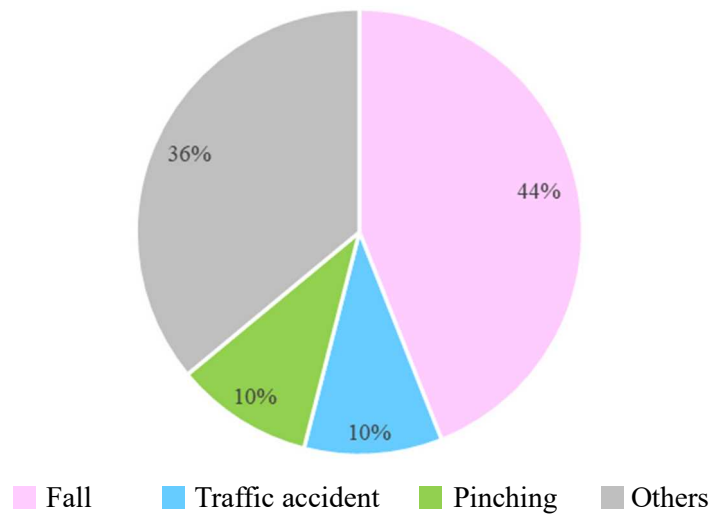
Figure 3.1.1 shows the accident ratio in 2018 for all industries in Japan. Regarding the accident rate of the construction work is 12% in all injuries and deaths. Moreover, regarding the death's accident rate, 34% of all accidents are caused by construction. Therefore it is essential to consider safety measures for the repair workers. In addition to the supervisor's understanding, it is essential to share among workers and educate them about the danger of repair work and safety measures.



Source: MLIT in Japan

**Figure 3.1.1 Accidents Result in all Industries (In Japan)**

Figure 3.1.2 shows the proportion of death causes at construction sites in Japan in 2018. 'Fall' and 'Traffic accident' are the main cause of fatality. A fall accident often occurs when workers are on the high place. To prevent the fall accident, it is necessary to install the scaffoldings, and the work floor on the scaffoldings must not have wide gaps, and handrails on the scaffoldings should be attached (Figure 3.1.3). Furthermore, if possible, please provide a temporary slope to access the bridge easily.



Source: MLIT in Japan

**Figure 3.1.2 Accidents Rate in Death in Construction Site (In Japan)**



**Figure 3.1.3 Scaffoldings**

Fatal traffic accidents occur more often in repair work because the repair work is likely to be conducted near traffic flow. As a countermeasure of reducing traffic accidents, it is practical to place some signboards on the road for the extra attention to drivers (Figure 3.1.4).



**Figure 3.1.4 Signboard**

Thus, the accident can be reduced substantially if appropriate safety measures are prepared in advance and arranged during the construction period. Also, an accident is likely to occur when workers get accustomed to working routines and start losing concentration. A supervisor should not forget this fact and keep attention even if no accident period continues.

The repair work must be carried out under the condition where the worker's safety is completely ensured. If the worker's safety cannot be guaranteed, any work must not be carried out.

### (2) Confirmation before Work

Before the commencement of repair work, it is necessary to check the site to confirm the target damages to be repaired and how to access them. Based on the site check, temporary facilities such as scaffoldings, work schedule, tools, and material shall be prepared. At the same time, it is necessary to plan safety management during work.

After the site check, to share the work procedures and the relevant information among participants, a preliminary meeting should be held. In this meeting, detailed work procedure, schedule, safety measures, number of workers, material, tools, and assignment of each worker are discussed and confirmed based on newly-obtained knowledge from site check.

Weeds, bushes, and trash on the site sometimes cause workers to stumble or slip and make scaffoldings unstable. Some trash contains hazardous substances such as glass, cutlery, and syringes, and they may be hidden under weeds and bushes (Figure 3.1.5). Therefore, it is essential to remove weeds, bushes, and trash before the work.

It is necessary to include this clearing period in the work schedule as it takes considerable time to remove them. In some cases, it should be done within a day before the commencement of work.



**Figure 3.1.5 Hazardous Materials in Site**

### (3) Confirmation during Work

All people entering the site, not only the workers but also the supervisors, must wear a protective helmet and safety shoes (Figure 3.1.6). Sandals are not allowed on the site.



**Figure 3.1.6 Protection Helmet and Safety Shoes**

Before the work, the supervisor has to gather all workers and have a meeting to confirm the proceedings of the day's work and caution for safety. After the site meeting, all members carry out site cleaning first if necessary. Ideally, site cleaning should be carried out every day to keep it safe and workable condition. When setting up scaffolding, the ground around its columns should be leveled or column length should be adjusted so that its floorboards are kept horizontal and stable (Figure 3.1.7).



**Figure 3.1.7 Fixed Scaffolding**

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

### **3.2 Routine Maintenance**

#### **(1) Purpose**

For preventing deterioration of the bridge structure, it is necessary to perform cleaning works. They include removing all accumulated foreign materials from the entire areas of the bridge such as deck slab, sidewalk, curbs, pier top, truss, and web members, lower flanges of beams or girders, expansion joints, bearings, and drain facilities. After the cleaning, there should be no remaining sand, gravel, dirt, and other foreign materials in the areas. Especially, drainage must be cleaned regularly to prevent rainwater retention, which may often trigger rusting of structural members.

(2) Application Criteria

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

a) Bridge Surface

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

b) Bridge Substructure

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

c) Surface of Steel Plate

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

(3) Work Sequence

a) Bridge Deck and Drainage Cleaning

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



**Figure 3.2.1 (Left) Expansion Joint, (Right) Drainage**

b) Cleaning of Bridge Substructure

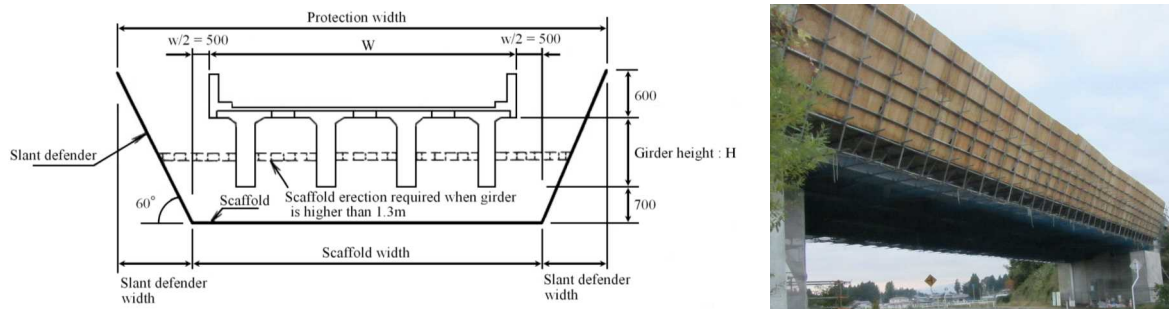
All foreign materials such as dirt, dust, sand, rainwater, and moss on abutment surface and pier bearing seats and coping shall also be entirely removed manually and then washed using a high-pressure water bluster. Mud and sand deposits at the sides of the abutment shall be excavated to maintain their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



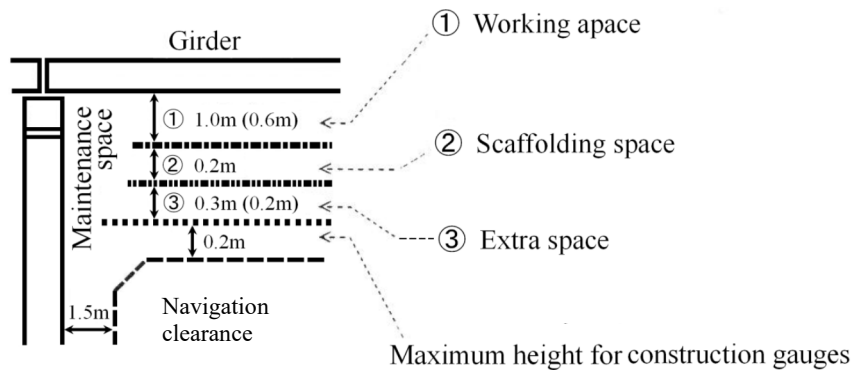
**Figure 3.2.2 Debris and Sand Deposits around Bearing Seat Areas**

### 3.3 Working Clearance for Repair

For repair of the superstructure, the scaffoldings must be set under and beside the superstructure. Figure 3.3.1 shows the form of scaffoldings. As a general rule of working clearance, a total of 1.5m (1.0m as working space, 0.2m as scaffolding space, and 0.3m as extra space) under the girder and more than 0.5m besides the main girder are required.



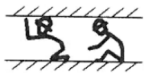

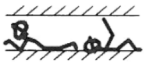
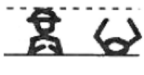
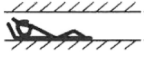

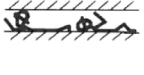

**Figure 3.3.1 Standard Setting of Scaffolding**



**Figure 3.3.2 Detail of Working Clearance**

Table 3.3.1 compares worker's positioning and the required spaces. It is necessary to provide enough working space as much as possible to work and move without physical hindrance.

Table 3.3.1 Working Positions and its Space

Working Position			Required Space (Standard Size): m		
Position	Sketch		Height	Width	Length
	Side View	Front View			
Work with kneeling and sitting position			1.0	1.0	1.0
Work with lying face down or face up and stretching or flexing lower limbs			>0.6	0.8	1.6
Work with lying sideways and stretching or flexing lower limbs			0.7	0.8	1.8
Work with lying face down, with arms and abdomen on the floor, and lying face-up			0.4	0.8	1.8

## 4. SURVEY FOR BRIDGE REPAIR AND RETROFITTING

### 4.1 Outline

#### 4.1.1 Purpose of Survey

In bridge maintenance, it is necessary to conduct an inspection, survey, design, and repair work systematically according to a planned schedule with a long-time perspective, under appropriate methods, timing, and management systems, considering each bridge's characteristics. For an appropriate repair, it is essential to conduct the bridge survey before the bridge repair and collect enough bridge condition information. Table 4.1.1 shows the position of survey and design in bridge maintenance and the main work contents.

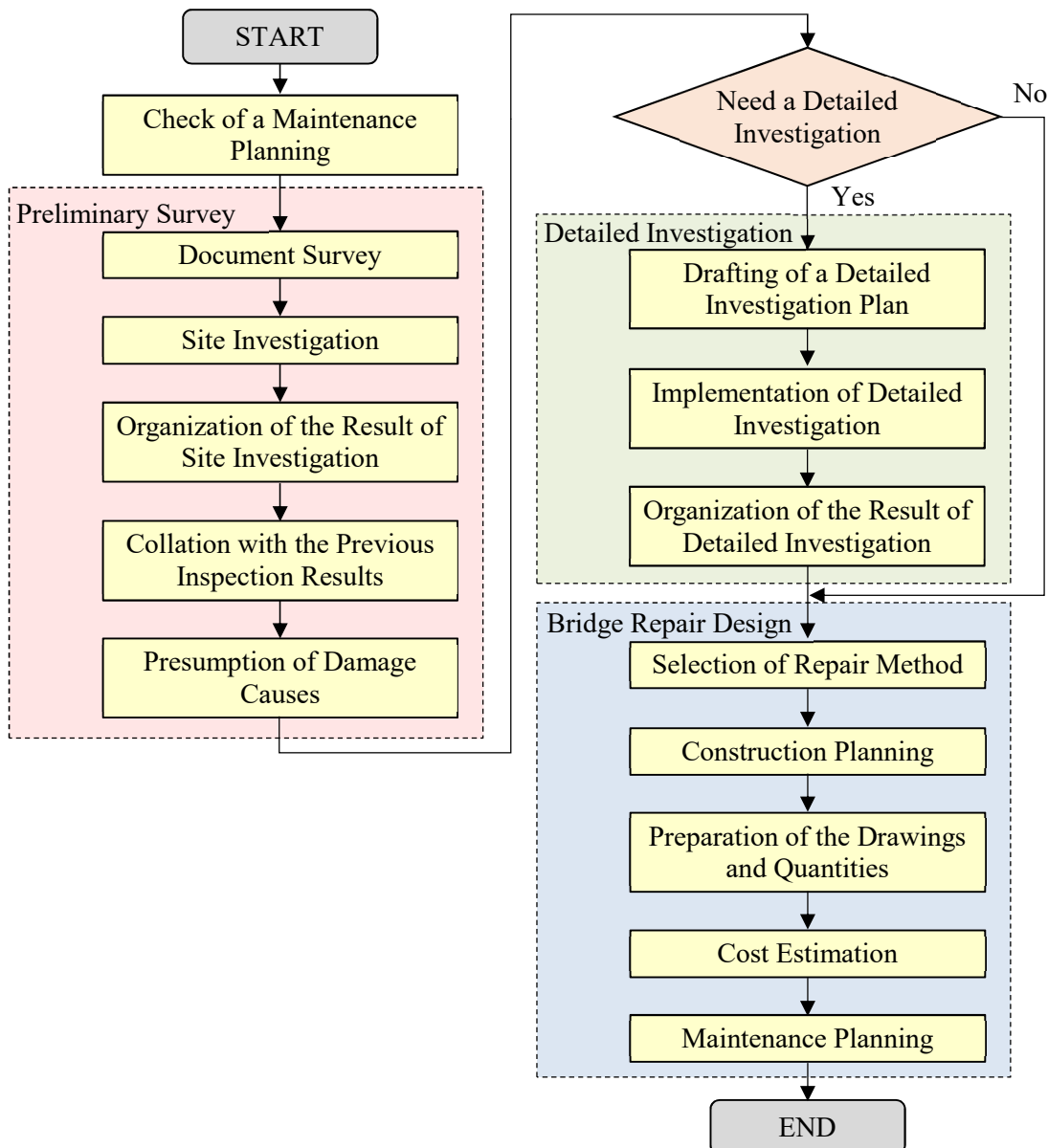


Figure 4.1.1 Survey and Design Work Flow for Bridge Repair

**4.1.2 Common Rules in Bridge Survey**

When investigating the damaged areas of the bridge to be repaired, the following common rules shall be followed. Table 4.1.1 shows the common rules in the bridge survey.

**Table 4.1.1 Common Rules for Bridge Survey**

Surveys	Common Rules
Survey on compressive strength of concrete	A simple strength test (non-destructive test) using a rebound hammer shall be performed in principle. However, as a result of the simple strength test, if the concrete strength is insufficient over a wide area and is likely to require reinforcement work, a core sample shall be taken to confirm the compressive strength by a uniaxial compressive strength test.
Survey on carbonation of concrete	Tests only to confirm the carbonation shall not be performed in principle. However, when a core is taken for other tests, a phenolphthalein test can also measure carbonation depth.
Survey on the alkali-silica reaction of concrete	When an alkali-silica reaction is suspected by visual inspection, the detailed investigation should be conducted desirably by the Bridge Inspection Manual.

**4.2 Preliminary Survey**

**4.2.1 Document Survey**

In order to implement repair planning and design, it is necessary to collect the existing data and documents shown below and confirm the characteristics and history of target bridges.

- a) Inspection Report (Latest and Past)
- b) Bridge Inventory List (Bridge Management Carte)
- c) Design Document
- d) As-built Document
- e) Repair History
- f) Repair Design Report
- g) Road Information Drawing
- h) Construction Management Record (generally unnecessary)

Table 4.2.1 shows the survey item for each document.

Table 4.2.1 Survey Item for Each Document

	Name of Document		Survey Item	Necessity
a	Inspection Report	Latest	<ul style="list-style-type: none"> <li>➤ Confirmation of current damage situation</li> <li>➤ Selection of damage to be repaired</li> </ul> (If there is a diagnosis result in the inspection document, its result should be referred.)	◎
		Past	If there are damages for which repair is required, <ul style="list-style-type: none"> <li>➤ Confirmation of damage progress</li> <li>➤ Prediction of progress rate of damage</li> </ul>	○
b	Bridge Inventory List		<ul style="list-style-type: none"> <li>➤ Bridge information, construction year, design specification</li> </ul>	◎
c	Design Report		<ul style="list-style-type: none"> <li>➤ Confirmation of bridge detail information such as structural dimension, concrete strength, rebar arrangement, and prestressing cable for bridge repair</li> <li>➤ Presumption of damage causes such as the lack of concrete cover and structural failure, insufficient load capacity.</li> </ul>	○
d	As-built Report		If the design was changed during construction, <ul style="list-style-type: none"> <li>➤ Confirmation of bridge detail information from not design report but this material</li> </ul>	○
e	Repair History		If the repair was repeatedly carried out, <ul style="list-style-type: none"> <li>➤ Presumption of structural weakness and original causes of damage</li> </ul>	○
f	Repair Design Report		If the bridge repair was carried out after construction, <ul style="list-style-type: none"> <li>➤ Confirmation of the latest information because of the differences from the original structure</li> </ul>	○
g	Road Information Drawing		<ul style="list-style-type: none"> <li>➤ Confirmation of the bridge location, information surrounding the target bridge</li> <li>➤ Use of this material for planning site investigation and traffic limitation</li> </ul>	◎
h	Construction Management Record		If the damage is caused by the material used in construction, <ul style="list-style-type: none"> <li>➤ Confirmation of record of material content testing and quarry site as well as identification of the damage causes</li> </ul>	△

Note: ◎: Essential document, ○: Desirable document, △: Generally unnecessary document

#### 4.2.2 Site Investigation

A bridge site investigation is a critical survey to be carried out following the document survey as shown in Figure 4.1.1. The reason is that the inspection record includes detailed photographs of the damaged part, but there is little information about the damage causes. In order to confirm the damage condition and presume the damage causes, therefore, it is necessary to confirm the following item during the site investigation.

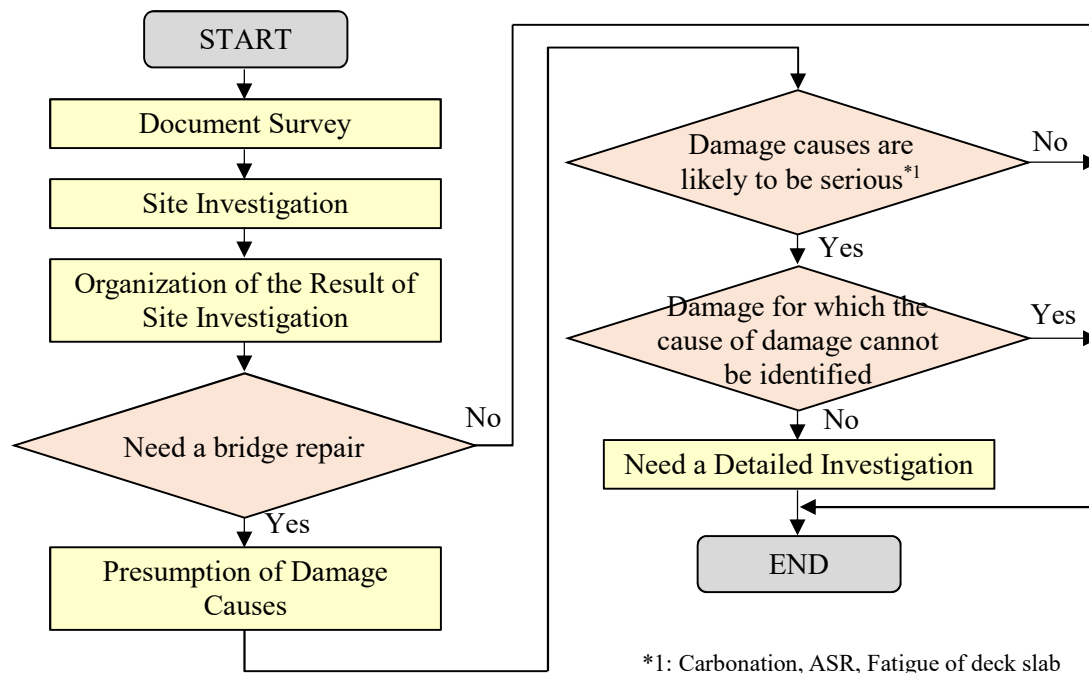
**Table 4.2.2 Confirmation Item during Site Investigation**

Purpose	Confirmation Item during Site Investigation
Confirmation of damage condition	<ul style="list-style-type: none"> <li>➤ Damage condition by close visual inspection comparing the pictures of damaged part in an inspection report.</li> <li>➤ Touch by hand and do the hammering survey if necessary.</li> <li>➤ Critical damages</li> <li>➤ Reviewing the damage drawing in an inspection report</li> </ul>
Presumption of damage causes	<ul style="list-style-type: none"> <li>➤ Surrounding environment</li> <li>➤ Road surface condition</li> <li>➤ Damage condition near the damaged part</li> <li>➤ Characteristics of damage</li> <li>➤ Rainwater flow and leakage situation</li> <li>➤ Traffic noise and vibration when a large vehicle is passing</li> </ul>

**4.2.3 Judgement of Necessity for Detailed Investigation**

(1) Overview

After the site investigation, it is necessary to decide whether a detailed investigation is required or not. A detailed investigation shall be conducted if the damage causes cannot be identified by site the investigation or the current investigation result. Figure 4.2.1 shows a general flowchart in order to judge the implementation of a detailed investigation.



**Figure 4.2.1 Judgement Flowchart of Necessity for Detailed Investigation**

(2) Judgement of necessity for detailed investigation of concrete member

It is too difficult to identify the damage causes because there are many damages and damage causes of the concrete member. Therefore, it is crucial that the surrounding environment/damage condition should be compared with the characteristics on the existing literature and the cause of damage should be

assumed. If the cause cannot be identified at this stage, a detailed investigation shall be conducted. Table 4.2.3 shows the possibility between the damage and typical damage causes of the concrete member.

**Table 4.2.3 Table for the Judgement of Damage Causes of Concrete Member**

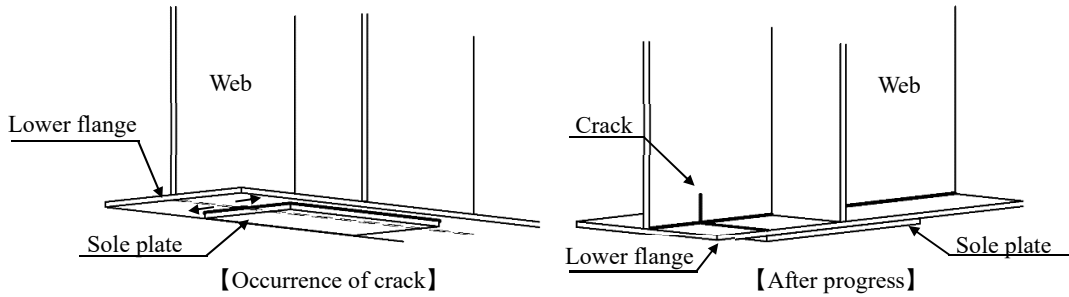
		Cause of damage and deterioration						
		Carbon-ation	ASR	Fatigue		Heat / temperature action	Lack of concrete cover	Poor water-proofing
				Slab	Girder			
Crack condition	Parallel to rebar	⊙	⊙				⊙	○
	Alligator		⊙					
	Micro					⊙		
	Mesh type			⊙		⊙		
	Flexural / Shear			⊙	⊙			
	Penetration					⊙		
Spalling		⊙	○				⊙	○
Rebar exposure		⊙	○				⊙	○
Rebar corrosion		⊙	○					○
Free lime		○	○	⊙				⊙

Note: ⊙: Higher possibility, ○: Moderate possibility

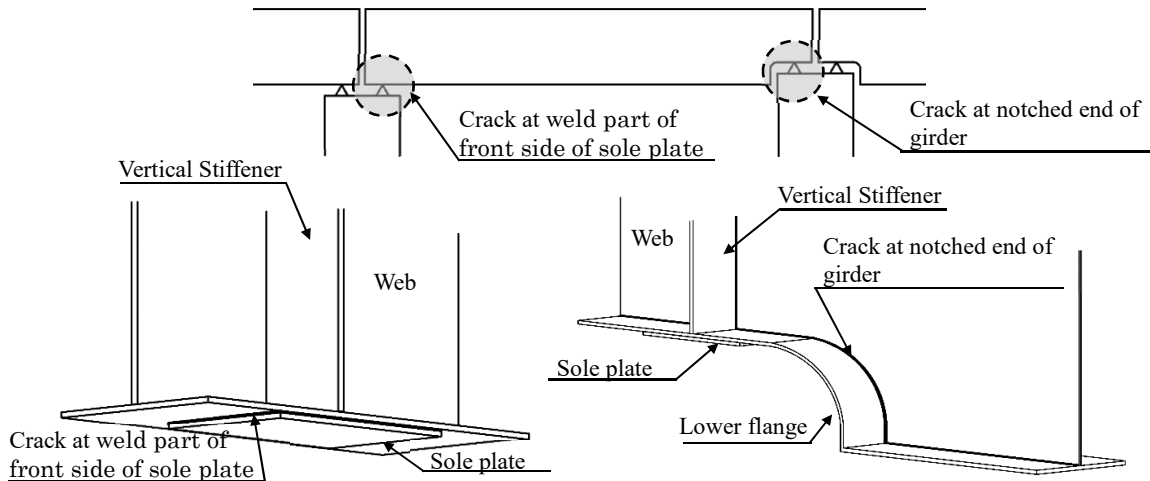
(3) Judgement of necessity for detailed investigation of steel member

Figure 4.2.2 shows the areas where the crack is likely to occur. If they are recognized during the inspection or the site investigation, the Engineer should consider and decide the necessity of the detailed investigation.

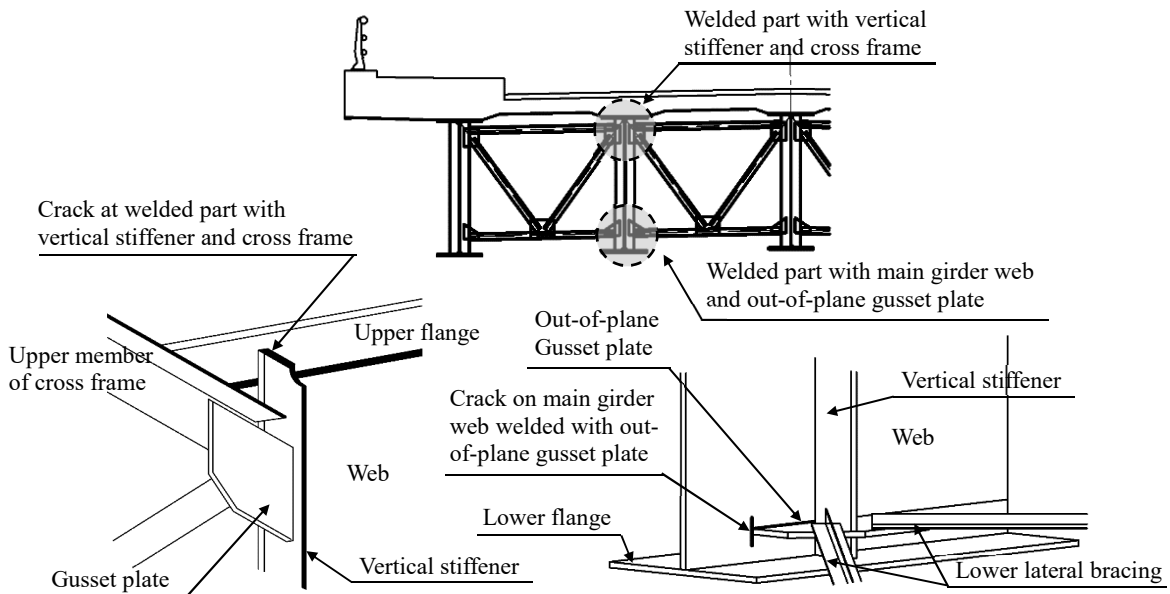
a) Weld point at the front side of the soleplate



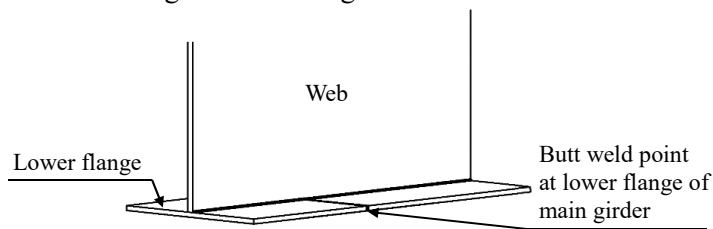
b) Notch point at the girder end



c) Vertical stiffener point connected with cross frame



d) Buttweld point at the lower flange of the main girder



**Figure 4.2.2 Areas Where Crack is Likely to Occur**

(4) Judgement of necessity for detailed investigation of other members

There are various cases of the necessity for detailed investigation of other members/structures. Basically, similar to concrete members, if the cause cannot be identified at this stage, a detailed investigation shall be conducted.

As the common detailed investigation, there are cases where the following on site investigation is required, and there are detailed investigations common to concrete members and steel members.

- Cases where the damage situation cannot be understood only by periodic inspection and more detailed investigation is required; scour, settlement, move, and inclination of foundation
- When the damage such as corrosion and cracks requires quantitative investigation such as corrosion thickness, area, width, and length
- When it is necessary to investigate the relation between the cause of damage and the damage of other parts (for example; relation between the settlement of pavement and crack on slab)

**4.3 Detailed Investigation**

**4.3.1 Planning**

If the preliminary survey determines it is necessary to conduct the detailed investigation, the Engineer must formulate the detailed investigation plan and follow the items shown below

- Clarification of the purpose of the detailed investigation
- Clarification of target members, damage, and deterioration mechanism
- Clarification of information obtained through detailed investigation
- Selection of an appropriate detailed investigation method that can obtain the desired results for the target member, damage, and deterioration mechanism

**4.3.2 Detailed Investigation Method**

A detailed investigation method shall be selected using Bridge Inspection Manuals. It is necessary to select it by considering the defect type and deterioration, the environment surrounding the bridge, and traffic volume.

**4.3.3 Organization of Detailed Investigation Results**

Since the detailed investigation results are to identify the cause of damage and estimate the quantity, it is necessary to organize them according to its method. The investigation results are recorded in a format determined for each investigation method and organized according to the method of usage. An example how to summarize the method of usage based on the result of detailed investigation is shown below.

**Table 4.3.1 Examples How to Summarize the Method of Usage**

Investigation Method	Method of Usage
1) Identification of damage causes:	To compare the obtained values and results with the general values of the causes of targeted damages.
2) Necessity and timing of repair measures:	To compare the obtained values and results with the damage degree classification, deterioration grade, and countermeasure classification.
3) Selection of repair method:	To organize the obtained values and results in a list according to the information required for selecting repair methods.
4) Quantity estimation:	To prepare drawings indicated in the current bridge situation and damages and defects

## **4.4 Defect Causes and Soundness Evaluation**

### **4.4.1 Concrete Structure**

#### (1) Defect types

The main defects of concrete structures are:

- 1) Crack
- 2) Peeling off and flaking
- 3) Rebar exposure
- 4) Spalling
- 5) Free lime and water leakage
- 6) Surface deterioration (Color change)
- 7) Insufficient grouting
- 8) Corrosion and breakage of PC tendons
- 9) Defects of PC anchors

The defects of 7) through 9) as shown above cannot be identified by visual inspection.

#### (2) Defect causes

The defect causes of bridges are varied, and the causes are often complicatedly related to various factors. Therefore, it is difficult to identify the defect causes precisely, but it is possible to presume the main causes by visual inspection and detailed investigation.

Table 4.4.1 shows the defects and main causes, and Table 4.4.2 shows the deterioration of the main defect causes.

**Table 4.4.1 Damage Causes of Concrete Structure**

Defects	Member	Major causes of defects	
Cracks	Main girder, RC deck slab, Pier, Abutment, Parapet, Curb	External forces	Cyclic loading, Continuous loading, Collisions, Scour and erosion
		Environment	Dry shrinkage, thermal changes Chemical attack
		Material deterioration	ASR, Carbonation
		Construction quality	Poor quality of construction, Poor waterproofing or poor drainage
Peeling off, Rebar exposure	Ditto	External forces	Cyclic loading, Collisions, Scour and erosion
		Environment	Dry shrinkage, thermal changes Chemical attack
		Material deterioration	ASR, Carbonation
		Construction quality	Poor quality of construction, Poor waterproofing or poor drainage
Free lime, Water leakage	Ditto	Environment	Dry shrinkage, thermal changes
		Material deterioration	ASR, Carbonation
		Construction quality	Poor quality of construction, Poor waterproofing or poor drainage
Spalling	RC deck slab, Parapet, Curb, etc.	External forces	Cyclic loading, Collisions
		Material deterioration	ASR, Carbonation
		Construction quality	Poor quality of construction Poor waterproofing or poor drainage
Surface deterioration (Color change)	Main girder, RC deck slab, Pier, Abutment, Parapet, Curb	Environment	Dry shrinkage, thermal changes
		Material deterioration	ASR Carbonation
		Construction quality	Poor quality of construction Poor waterproofing or poor drainage

**Table 4.4.2 Relation among Deteriorations, Causes, Indicators and Phenomenon**

Deterioration	Cause of deterioration	Deterioration phenomenon	Example of deterioration indicator
Carbonation	Carbon dioxide	A deterioration phenomenon in which carbon dioxide triggers a carbonation reaction with cement hydrate and causes the decrease of pH in the pore solution, which promotes corrosion of steel materials, causing cracks in concrete and decreasing cross-sectional area of steel materials because of peeling off.	Depth of carbonation, Rebar Corrosion amount, Crack by corrosion
ASR	Reactive aggregate	Deterioration phenomenon in which reactive silica minerals in aggregate react with an alkaline aqueous solution in concrete to cause abnormal expansion and cracking in concrete.	Crack by volume expansion
Fatigue of deck slab	Overloaded vehicle, Cyclic loading	A phenomenon in which the RC slab of a road bridge cracks or collapses due to the overloaded vehicle and cyclic loading of wheel load	Density of cracks, Deformation

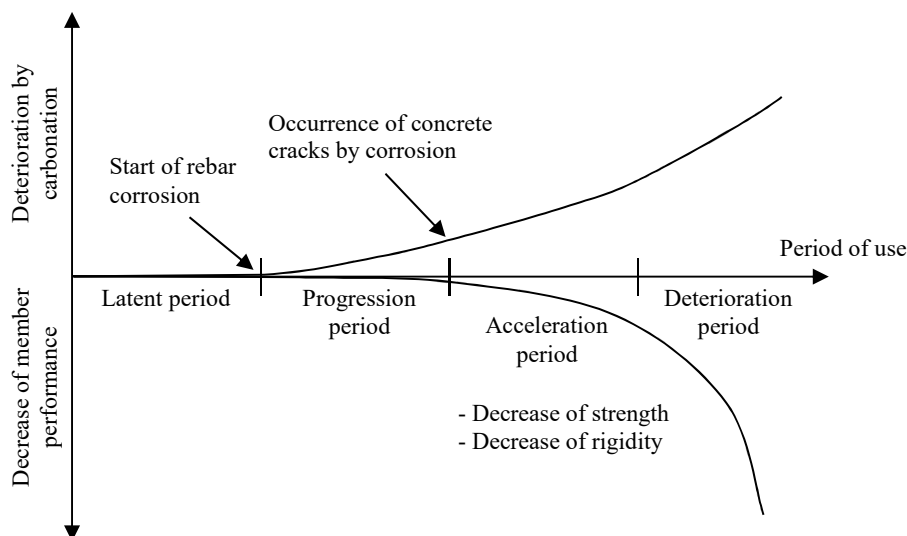
Mechanism of each deterioration shows in Bridge Inspection and Diagnosis Manual.

(3) Soundness evaluation

Soundness evaluation of concrete structure shall conform to the Bridge Inspection Manual.

In order to evaluate the soundness of concrete structure, it is important to take into account the current deterioration progress. The total period can be divided into four periods; Latent period, Progression period, Acceleration period, and Deterioration period. Figure 4.4.1 through Figure 4.4.3 and Table 4.4.3 through Table 4.4.5 show the concept of deterioration progress.

a) Carbonation

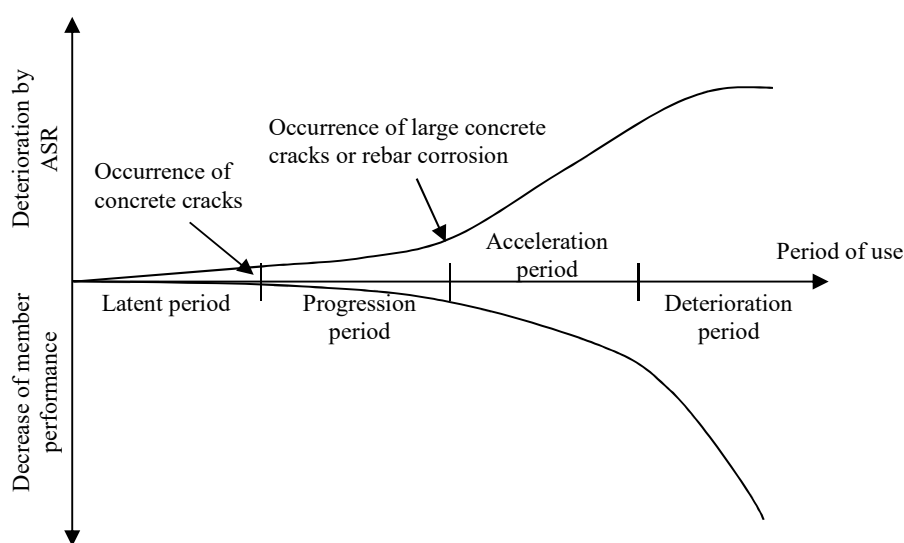


**Figure 4.4.1 An Example of a Conceptual Diagram of the Deterioration Progress Process due to Carbonation**

**Table 4.4.3 Definition of Deterioration Progress related to Carbonation**

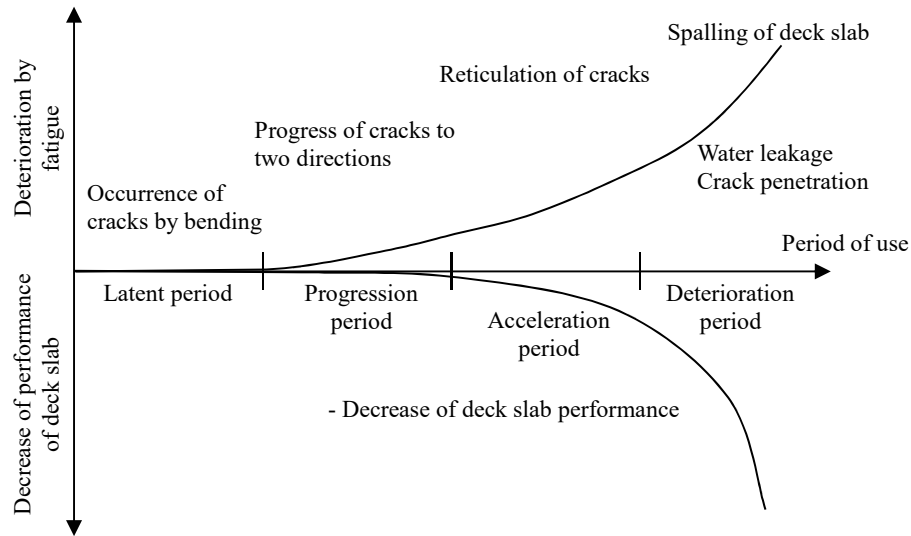
Deterioration progress	Definition
Latent period	The period until the carbonation depth reaches the corrosion occurrence limit of rebar
Progression period	The period from the start of rebar corrosion to the occurrence of concrete cracks by corrosion
Acceleration period	The period during which the corrosion is accelerated due to the occurrence of concrete cracks by corrosion
Deterioration period	The period in which the strength is significantly reduced due to the increase in the amount of rebar corrosion

b) ASR

**Figure 4.4.2 A Conceptual Diagram of the Deterioration Progress Process due to ASR****Table 4.4.4 Definition of Deterioration Progress related to ASR**

Deterioration progress	Definition
Latent period	The period in which ASR progresses but the volume expansion of Alkali-Silica-Gel and the cracks by it do not progress
Progression period	The period during which Alkali-Silica-Gel volume expansion progresses continuously and cracks occur under water and alkali supply, but rebar corrosion does not occur.
Acceleration period	The period during which volume expansion is accelerated due to ASR, cracks progress, and rebar corrosion may occur.
Deterioration period	The period in which the width and density of cracks increase and the member's function is impaired. The strength is significantly reduced due to the sectional decrease of rebar by corrosion.

c) Fatigue of deck slab



**Figure 4.4.3 An Example of a Conceptual Diagram of the Deterioration Progress Process due to Fatigue of Deck Slab**

**Table 4.4.5 Definition of Deterioration Progress related to Fatigue of Deck Slab**

Deterioration progress	Definition
Latent period	Phase in which some of the one-directional cracks along the main rebar due to dry shrinkage or loading can be found.
Progression period	Phase in which the two-directional cracks along not only main rebar but also transverse rebar occur.
Acceleration period	Phase in which reticulation of cracks progresses and shear deck slab capacity is significantly reduced if loss of corners occurs.
Deterioration period	Phase in which the deck slab strength is significantly reduced and spalling of deck slab and crack penetration occurs.

#### 4.4.2 Steel Structure

##### (1) Defect types

The main defects of steel structures are:

- 1) Corrosion
- 2) Crack
- 3) Loosening and falling off of bolts
- 4) Breakage
- 5) Deterioration of corrosion protection performance

##### (2) Defect causes

Table 4.4.6 shows the defect causes.

**Table 4.4.6 Damage Causes of Steel Structure**

Defect	Member	Major causes of defects	
Corrosion	Girder end, Joint of members, Panel point of arch and truss members, Maintenance hole	Material deterioration	Poor quality
		Manufacturing and construction	Manufacturing and construction failure, Insufficient waterproofing
		Structure	Defective structure type and its shape
Cracks	Soleplate, Notch of end girder, Welding point of vertical stiffener, Gusset of main girder	External force	Cyclic loading, Collisions
		Material deterioration	Poor quality
		Manufacturing and construction	Manufacturing and construction failure
		Structure	Defective structure type and its shape
Loosening and falling off of bolts	Joint of members by bolts	External force	Cyclic loading, Collisions
		Material deterioration	Poor quality
		Manufacturing and construction	Manufacturing and construction failure
		Structure	Defective structure type and its shape
Breakage	Floor members, Cross frame, Lateral bracing, Diagonal member of truss,	External force	Cyclic loading, Collisions
		Material deterioration	Poor quality
		Manufacturing and construction	Manufacturing and construction failure
		Structure	Defective structure type and its shape
Deterioration of corrosion protection performance	Girder end, Joint of members, Panel point of arch and truss members, Near the drainage device	Material deterioration	Poor quality
		Manufacturing and construction	Manufacturing and construction failure, Insufficient waterproofing
		Structure	Defective structure type and its shape

(3) Soundness evaluation

Soundness evaluation of steel structure shall conform to Bridge Inspection Manual.

The deterioration progress of corrossions and deteriorations of corrosion protection performance can be divided into 4 periods which are the same as the case of concrete structure.

Regarding the other defects, it is necessary to conduct the repair. Section 5.4.2 of Chapter 5 shows the degree of defect and judgement of countermeasures.

**Table 4.4.7 Definition of Deterioration Progress related to Corrosion of Steel Members Painted by General Painting**

Deterioration progress	Definition	Standard condition
Latent period	The period in which painting keeps the protection performance	Color changes and decreases in gloss can be partially recognized by visual inspection
Progression period	The period during which the protection performance gradually decreases and corrosion occurs at the underpainting	Progression of decrease in gloss The disappearance of topcoat painting Occurrence of deterioration of painting such as partial rusting, cracks, peeling off
Acceleration period (early)	The period during which corrosion is significantly accelerated	Expansion of rusting area (around 2%). Occurrence of cross-sectional defect partially
Acceleration period (latter)		Outstanding rusting area (around 5%) Reduction of steel thickness
Deterioration period	The period in which strength against tension, buckling, and fatigue significantly decreases due to corrosion	Reduction of steel thickness entirely (half thickness partially)

**4.4.3 Foundation**

(1) Defect types

The main foundation defects are:

- 1) Scour
- 2) Settlement, movement, inclination

It is difficult to inspect the defect of the foundation visually. However, it is crucial to try to detect the defects of the foundation because the foundation defect causes damages of superstructure, pier, and abutment.

(2) Defect causes

Table 4.4.8 shows the defect causes.

**Table 4.4.8 Damage Causes of Foundation**

Defect	Defect causes
Scour	Reduction of riverbed
Settlement, Movement, Inclination	Poor Construction Use of insufficient materials for backfilling Defective structure type and its shape

## (3) Soundness evaluation

Soundness evaluation of foundation shall conform to the Bridge Inspection Manual.

**4.4.4 Bearing**

## (1) Defect types

The main bearing defects are:

- 1) Loosening and falling off
- 2) Breakage
- 3) Cracks of mortar

## (2) Defect causes

Table 4.4.9 shows the defect causes.

**Table 4.4.9 Damage Causes of Bearing**

Causes \ Defects	Mistake of bearing type selection	Lack of design consideration	Poor manufacture and Construction failure	Insufficient maintenance
Loosening and falling off		○	○	○
Breakage	○	○		○
Cracks of mortar	○	○	○	

○: Higher possibility

## (3) Soundness evaluation

Soundness evaluation of bearing shall conform to the Bridge Inspection Manual.

**4.4.5 Expansion Joint**

## (1) Defect types

The main defects of the expansion joint are:

- 1) Cracks and breakage
- 2) Deformation
- 3) Abnormal opening width
- 4) Cracks or peeling off of the post-cast mortar
- 5) Water leakage

## (2) Defect causes

Table 4.4.10 shows the defect causes.

**Table 4.4.10 Damage Causes of Expansion Joint**

Defects	Major causes of defects	
Cracks and breakage, Deformation	External force	Cyclic loading
	Material deterioration	Poor quality
	Manufacturing and construction	Construction failure
	Structure	Defective structure type and its shape
Abnormal opening width	External force	Cyclic loading Scour, erosion Settlement
	Environment	Dry shrinkage, thermal changes
	Manufacturing and construction	Construction failure
	Structure	Defective structure type and its shape
Cracks or peeling off of the post-cast mortar	Environment	Dry shrinkage, thermal changes
	Material deterioration	Poor quality
	Manufacturing and construction	Construction failure
Water leakage	Environment	Dry shrinkage, thermal changes
	Material deterioration	Poor quality
	Manufacturing and construction	Construction failure Poor waterproofing
	Structure	Non-drainage system or breakage of drainage system

## (3) Soundness evaluation

The repair methods for the expansion joint are whether a partial repair or the total replacement. Therefore, it is unnecessary to conduct a soundness evaluation but it is necessary to evaluate the necessity of repair.

**4.4.6 Others**

## (1) Defect types

As the other bridge accessories except for the bearing and expansion joint, there are handrail and drainage facilities. Table 4.4.11 and Table 4.4.12 show the defects of each item.

**Table 4.4.11 Defects of Handrail and Curb**

Type of handrail and curb	Defects
RC handrail, RC railing post, parapet, curb	Flaking of surface cover concrete Cracks and breakage due to vehicle collisions
Steel handrail	Corrosion of handrail and post Deformation and breakage due to vehicle collisions

**Table 4.4.12 Defects of Drainage Facility**

Part of drainage facility	Defects
Drainage basin, lid of a drainage basin	Breakage of the lid of drainage basin, Clogging
Drainage pipe	Breakage of drainage pipe at joints Corrosion of drainage pipe itself

(2) Defect causes

External force and deterioration over time mainly cause defects of handrail and curb, which can be inspected visually. Defects by external force cause cracks and deformation. Defect by deterioration over time is corrosion mainly.

On the other hand, cyclic loading transmitted from the girder and deterioration over time cause defects of drainage facilities.

(3) Soundness evaluation

The handrail and drainage facility function is relatively more straightforward than the concrete girder and steel member. Therefore, it is necessary to consider the damages on third parties. The handrail shall have sufficient function to prevent vehicle and pedestrian from falling off, and the drainage facility shall have sufficient drainage function.

## 5. BRIDGE REPAIR DESIGN

### 5.1 Repair Design Procedure

To plan a repair design, the performance of a structure should not be lowered below the expected necessary performance level during its design service life. Based on this design, the structure should be repaired.

Suppose a member of a structure is left unrepaired for a long time, although the member was judged necessary to be repaired. In that case, the deterioration of the member could proceed further to result in a larger repair work such as the exchange of the member by a new member or the total reconstruction of the bridge, as the smaller repair works could no longer satisfy the necessary performance level. It leads that not only a larger amount of cost is needed but also for a longer period, the structure cannot be utilized. Therefore, the earlier repair work in an appropriate period is indispensable based on the proper assignment of the maintenance budget. Figure 5.1.1 shows the basic idea of the proper maintenance works. Generally speaking, the deterioration of a structure is accelerated with the elapsed years. The earlier repair works could save the total cost LCC more than the later large-scale repair works after several years.

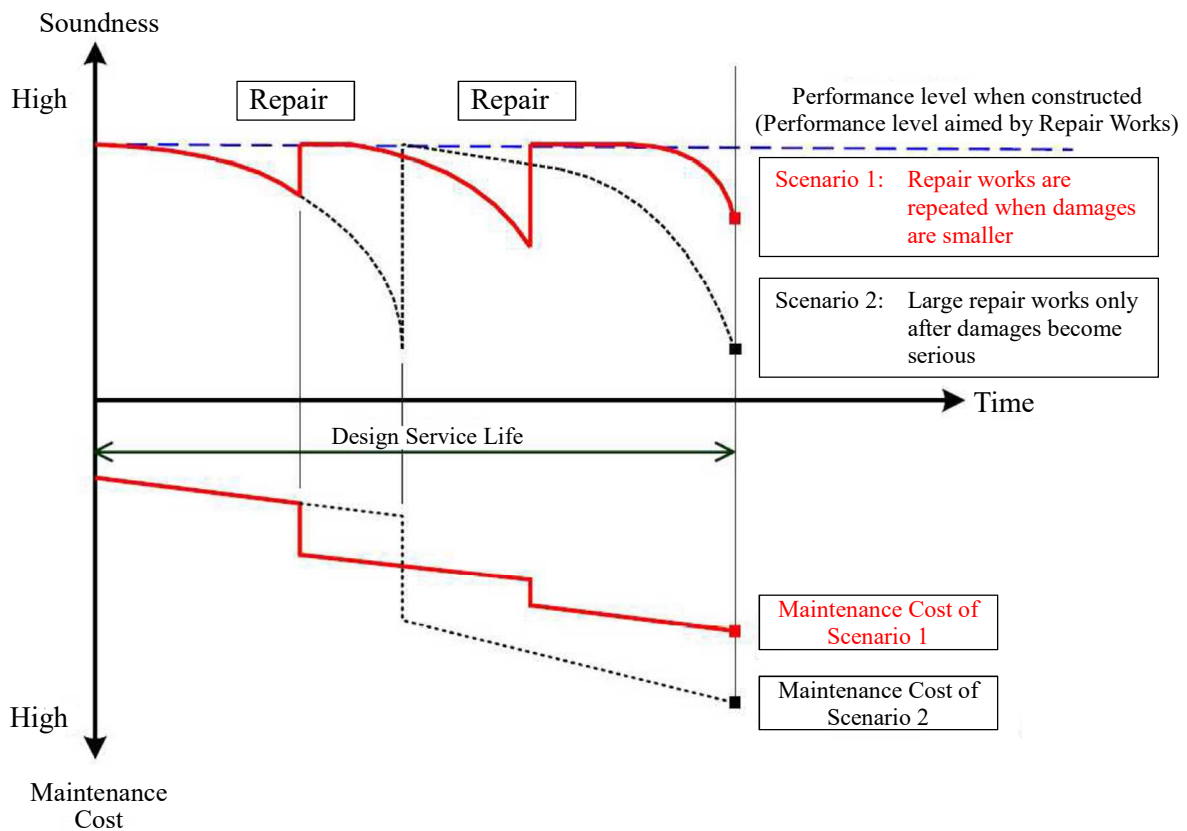
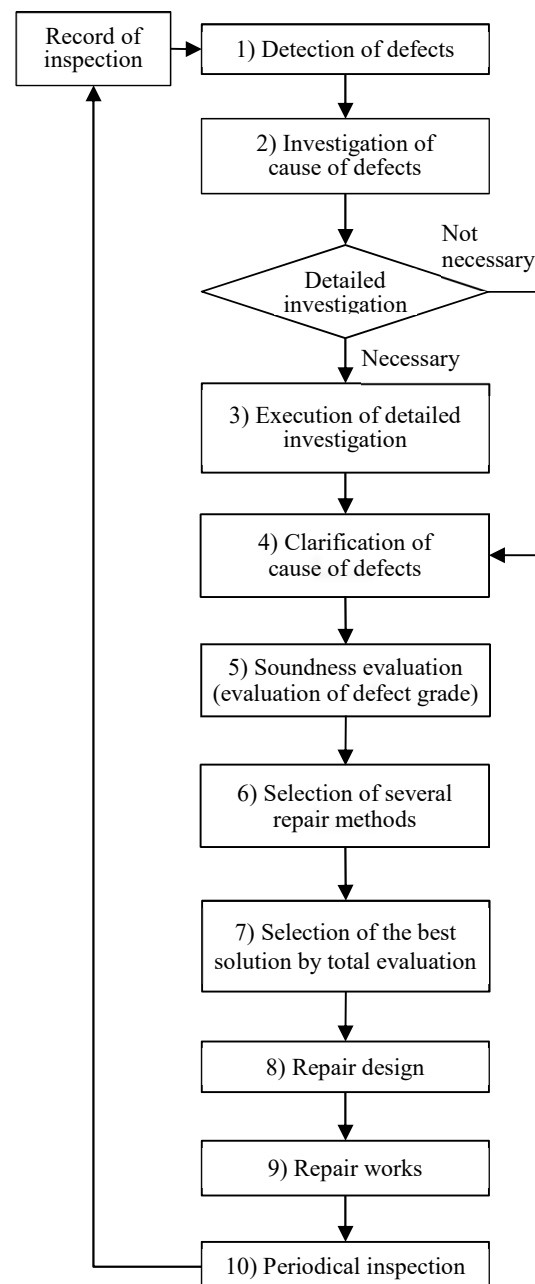


Figure 5.1.1 Basic Idea of the Proper Maintenance Works

The planning, design, and execution of the repair should follow the following procedure.

- 1) When there are structural defects, the cause of the defects needs to be investigated by the existing documents such as the construction records, the result of periodic inspections, or by the close eye inspection.
- 2) When the cause of the defects is difficult to be clarified, a detailed investigation should be executed if necessary.
- 3) Based on the result of the detailed investigation, the kind of defects, the degree and the area of defects, the cause of defects, and the deterioration mechanism should be clarified.
- 4) The soundness of the structure should be evaluated by the deterioration rating.
- 5) The repair level to achieve the level of recovery should be decided.
- 6) The applicable repair methods should be selected based on the deterioration mechanism, the necessary performance level, and the deterioration degree.
- 7) The selected repair methods should be compared to find the best solution based on the total evaluation of the importance level of the structure, the influence to the third party, the environmental condition, the remaining service life, LCC, the aimed recovery level of repair, the easiness of maintenance work after the repair.
- 8) After selecting the best repair method, the repair design, such as the construction planning, the preparation of the design drawings, the quantity survey, the cost estimate, should be performed. In the repair design, the kind of repair materials and their combination, the cross-section dimensions after the repair, the thickness of the cover materials, the construction method should be decided. The result of repair is greatly influenced by the quality of construction so that the construction plan should be carefully decided based on the construction condition, the season, and the length of period.
- 9) Based on the construction plan, the repair work should be executed. The process of construction and the result of construction should be carefully checked and inspected.
- 10) After the repair, to examine the effect of the repair, the structure needs to be periodically inspected, and the results should be kept.



**Figure 5.1.2 Repair Flow**

## 5.2 Concept for Bridge Repair

To maintain the performance level of bridges, it is necessary to repair the bridges periodically based on the observed level of deterioration such as level of defects and area scale, its future progress, the expected remaining service life, LCC calculated from the periodical inspection and the detailed investigation of the bridges.

Before the repair design, it is necessary to confirm the degree of deterioration of the defects and the kind of defects, area of defects, the cause of defects, and the mechanism of deterioration. The degree of deterioration of the defects needs to be rated and evaluated. It is crucial to select the appropriate repair method based on the total evaluation of the importance level of the structure, the influence to the third party, the environmental condition, the remaining service life, LCC, the aimed recovery level of repair, and the easiness of maintenance work after the repair.

The deterioration grade can be rated based on the progress of deterioration such as the Latent period, the progression period, the acceleration period, and the deterioration period. The grade of deterioration and its appearance of bridge deteriorations are shown in the table below.

### a) Carbonation (Neutralization of concrete)

**Table 5.2.1 Grade of Deterioration of Carbonation from its Appearance**

Grade	Definition	Appearance
Latent period	The period during which the remaining amount of concrete without carbonation is more than the limit value of concrete, below which the rebar rusting begins.	No appearance
Progression period	The period during which rebar rusting begins till the appearance of concrete cracks on the surface due to rebar rusting	No appearance
Acceleration period (earlier)	The period during which the progress of rebar rusting is accelerated due to the concrete cracks.	A few cracks due to rebar rusting appear on the surface.
Acceleration period (later)		Many cracks appear. Partial area flaking of concrete cover.
Deterioration period	The period during which the strength becomes lower due to the increase of rebar rusting.	Many places of concrete cover flaking. Larger displacement.

### b) ASR (Alkali-Silica Reaction)

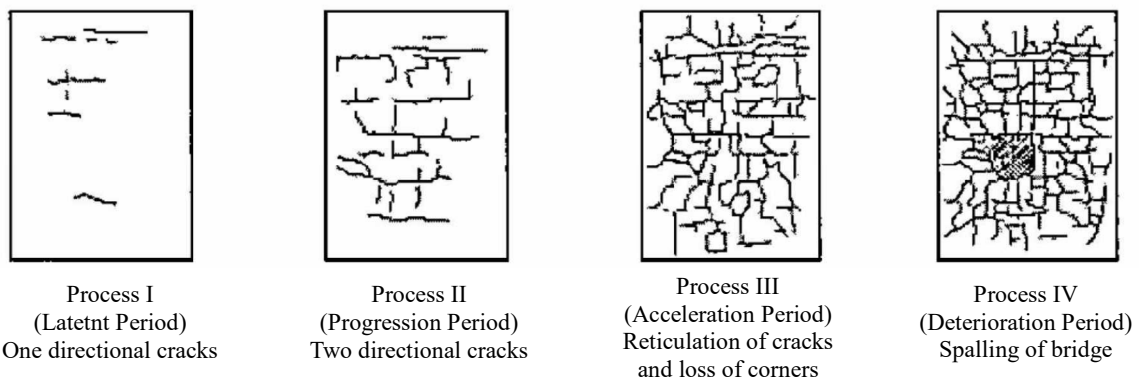
**Table 5.2.2 Grade of Deterioration of ASR from its Appearance**

Grade	Definition	Appearance
Latent period	The period during which ASR itself progresses but the volume expansion and consequent cracks do not appear yet.	No appearance
Progression period	The period during which the volume expansion progresses continuously till the appearance of concrete cracks on the surface.	<ul style="list-style-type: none"> <li>• A few cracks appear.</li> <li>• A color change (efflorescence) can be seen.</li> <li>• The silica gel exudation appears.</li> </ul>
Acceleration period	The period during which the volume expansion due to ASR appears evidently, the speed of expansion reaches its maximum, and the cracks proceed further.	Number, width and density of cracks increase significantly.
Deterioration period	The period during which the width and the density of cracks increase and the re-bar rusting proceeds. If an excessively larger expansion occurs, the yielding or the breakage of re-bars can happen, which will influence the strength of members.	Concrete cover flaking and spalling appear in some places. Larger displacement.

c) Fatigue of concrete bridge deck

**Table 5.2.3 Grade of Deterioration of Concrete Bridge Deck from its Appearance**

Deterioration process	Definition	Deciding factor of period length
Latent period (Process I)	The period when only a few transverse directional cracks along with the main rebar due to the dry shrinkage or the loading, can be confirmed. Sometimes these transverse directional cracks proceed due to the dry shrinkage or the temperature variation of the main girders, depending on the restriction conditions of the main girders.	<ul style="list-style-type: none"> <li>- Applied design standard</li> <li>Bridge deck thickness</li> <li>Amount of transverse reinforcement</li> <li>Span length of bridge deck</li> <li>- Construction</li> <li>Dry shrinkage</li> </ul>
Progression period (Process II)	The cracks due to main girder bending along the main reinforcement proceed further together with the progress of the cracks along with the transverse rebar to form the grid shape cracks. The density of cracks increases evidently, but the two-directional continuity of the bridge deck is not lost yet.	<ul style="list-style-type: none"> <li>- Condition of utilization</li> <li>Traffic amount</li> <li>Vehicle weight (Axle weight)</li> <li>Vehicle position</li> </ul>
Acceleration period (Process III)	The reticulation of cracks proceeds further, and the repetition of opening and closing of cracks begins. The grinding of each other of crack surfaces also begins. If the cracks are widened or the corners of cracks are ground, the connection between the concrete segments cannot be expected, and the strength against the punching shear is decreased rapidly.	<p>In addition to the above items,</p> <ul style="list-style-type: none"> <li>- Environmental condition</li> <li>Influence of seepage water</li> <li>- Countermeasures adopted</li> <li>Existence of waterproof layer</li> <li>Repaired or retrofitted before</li> </ul>
Deterioration period (Process IV)	Cracks penetrate through the bridge deck, and the continuity of the deck is lost. Beam members encircled by the penetrated cracks resist the vehicle wheel load as a beam. The widths of penetrated cracks, the concrete strength, and the amount of rebars influence the final strength. The water seepage and the rusting of re-bars need to be avoided.	All of the above items.



**Figure 5.2.1 Progress of Cracks on bottom of Bridge Deck**

The damage of the concrete bridge deck, whether it is from the fatigue damage or the other mechanism, cannot be judged only from the grade of outer appearances. It should be appropriately judged based on the investigation of the shrinkage cracks from the earlier stage of construction, carbonation, combined deterioration.

When the repair methods are selected, the deterioration mechanism, the expected repair performance level, the process of deterioration, the kind of defects should be clarified. It is crucial to select the methods according to the kind of defects.

For the case of bridge repair, the major deterioration mechanism, the expected repair performance level, the deterioration process can be divided into the following categories.

- Deterioration mechanism:
  - a) carbonation,
  - b) alkali-silica reaction,
  - c) deterioration of corrosion resistant system (painting)
  
- Expected repair performance level:
  - a) shut out of deterioration factor,
  - b) suppression of deterioration speed,
  - c) removal of deterioration factor,
  - d) improvement of strength or deformation performance.
  
- Process of deterioration:
  - I) Latent period,
  - II) Progression period,
  - III) Acceleration period,
  - IV) Deterioration period

Selected repair methods corresponding to the major deterioration mechanism are shown in the tables below.

Table 5.2.4 Selection of Repair Methods against Carbonation

Expected performance level	Latent period		Progression period to acceleration period(earlier)		Acceleration period(later)		Deterioration period	
	Major defects	- no surface change - no color change	Major defects	- a small number of rust fluid - a few cracks	Major defects	- a large number of rust fluid - many cracks - partial flaking and spalling	Major defects	- a large number of rust fluid - many cracks - extensive flaking and spalling - displacement and deformation
	Applicability	Method	Applicability	Method	Applicability	Method	Applicability	Method
Shutting out of deterioration factor	good	Surface coating (prevention of entrance of CO <sub>2</sub> )	good	Surface coating (prevention of entrance of deterioration factors, such as CO <sub>2</sub> , H <sub>2</sub> O, O <sub>2</sub> )	poor	Surface coating (prevention of entrance of deterioration factors, such as CO <sub>2</sub> , H <sub>2</sub> O, O <sub>2</sub> )	poor	Surface coating (prevention of spalling)
			good	Crack repair (prevention of entrance of deterioration factors, such as CO <sub>2</sub> , H <sub>2</sub> O, O <sub>2</sub> )	poor	Crack repair (prevention of entrance of deterioration factors, such as CO <sub>2</sub> , H <sub>2</sub> O, O <sub>2</sub> )	poor	Crack repair (prevention of entrance of deterioration factors, such as CO <sub>2</sub> , H <sub>2</sub> O, O <sub>2</sub> )
Suppression of deterioration speed	good	Application of barrier penetrant (preventive maintenance: protection of passive layers of re-bars.)	good	Application of barrier penetrant (reformation of passive layers of re-bars against the alkali concentration below the limit value.)	poor	Application of barrier penetrant (reformation of passive layers of re-bars against the alkali concentration below the limit value.)	poor	Application of barrier penetrant (reformation of passive layers of re-bars against the alkali concentration below the limit value.)
Removal of deterioration factor			fair	Sectional repair (re-alkalization of low alkalinized parts below the limit value.)	good	Sectional repair (re-alkalization of low alkalinized parts below the limit value.)	good	Sectional repair (re-alkalization of low alkalinized parts below the limit value.)
Improvement of strength or deformation performance							good	Reinforcement (FRP lining, Steel plate lining)
							fair	Concrete replacement (concrete of deteriorated member is replaced by new concrete.)
Selection reason of method. (Expected performance level)	No cracks are observed yet. Alkalinity near re-bars lowers close to the limit value of corrosion occurrence. It is essential to primarily consider the countermeasures to shut out the deterioration factors or control the deterioration speed.		In this period, corrosions of re-bars begin and result in corrosion cracks finally. It is necessary to shut out the deterioration factors of re-bar corrosions and to reduce the corrosion speed. The deteriorated parts where the re-bar corrosions proceeded and cracks appeared may need to be repaired.		In this period, the corrosions proceed rapidly due to the corrosion crack openings. Flaked and floating concrete needs to be removed, and the countermeasures need to be investigated to prevent the spalling of concrete pieces, which may fall on passers-by.		In this period, the member strength lowering due to the corrosion and the consequent sectional area loss of rebars is feared. The repair of damaged sections and the countermeasures against spalling is needed. The reinforcement of members may be needed to restore the member's strengths.	

Good: the method which needs to be adopted mainly.

Fair: the second mainly adopted method.

Poor: the method, the applicability of which needs to be investigated based on the deterioration of structures.

**Table 5.2.5 Selection of Repair Methods against ASR (Alkali-Silica Reaction)**

Expected performance level	Latent period		Progression period		Acceleration period		Deterioration period	
	Major defects	- no surface change - no color change	Major defects	- a few cracks - color change (brown) - The silica gel exudation appears.	Major defects	- many cracks	Major defects	- many cracks - partial flaking and spalling - displacement and deformation
	Applicability	Method	Applicability	Method	Applicability	Method	Applicability	Method
Shutting out of deterioration factor	good	Surface coating (prevention of entrance of water.)	good	Surface coating (prevention of entrance of water.)	good	Surface coating (prevention of entrance of water and spalling of concrete pieces.)	fair	Surface coating (prevention of entrance of water and spalling of concrete pieces.)
			good	Crack repair (prevention of entrance of deterioration factors.)	good	Crack repair (prevention of entrance of deterioration factors.)	fair	Crack repair (prevention of entrance of deterioration factors.)
Suppression of deterioration speed	fair	Constraint (lining by FRP, Steel plate, PC concrete)	fair	Constraint (lining by FRP, Steel plate, PC concrete)	fair	Constraint (lining by FRP, Steel plate, PC concrete)		
Removal of deterioration factor	good	Application of penetrant (impregnation which enables water evaporation from inside of concrete.)	good	Application of penetrant (impregnation which enables water evaporation from inside of concrete.)	good	Application of penetrant (impregnation which enables water evaporation from inside of concrete.)	fair	Sectional repair (removal of deteriorated parts and corrosion protection of re-bars.)
Improvement of strength or deformation performance.							good	Reinforcement (FRP lining, Steel plate lining)
							fair	Concrete replacement (concrete of deteriorated member is replaced by new concrete)
Selection reason of method. (Expected performance level)	No cracks are observed yet. The remaining expansion amount is the largest. In this stage, applying a surface coating or impregnation of water repellent penetrant should be considered. Crack followability needs to be compared to select the coating materials, water impervious quality, vapor permeability, and crack followability.		In this period, cracks appear and the speed of expansion is larger. The crack repair method in addition to the surface coating and the penetrant is generally adopted. If the expansion is larger, the constraint method can be adopted. The necessary performance of the reinforcing materials needs to satisfy the applicability to the concrete structures.		In this period, cracks appear and the speed of expansion is larger. The crack repair method in addition to the surface coating and the penetrant is generally adopted. If the expansion is larger, the constraint method can be adopted. The necessary performance of the reinforcing materials needs to satisfy the applicability to the concrete structures.		In this period, the expansion is in its final stage and smaller. When the strength or the deformation performance seems to be decreased, the constraint reinforcement method is recommended. If this is not feared, then the surface coating or the application of penetrant should be adopted.	

Good: the method which needs to be adopted mainly.

Fair: the second mainly adopted method.

Poor: the method, the applicability of which needs to be investigated based on the deterioration of structures.

**Table 5.2.6 Outline of Major Repair Methods**

Repair method		Outline
Crack repair	Crack injection method	Injection materials are injected into cracks with a pressure lower than 0.4MPa and with low speed using the special tools equipped with rubber springs or other springs.
	Crack filling method	The concrete surface is grooved along cracks, and the groove is filled with repair materials. This method is utilized for relatively larger cracks whose width is more than 0.5mm.
Surface coating		The concrete surface is covered with paintings or other materials to form a new protection layer to prevent the re-bar deterioration factors into the inside and increase the concrete structure's durability.
Application of impregnating material		The impregnating materials coat the concrete surface to prevent the re-bar deteriorating factors and suppress the re-bar deterioration.
Cross-sectional repair	Plastering method	When the repair area is comparatively small, this method is adopted. Plaster trowels apply the epoxy resin mortar or the polymer cement mortar.
	Filling method	When the repair area is large, this method is adopted. A formwork is constructed, and the fresh concrete with larger fluidity is filled.
	Spraying method	When the repair area is comparatively large, this method is adopted. There are two methods. One is to spray the premixed repair material directly on the repair surfaces, which is the wet spray method. The other is to pump the powder material and the water or the water with additives separately and mix them just in front of the spray nozzle. Then the mixture is sprayed on the surfaces, which is the dry spray method.
Partial re-concreting		When the methods above are judged insufficient to restore the necessary level of strength or durability, the deteriorated concrete parts should be removed and re-concreted.

**Table 5.2.7 Repair and Reinforcing Methods of Fatigued RC Decks and Expected Effects**

Expected effects	Methods
Improvement of appearance	Surface coating
Improvement of fatigue durability by removing water influences	Addition of deck waterproofing
Suppression of crack opening to improve fatigue durability	FRP bonding method, the introduction of prestressing
Restoration of sectional rigidity by adding some materials on the tension side of members	Steel plate bonding on the bottom of the bridge deck, an increase of sectional area, the addition of girders.
Improvement of fatigue durability by improving the shear rigidity of cross-sections in compression	Bridge deck upper side thickness increase

### 5.3 Concrete structure

#### 5.3.1 Outline

The repair methods of concrete structures need to be selected after the investigation of the combination of methods, the effects of the repair, the economy, the workability based on the cause of damages, the thorough understanding of the deterioration mechanism, the degree, and the area of damages, the deterioration process. The selection of repair methods may vary according to the places and the kind of members. The typical repair methods are shown in Table 5.3.1.

**Table 5.3.1 Typical Repair Methods of Concrete Structures**

Places and members	Typical repair methods
PC or RC superstructure	<ul style="list-style-type: none"> <li>- Crack repair (crack injection method, crack filling method)</li> <li>- Sectional repair (Plastering method, Spraying method, Filling method)</li> <li>- Surface treatment (Surface coating, Application of impregnating material)</li> <li>- Re-concreting</li> <li>- Peeling prevention method</li> <li>- Regrouting method</li> <li>- Protection of PC anchors</li> <li>- Re-prestressing method</li> <li>- Waterproofing method</li> </ul>
RC substructure	<ul style="list-style-type: none"> <li>- Crack repair (Crack injection method, Crack filling method)</li> <li>- Cross-sectional repair (Plastering method, Filling method, Spraying method)</li> <li>- Re-concreting</li> <li>- Surface treatment (Surface coating, Application of impregnating material)</li> <li>- Peeling prevention method</li> </ul>

### 5.3.2 Selection of Repair Methods

(1) Selection of repair methods according to kind of damages

Figure 5.3.1 and Table 5.3.2 show the selection flow of the repair method of concrete members

#### Selection of concrete member repair methods

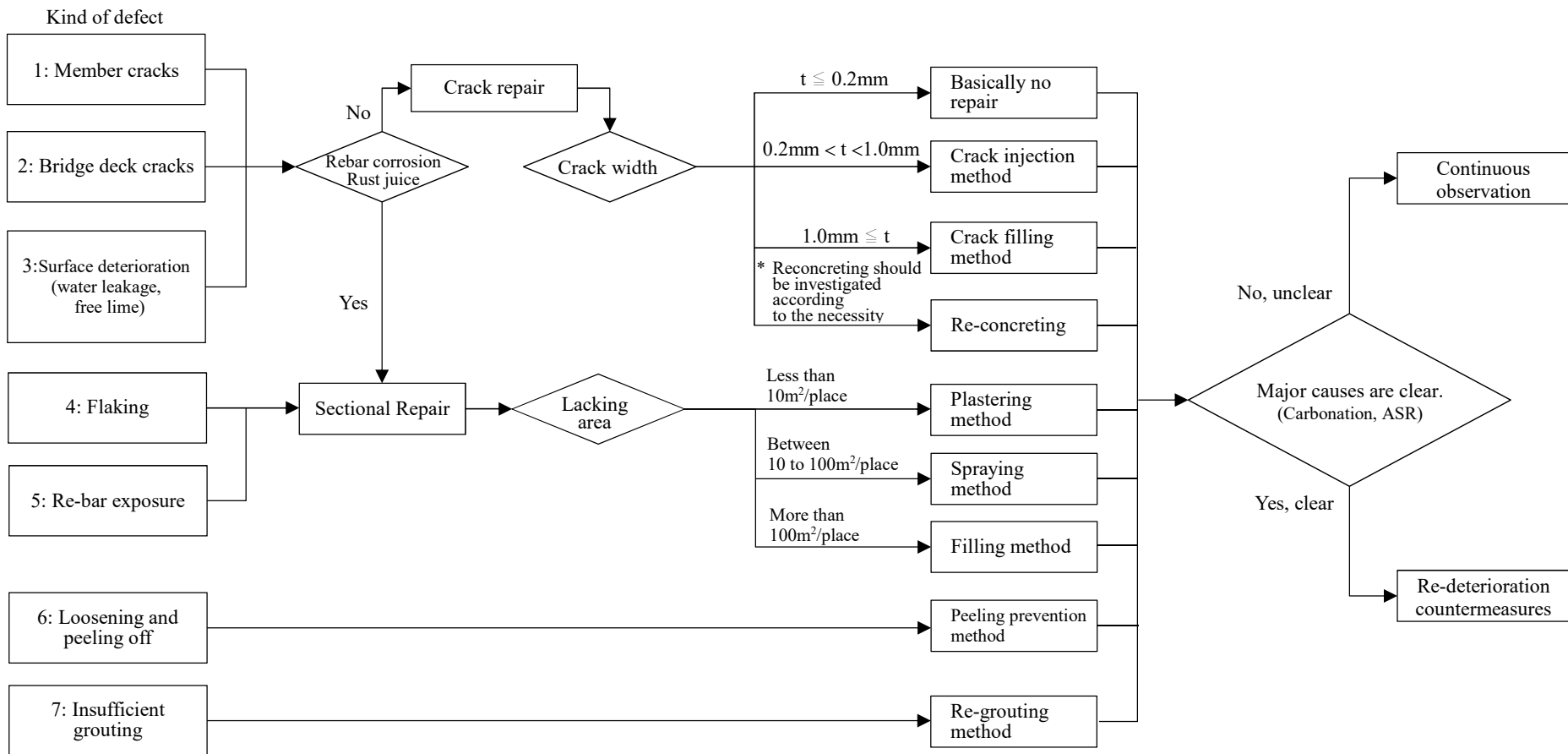


Figure 5.3.1 Selection Flow of Repair Methods of Concrete Members according to Kind of Defects

Table 5.3.2 Major Defects and their Causes of Concrete Members and Possible Repair Methods for Comparison

Defects	Major causes of deteriorations		Repair methods				
			Crack repair	Sectional repair	Partial Re-concreting	Surface coating	Waterproofing
Cracks	External forces	Cyclic loading	Suitable	Suitable		Suitable	
		Continuous loading	Effective	Suitable		Suitable	
		Collisions	Effective	Suitable		Suitable	
	Environment	Dry shrinkage, thermal changes	Effective	Suitable		Suitable	
	Material deterioration	ASR	Suitable	Effective		Suitable	
		Carbonation		Effective		Suitable	
	Construction quality	Poor quality of construction	Effective	Suitable			
		Poor waterproofing or poor drainage	Effective	Suitable	Suitable	Suitable	Effective
Concrete peeling and re-bar exposure	External forces	Cyclic loading		Effective	Suitable	Suitable	
		Collisions		Effective	Suitable	Suitable	
	Environment	Dry shrinkage, thermal changes		Effective	Suitable	Suitable	
	Material deterioration	ASR		Effective	Suitable	Suitable	
		Carbonation		Effective	Suitable	Effective	
	Construction quality	Poor quality of construction		Effective	Suitable	Suitable	
		Poor waterproofing or poor drainage		Effective	Suitable		Effective
	Free lime, water leakage	Environment	Dry shrinkage, thermal changes	Suitable	Effective	Suitable	Suitable
Material deterioration		ASR	Suitable	Effective	Suitable	Suitable	Effective
		Carbonation	Suitable	Effective	Suitable	Effective	Effective
Construction quality		Poor quality of construction	Suitable	Effective	Suitable	Suitable	Effective
		Poor waterproofing or poor drainage	Suitable	Effective	Suitable		Effective
Spalling	External forces	Cyclic loading			Effective	Suitable	
		Collisions			Effective	Suitable	
	Material deterioration	ASR			Effective	Suitable	
		Carbonation			Effective	Effective	
	Construction quality	Poor quality of construction			Effective	Suitable	
		Poor waterproofing or poor drainage			Effective		Effective
Surface deterioration (Color change)	Material deterioration	ASR				Suitable	
		Carbonation				Effective	
	Construction quality	Poor quality of construction				Suitable	
		Poor waterproofing or poor drainage					Effective

(2) Selection of repair methods of PC and RC superstructures

Figure 5.3.2 and Figure 5.3.3 show the selection flow of the repair method of PC and RC superstructures and RC substructures.

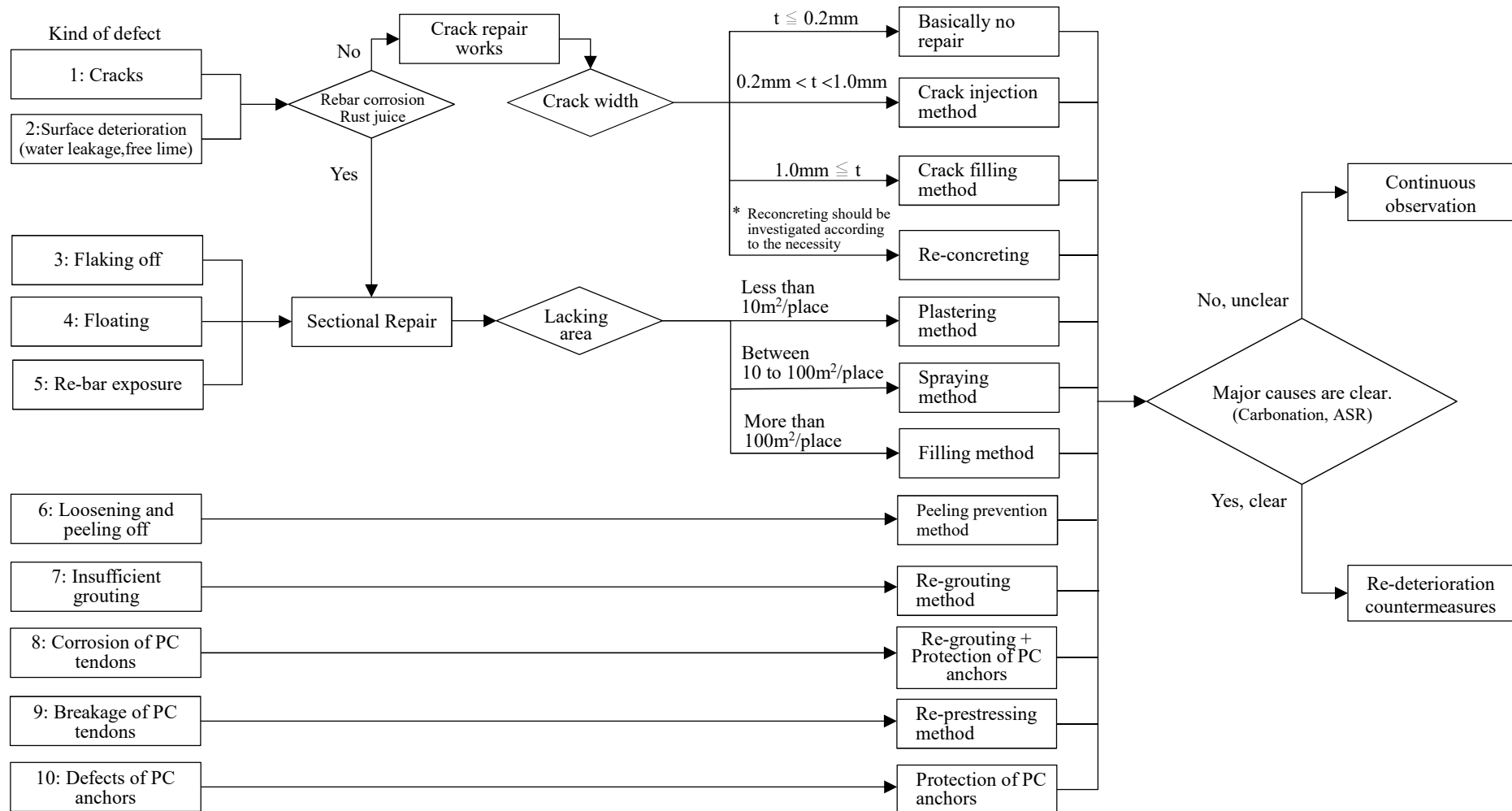


Figure 5.3.2 Major Defects of PC, RC Superstructures and a Flow to Select Repair Methods

(3) Selection of repair methods of RC substructures

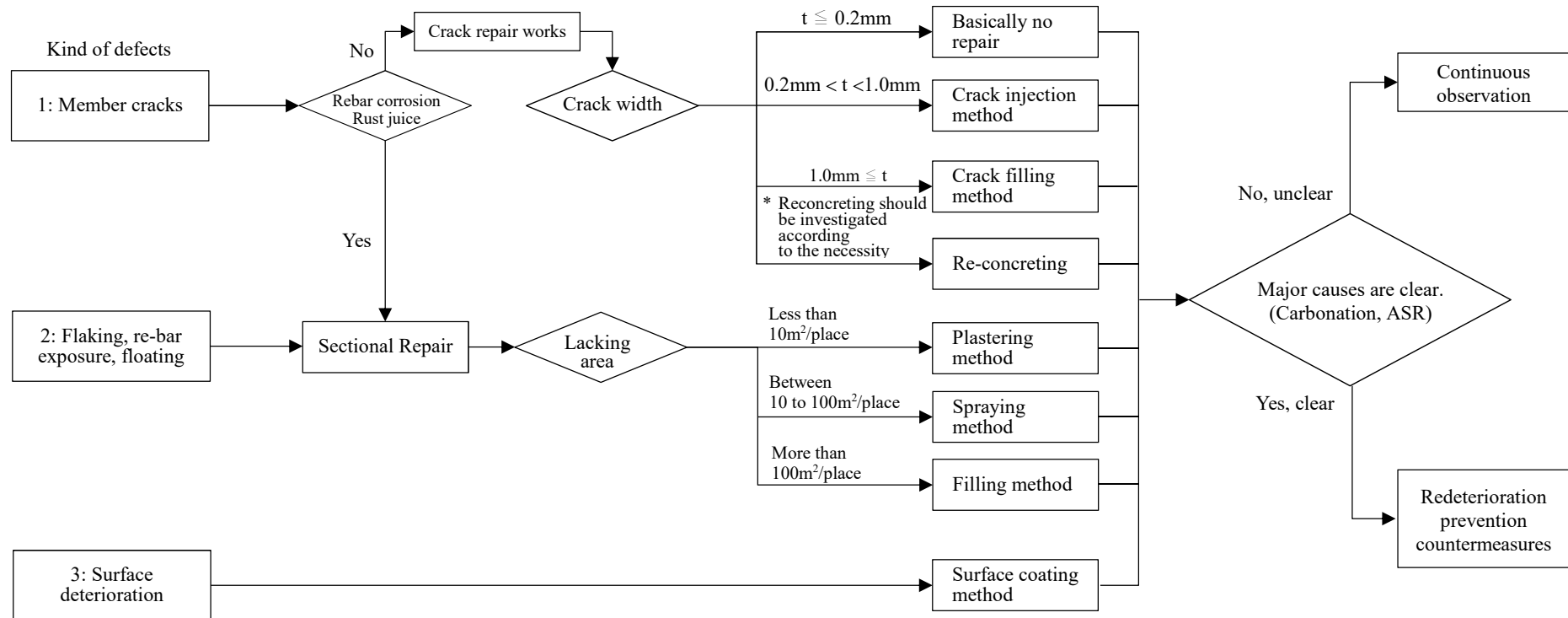


Figure 5.3.3 Major Defects of RC Substructures and a Flow to Select Repair Methods

(4) Outline and Selection of repair methods of the bridge deck

a) Outline

The repair method of the bridge deck is selected using Figure 5.3.1. However, regarding the damage and defect of the bridge deck caused by fatigue, it is necessary to study the methods shown in Table 5.3.3.

**Table 5.3.3 List of Repair Methods**

Methods	Applicable repair methods	Principle of repair
Repair methods	1) Surface waterproofing	- Removal of source of seepage water - Road surface water; Investigation of repair of drainages
	2) Surface cover method - Surface cover method by rustproof treatment or painting - Surface cover method to prevent peeling off (FRP wrapping)	- Prevention of entrance of chloride ion, water, and oxygen after the repair
	3) Crack repair method - Low-pressure automatic injection of epoxy resin - About 10mm width U-shaped or V-shaped grooves are formed along concrete cracks. Then the repair materials are filled in the grooves.	- Unity of bridge deck - Prevention of water and oxygen after the repair
	4) Sectional repair - Sectional repair by mortar filling	- Removal of deteriorated concrete - Prevention of entrance of chloride ion, water, and oxygen after the repair
Reinforcing methods	5) Bridge deck upper surface thickness increasing method - After removal of pavement, the upper surface is scraped. Re-bar reinforcements are added if necessary, and the ultrarapid hardening concrete is applied to increase the thickness.	- The shear strength and the bending strength are improved by increasing the area of resisting cross-section - The longitudinal gradient will be changed.
	6) Bridge deck under surface thickness increasing method - After the surface treatment of the under the surface, reinforcing bars are added, and the polymer cement mortar is sprayed or plastered to increase the thickness.	- The shear strength and the bending strength are improved by increasing the area of resisting cross-section - Bridge deck surface waterproofing needs to be added at the same time
	7) Carbon fiber sheet bonding method - After the surface treatment of the under the surface, the carbon fiber sheet is bonded on the surface.	- Bonding carbon fiber sheets on the bridge deck improves the shear strength and the bending strength - Bridge deck surface waterproofing needs to be added at the same time

As the bridge deck reinforcement method, the steel plate bonding method is also applied. The principle of this method is the same as 8) Carbon fiber sheet bonding method.

b) Selection of repair and reinforcing methods according to a degree of defects

The most appropriate repair methods for the bridge deck fatigue should be selected by comparing repair effects, workability, durability, and LCC from the methods shown in Table 5.3.4, in which the methods are classified according to the deterioration grade of the bridge deck.

**Table 5.3.4 List of Repair and Reinforcing Methods**

Deterioration grade of bridge deck from its appearance	Example of standard methods
I) Latent period	Waterproofing of bridge deck surface*
II) Progression period	Waterproofing of bridge deck surface, Steel plate bonding, FRP sheet bonding, Upper surface thickness increase, Under surface thickness increase, Additional longitudinal girder
III) Acceleration period with influence of seepage water	Waterproofing of bridge deck surface, Steel plate bonding, Upper surface thickness increase
IV) Acceleration period without influence of seepage water	Waterproofing of bridge deck surface, Steel plate bonding, Upper surface thickness increase, Additional longitudinal girder
V) Deterioration period	Restriction of service, Replacement

\*preventive method

The damage grade based on damage conditions of the bridge deck and necessary countermeasures, selection of repair methods and reinforcing methods are shown in Table 5.3.5 and Table 5.3.6.

**Table 5.3.5 Damage Conditions and Necessary Countermeasures of Bridge Deck Slab**

Category	Damage conditions	Necessary countermeasures
A	No damage	
B	[Crack intervals and characteristics] The directions of cracks are mainly only one direction and the smallest interval is about more than 1.0m. [Crack widths] The largest crack width is less than 0.05mm. (hair cracks)	Continuous observation Only hair cracks appear on the surface.
C	[Crack intervals and characteristics] The directions of cracks are mainly one direction and transverse directions are less. No grid formation of cracks. The crack intervals are between 0.5m to 1.0m. [Crack widths] The crack widths are mainly less than 0.1mm, but some exceed 0.1mm.	Continuous observation Although cracks are observed, no major changes of appearance
	[Crack intervals and characteristics] The crack intervals are about 0.5m. Slightly before the formation of grid cracks. [Crack widths] The crack widths are mainly less than 0.2mm, but some exceed 0.2mm.	Crack repair method
D	[Crack intervals and characteristics] The crack intervals are between 0.2m to 0.5m. The formation of grid cracks. [Crack widths] More than 0.2mm cracks are relatively evident and partial corner losses can be seen.	Crack repair method + sectional repair Carbon fiber sheet bonding method
E	[Crack intervals and characteristics] The crack intervals are less than 0.2m. The formation of grid cracks. [Crack widths] More than 0.2mm cracks are evident and continuous corner losses are observed.	Reinforcing method Carbon fiber sheet bonding method, Bridge deck upper surface thickness increasing method, Bridge deck under surface thickness increasing method, Method of Additional longitudinal girder, Light precast concrete bridge deck method

**Table 5.3.6 Repair and Reinforcing Methods Corresponding to Category**

Category	Repair and reinforcing methods						
	Surface water-proofing	Surface cover method	Crack repair method	Sectional repair	Bridge deck upper surface thickness increasing method	Bridge deck under surface thickness increasing method	Carbon fiber sheet bonding method
B	Effective	Effective	Effective	Effective			
C				Suitable	Suitable	Suitable	Effective
D					Effective	Effective	
E							Suitable

## 5.4 Steel Structure

### 5.4.1 Outline

It is necessary to understand the cause of steel structure's defects when the repair methods are selected. The effects, workability, and economy need to be investigated. There are examples of reoccurrence of defects within a short time due to selecting the inappropriate repair method which does not suit the cause of defects. Therefore the understanding of the cause is essential. The progress of fatigue cracks in the main members needs to be monitored closely and carefully. Otherwise, the bridge may collapse finally.

### 5.4.2 Selection of Repair Method

#### (1) Selection of repair method

The repair methods of steel structures are shown below. Figure 5.4.1 shows the selection flow of repair methods.

- |                       |                  |                      |
|-----------------------|------------------|----------------------|
| 1) Cover plate method | 4) Waterproofing | 6) Repair by welding |
| 2) Member replacement | 5) Stop hole     | 7) Bolt replacement  |
| 3) Repainting         |                  |                      |

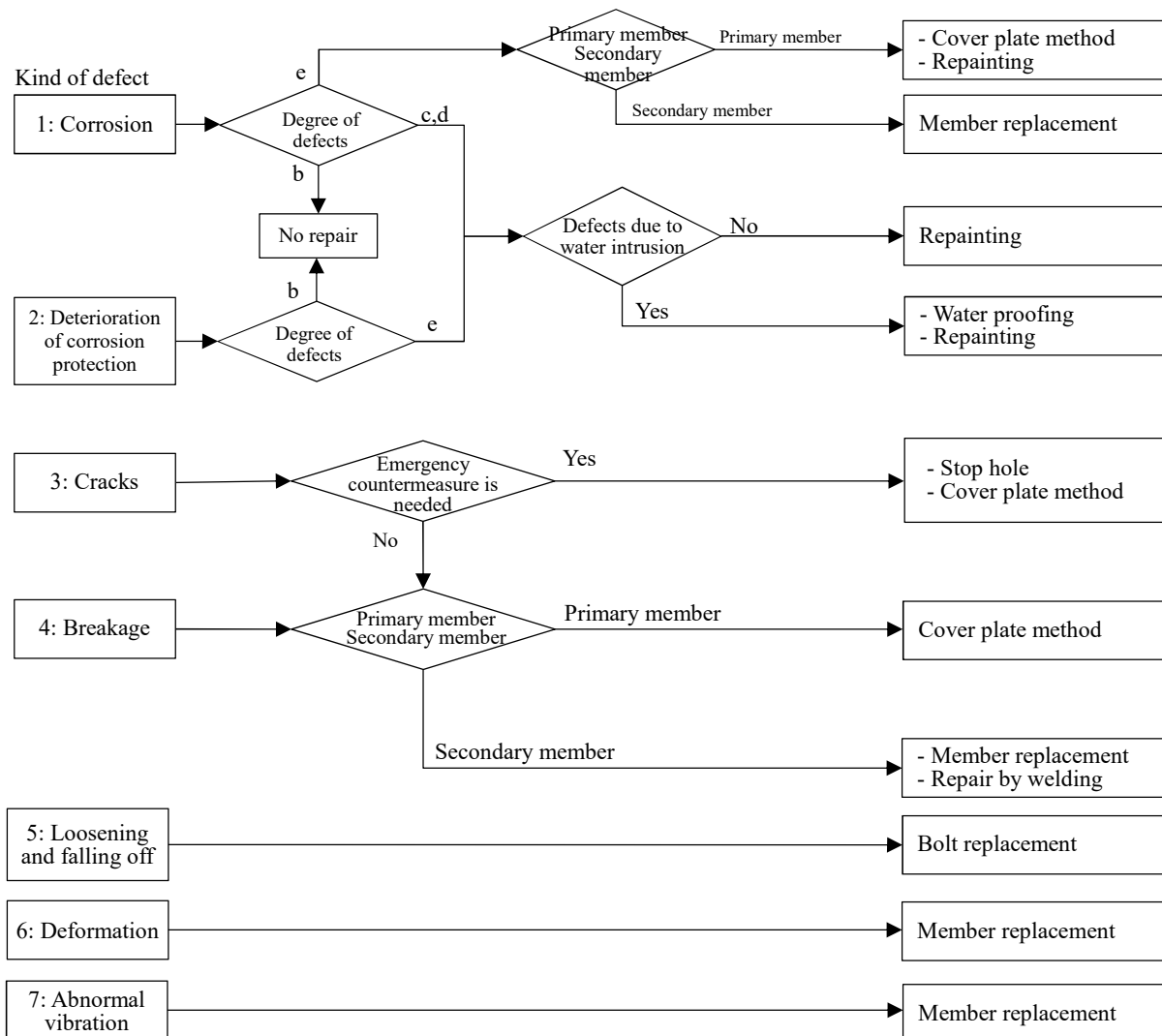


Figure 5.4.1 Selection Flow of Repair Methods of Steel Structure according to Kind of Defects

※ Reference: Degree of Defects

– Degree of defects

Degree	Depth and area	
	Depth of defects	Area of defects
a	No defects	
b	Shallow	Small
c	Shallow	Large
d	Deep	Small
e	Deep	Large

– Definition of depth and area

a) Depth of defects

Description	Explanation
Large	Remarkable swelling of steel surfaces or the evident thickness reduction of steel plate can be confirmed by eye inspection.
Small	Rusts remain only on the surfaces, and the evident thickness reduction cannot be confirmed by eye inspection.

Note) Irrespective of rust conditions, i.e., exfoliation corrosion or pitting corrosion, the condition is judged from the degree of thickness reduction.

b) Area of defects

Description	Explanation
Large	The inspected area is covered with rust. Several larger areas of rust-covered places can be confirmed inside of the inspected area.
Small	The area of defects is small and limited.

(2) Judgement of countermeasures

The judgement of countermeasures for the condition of defects should be decided according to the places and members of the structure. The importance of members, the progress of defects, the environmental conditions should be investigated and evaluated. Afterward, the judgement should be decided. The defect condition at the site, the understanding of structural characteristics, the adopted materials to the bridge, and the investigation of the design documents are needed.

Generally speaking, the necessary information is as follows;

- Structural form, characteristics, traffic amount of trucks, surrounding environment
- Year of design, applied design standard, year of construction, repair and reinforcement records, disaster-damaged history

The judgement of countermeasures against the defects is shown in Table 5.4.1 to Table 5.4.5.

**Table 5.4.1 Judgement of Countermeasures against Corrosion**

Category	Explanation	Comment
A	Repair works is unnecessary.	
B	Normal maintenance works can repair this defect.	Overall defects are not confirmed, but partial small defects or scratches with rusts are found. When the scale of defects is smaller, or defects are found in easily accessible places, these defects should be repaired during the normal maintenance works.
C, D	A detailed investigation is needed.	There might be a case in which only one bridge largely deteriorates among other same type bridges constructed in the same year and on the same route. When the cause of this deterioration cannot be clarified through the general investigation of the typical damage causes, a detailed investigation should be performed to clarify the deterioration speed and the cause of damages.
E	An emergency countermeasure is needed for the safety of the bridge structure.	When the web plates at the girder end of plate girder bridges are severely corroded and suffer sectional area losses, the strength of the members can be decreased considerably. In these situations, the necessity of the emergency countermeasures can be judged from the observation.

**Table 5.4.2 Judgement of Countermeasures against Deterioration of Corrosion Protection**

Category	Explanation	Comment
A	Repair works is unnecessary.	
C, D	Normal maintenance works can repair this defect.	Overall defects are not confirmed, but partial small defects or scratches with paint peeling or rusts are found. When the scale of defects is smaller, or defects are found in easily accessible places, these defects should be repaired during the normal maintenance works.
E	A detailed investigation and emergency countermeasure are needed for the safety of the bridge structure.	A detailed investigation should be performed to clarify the cause of damages in case of the following condition; 1) when a large scale surface floating or flaking is observed and a rapid paint flaking off is feared due to the poor construction or inappropriate selection of the combination of painting materials, 2) when the abnormal surface color change is observed, 3) when the inappropriate selection of painting materials for the environment is suspected, 4) when inappropriate materials or the influence of fire are suspected

**Table 5.4.3 Judgement of Countermeasures against Cracks**

Category	Explanation	Comment
A	Repair works is unnecessary.	
C	A detailed investigation is needed.	<ul style="list-style-type: none"> <li>• For investigating the crack causes and the health condition of the members with cracks, it is necessary to evaluate; 1) surface crack length, 2) crack width, 3) depth, 4) structural characteristics of the place of cracks, 5) condition of the steel materials such as internal defects, kind of welding, combination of plates, and kind of grooves, 6) stress level. Therefore, it is necessary to conduct a detailed investigation except for cases in which the cause of cracks and the degree of progress are easily understood.</li> <li>• When it is difficult to judge whether the paint cracks are due to the fatigue cracks, it is recommended to perform a detailed investigation. Because if it is due to fatigue cracks, the progress and the consequent failure can be suspected.</li> </ul>
E	An emergency countermeasure is needed for the safety of the bridge structure.	When a fatigue crack reaches a web plate of the main girder, and the structural stability or safety is feared due to the rapid growth of the crack, an emergency countermeasure should be adopted.

**Table 5.4.4 Judgement of Countermeasures against Bolt Loosening or Falling off**

Category	Explanation	Comment
A	Repair works is unnecessary.	
C	A detailed investigation is needed.	When bolts fall off, and the same lot of bolts or other bolts manufactured simultaneously are feared to fall off, and the consequent delayed failure is suspected, a detailed investigation may be needed.
E	An emergency countermeasure is needed for the safety of the bridge structure.	When many bolts fall off, the friction bonding is insufficient, and the structural stability is lost, an emergency countermeasure should be adopted.

**Table 5.4.5 Judgement of Countermeasures against Breakage**

Category	Explanation	Comment
A	Repair works is unnecessary.	
E	An emergency countermeasure is needed for the safety of the bridge structure.	Generally speaking, it is often judged that the countermeasure to stop the progress or the repair is needed irrespective of the degree of the fatigue cracks.

Table 5.4.6 Major Defects, and Causes, Repair Methods of Steel Structures to Select Repair Methods.

Defects	Causes of defects		Repair methods					
			Repair by welding*2	Stop hole	Cover plate method	Member (Bolt) replacement	Repainting	Waterproofing
Corrosion	Material deterioration	Poor quality			Suitable	Suitable	Effective	
	Manufacturing and construction	Manufacturing and construction failure			Suitable	Suitable	Effective	
		Insufficient waterproofing				Suitable	Suitable	Effective
	Structure	Defective structure type and its shape*1						
Cracks	External force	Cyclic loading	Effective	Suitable	Effective	Suitable		
		Collisions	Effective		Effective	Suitable		
	Material deterioration	Poor quality			Suitable	Suitable		
	Manufacturing and construction	Manufacturing and construction failure	Effective		Suitable	Suitable		
	Structure	Defective structure type and its shape*1						
Loosening and falling off	External force	Cyclic loading				Effective		
		Collisions				Effective		
	Material deterioration	Poor quality				Effective		
	Manufacturing and construction	Manufacturing and construction failure				Effective		
	Structure	Defective structure type and its shape*1						
Breakage	External force	Cyclic loading	Suitable		Suitable	Suitable		
		Collisions	Suitable		Suitable	Effective		
	Material deterioration	Poor quality			Suitable	Effective		
	Manufacturing and construction	Manufacturing and construction failure	Suitable		Suitable	Suitable		
	Structure	Defective structure type and its shape*1						
Deterioration of corrosion protection performance	Material deterioration	Poor quality					Effective	
	Manufacturing and construction	Manufacturing and construction failure					Effective	
		Insufficient waterproofing					Effective	Effective
	Structure	Defective structure type and its shape*1						
Deformation	External force	Cyclic loading*1				Suitable		
		Collisions*1				Effective		
	Manufacturing and construction	Manufacturing and construction failure*1				Suitable		
	Structure	Defective structure type and its shape*1						
Abnormal vibration	External force	Cyclic loading*1				Suitable		
	Manufacturing and construction	Manufacturing and construction failure*1				Suitable		
	Structure	Defective structure type and its shape*1						

\*1: Reinforcement according to causes is needed. \*2: Only for secondary members

## 5.5 Foundation

### 5.5.1 Outline

It is necessary to understand the cause of defects of foundations when the methods of repair are selected. The effects of countermeasures, workability, and economy including LCC needs to be investigated. However, the stability of bridges influences the damage and defect of the foundation. Therefore, if settlements, movements, inclinations of foundations are found, the countermeasures including the reconstruction of the whole bridge need to be investigated and selected.

This section of this manual prescribes the countermeasures of foundation except for settlement, movement, and inclinations of foundation.

There is a decrease in the foundation's embedment depth due to scouring as typical damage and the foundation defect. It greatly influences the stability of bridges. Therefore, it is necessary to conduct the countermeasures to prevent scouring and not influence the foundation stability.

### 5.5.2 Selection of Repair Methods

There are two types of countermeasure. One is to repair the foundation structure itself, and another is to reinforce the surrounding ground to prevent scouring. In Table 5.5.1, the repair and reinforcing methods are shown.

**Table 5.5.1 Repair Methods of Foundations**

Damage and Defect	Repair method
Spalling / Exposed rebar of bored pile	Repair of the foundation structure itself – Sectional Repair Method (Filling pile mortar/concrete)
Scouring	Reinforcement of the surrounding ground to prevent scouring – Foot protection method (Footing consolidation, Gabion mattress)

## **5.6 Bearing**

### **5.6.1 Outline**

It is necessary to understand the cause of defects of bearings when the methods of repair are selected. The effects of countermeasures, workability, economy including LCC needs to be investigated.

If an unsuitable repair method is adopted, the repaired part could sometimes be broken within a comparatively short time. Therefore, the cause of defects shall need to be fully understood to select the suitable repair method.

There are cases that the sideways movement and the substructure's settlement, the water leakage of expansion joints will cause the movement and the bearing's corrosion. In these cases, together with the repair of bearings themselves, the repair of substructures, expansion joints becomes necessary.

If the bearings need to be exchanged, the bearings need to be jacked up. Then various reinforcements, such as the reinforcement of main girders, lateral girders, the reinforcement, and the widening of bearing seats, pier heads, abutment heads, need to be studied carefully.

## 5.6.2 Selection of Repair Methods

The repair and reinforcing methods of bearings according to the kind of causes are shown in Table 5.6.1.

**Table 5.6.1 Repair Methods of Bearings according to Causes**

Defects	Repair method	Partial repair	Replacement, same type bearings	Replacement, other type bearings	Mortar replacement
	Causes				
Loosening and falling off	Cyclic loading	Suitable	Suitable	Effective	
	Poor quality	Effective	Suitable	Suitable	
	Manufacturing and construction failure	Effective	Suitable	Suitable	
	Defective structure type and its shape			Effective	
Breakage	Cyclic loading	Effective	Suitable	Effective	
	Poor quality	Effective	Suitable	Suitable	
	Manufacturing and construction failure	Effective	Suitable	Suitable	
	Defective structure type and its shape			Effective	
Cracks of mortar	Cyclic loading		Suitable	Effective	Effective
	Drying shrinkage, thermal change				Effective
	Poor quality				Effective
	Manufacturing and construction failure				Effective
	Defective structure type and its shape			Effective	Suitable

## 5.7 Expansion Joint

### 5.7.1 Outline

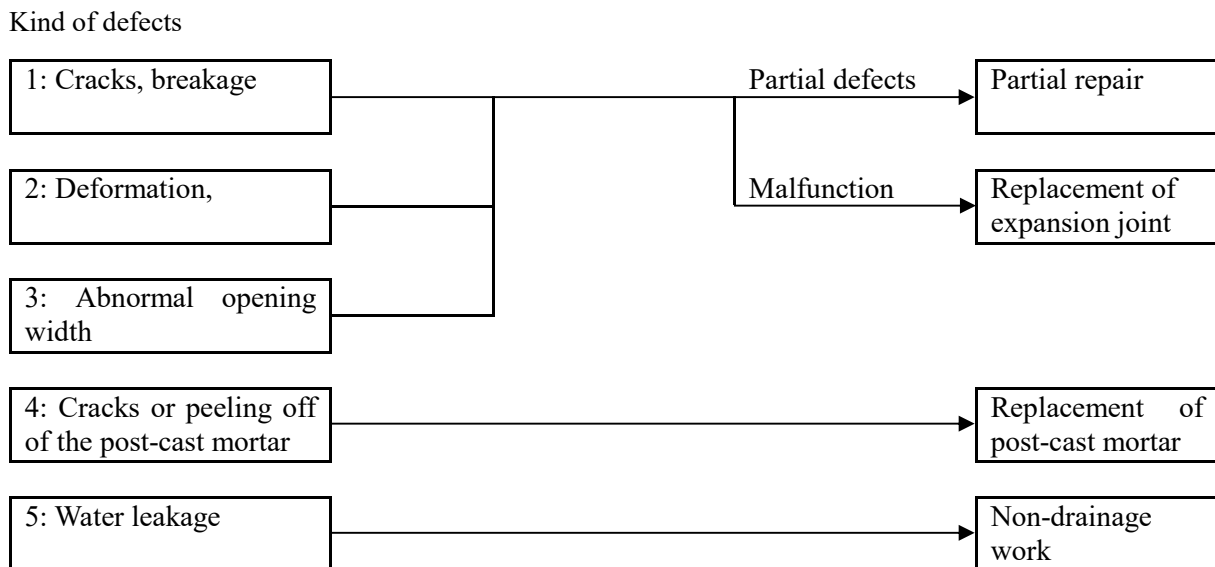
It is necessary to understand the defects of expansion joints and decide whether a partial repair will recover the function or a total replacement when the repair design is investigated.

### 5.7.2 Selection of Repair Methods

The repair methods of expansion joints can be classified as follows. The appropriate repair methods according to the kind of defects need to be selected.

- Partial repair
- Total replacement; replacement of the same type, replacement of other types
- Replacement of post-cast member
- Water-proofing

Figure 5.7.1 shows the selection flow of repair methods.



**Figure 5.7.1 Selection Flow of Repair Methods of Expansion Joint**

When the repair methods are selected, the Engineer should not follow the selection flow automatically but carefully select the suitable method to solve the problem which causes the defect.

For example, if the cause of breakage of the faceplate of finger joints is the inadequate thickness of the plate, then the partial replacement will not improve the situation. The whole replacement is needed. If the abnormal gaps due to the deformation of substructures or bearings or due to the settlement of substructures, then not only the replacement of the expansion joints but also the repair of substructures or bearings are needed at the same time.

## **5.8 Protection around Substructure**

### **5.8.1 Outline**

Protection around substructure is the critical structure to keep the stability of bridge and approach road, which is essential for the river bridge in particular.

The definition of scouring is the removal of soil from around foundations. Flowing water transports soils around bridge foundations and moves them downstream, leaving the foundations exposed and in some cases undermined. Depending on the severity of the scour, a bridge's integrity could be at risk, in some cases, or a bridge could be led to a partial or total collapse. The scour is a dynamic phenomenon, and conditions can change rapidly. Many variables affect the rate of progress at which bridge scour happens. Two of the primary variables are the soil type and the water velocity. Some soils are more susceptible to scour than others. Loose unconsolidated soil is easily carried away, while hard bedrock layers are generally not susceptible to scour. High flow velocities scour away soils faster than lower velocities.

On the other hand, the slope embankment may become unstable and collapse even if it is a normal bridge that is not a river bridge because of the following reason;

- No calculation of embankment stability
- Use of improper embankment material
- Improper embankment gradient

By taking into account the above possibilities, it is necessary to understand the defects of protection and select the optimum repair method.

### **5.8.2 Selection of Repair Method**

Figure 5.8.1 shows the selection flow of repair methods.

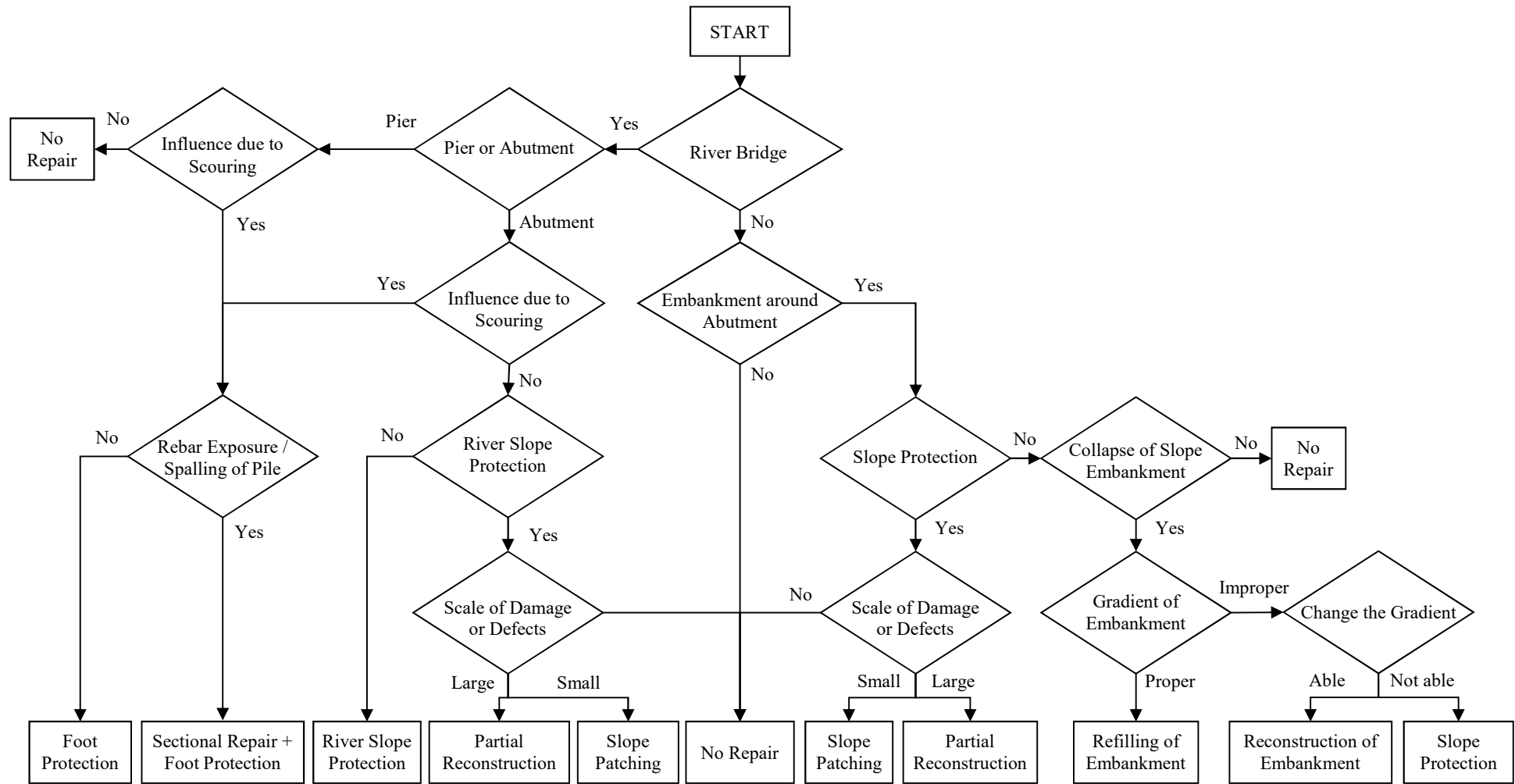


Figure 5.8.1 Selection Flow of Repair Methods of Protection around Substructure

## 5.9 Other Bridge Accessories

### 5.9.1 Outline

When the repair design of bridge railings or the drainage facilities is investigated, the replacement method should be adopted basically as the economic efficiency of the repair works is not high except for the cases of PC wall balustrade, curbs, deterioration of paintings.

### 5.9.2 Selection of Repair Method

Some defects can be recovered mainly by replacement. Some minor defects should be repaired to recover the original performance. The selection flow of repair methods is shown below.

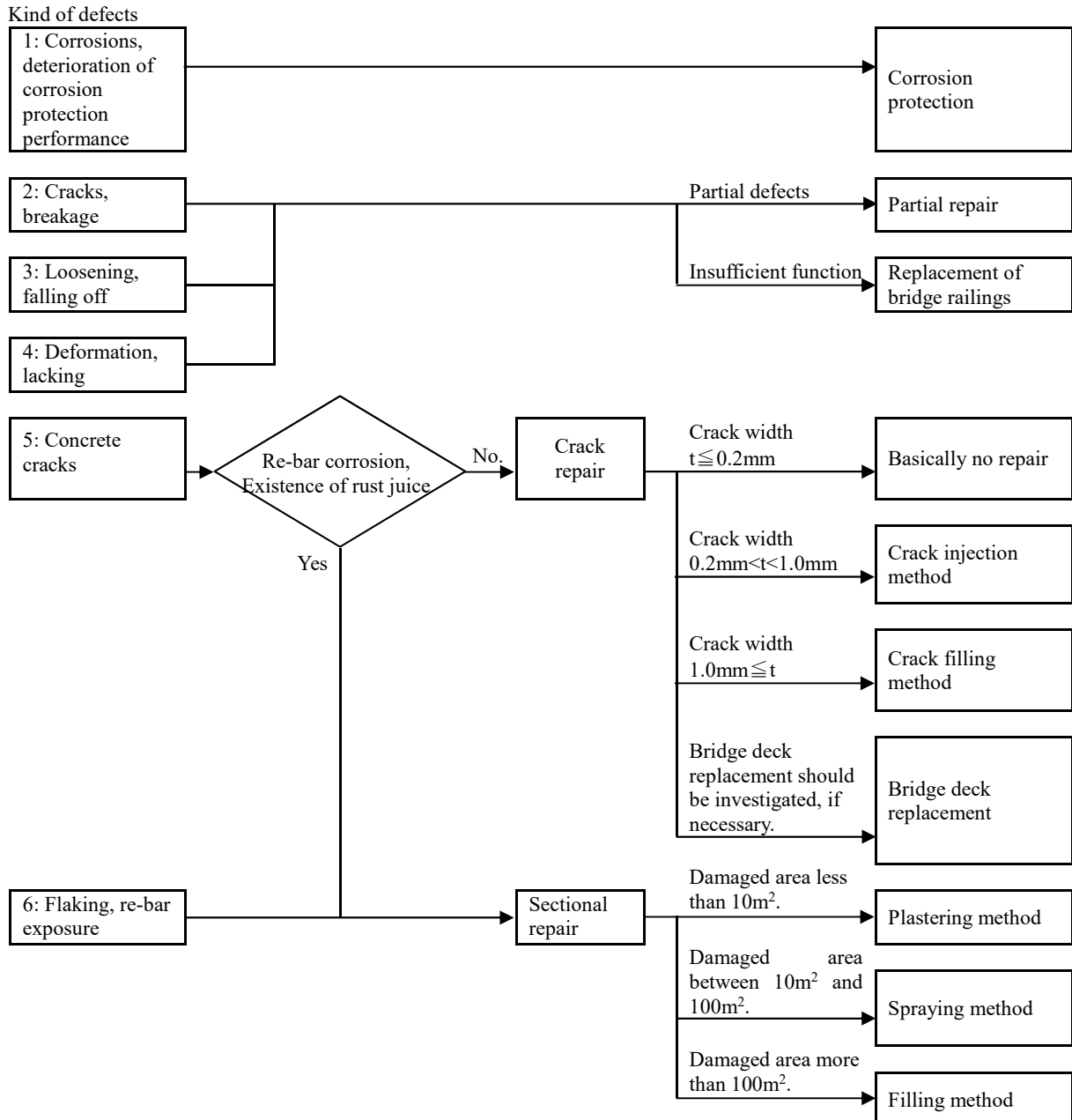
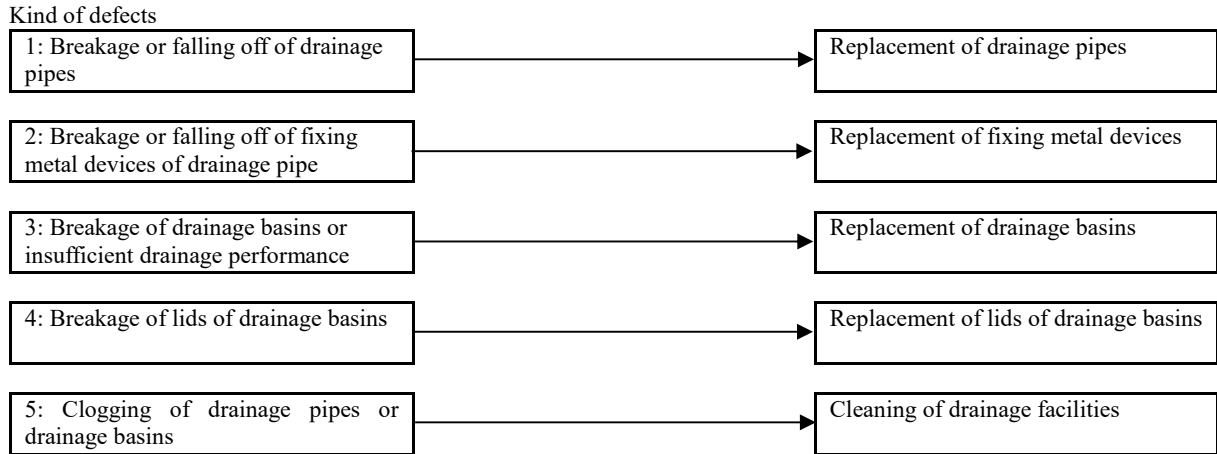


Figure 5.9.1 Selection Flow of Repair Methods of Bridge Railings, Railing Posts, Curbs



**Figure 5.9.2 Selection Flow of Repair Methods of Drainage Facilities**

When drainage basins are cleaned, the performance of the drainage facilities should be checked. If it is insufficient, the structure should be improved.

## **5.10 Preventive Measures against Re-Deterioration**

### **5.10.1 Main Causes of Re-Deterioration after Repair**

Some cases report the earlier re-deterioration of structures after the repair and the consequent re-repair. Therefore structures need to be continuously and periodically monitored after the repair. The main causes of re-deterioration after the repair are shown below.

- 1) Re-bar corrosions due to the insufficient removal of deterioration factors
- 2) Re-bar corrosions due to the re-penetration of deterioration factors, such as water, oxygen, carbon dioxide
- 3) Deterioration or peeling off of repair materials, painting materials
- 4) Macrocell corrosion after the repair

\*) macrocell corrosion: If a potential difference occurs between the re-bars inside the repaired concrete and the re-bars inside the existing healthy concrete, the re-bars inside the healthy concrete will be corroded. The phenomenon is called macrocell corrosion.

### 5.10.2 Selection of Preventive Measures against Re-Deterioration

Figure 5.10.1 and Figure 5.10.2 show the selection flow of preventive measures against re-deterioration for each major deterioration mechanism.

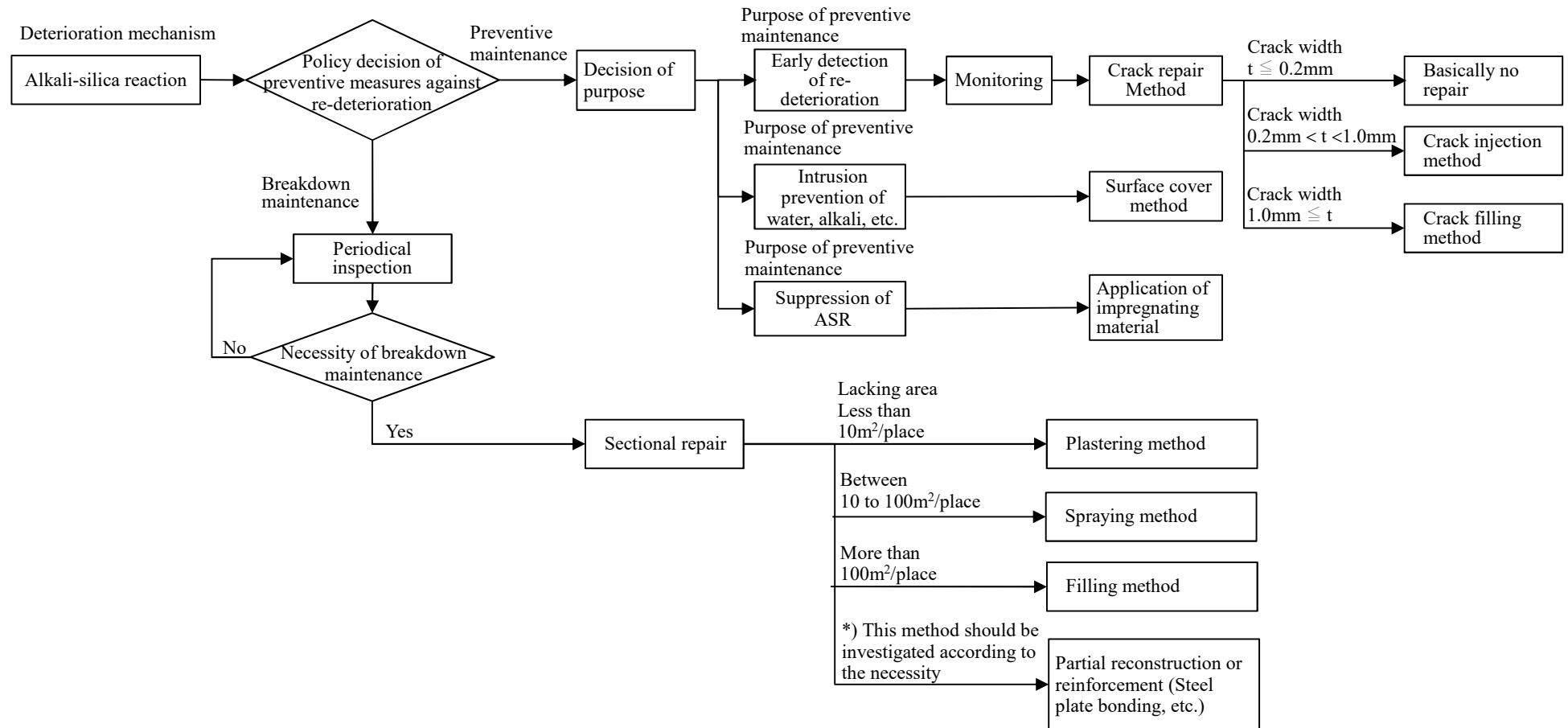


Figure 5.10.1 Selection Flow of Preventive Measures against Re-Deterioration for Alkali-Silica Reaction

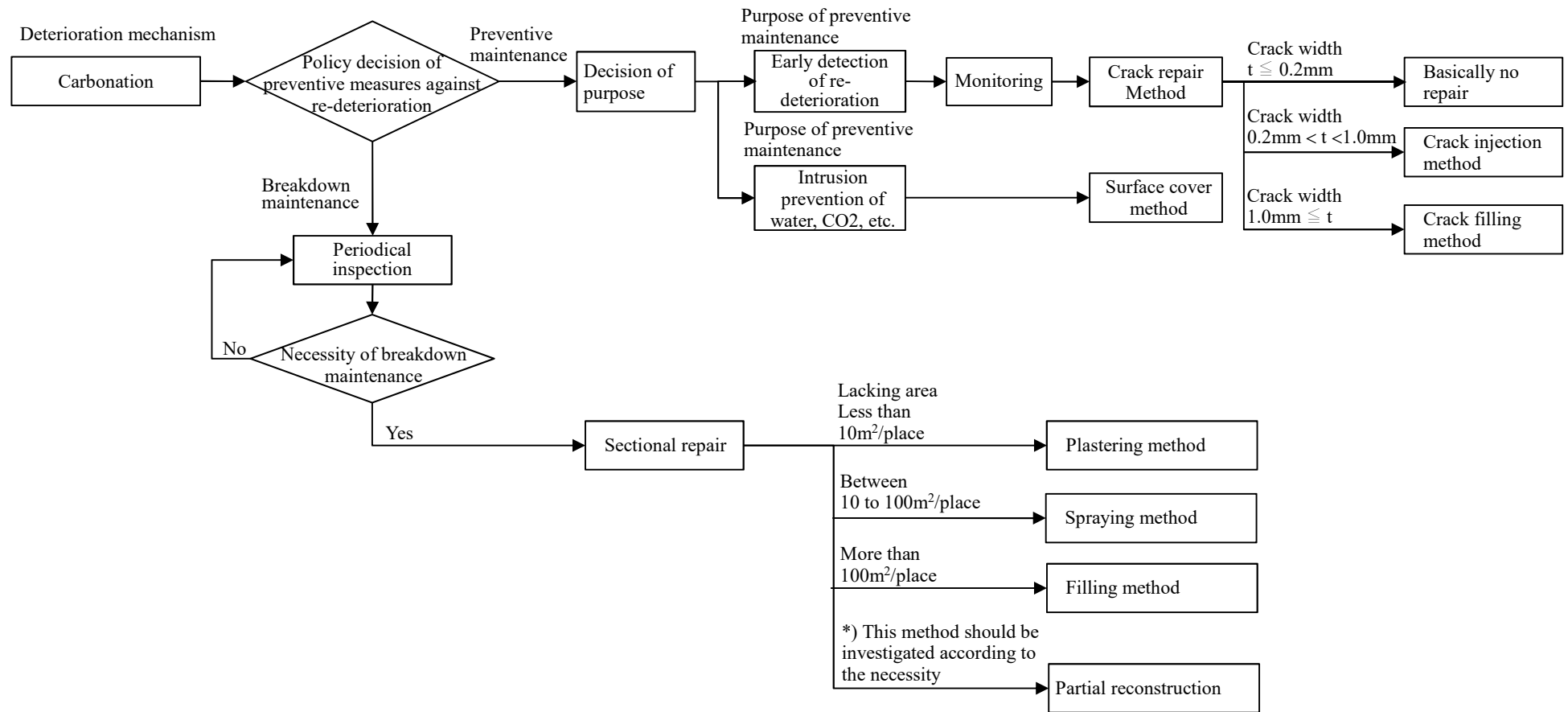


Figure 5.10.2 Selection Flow of Preventive Measures against Re-Deterioration for Carbonation

### 5.10.3 Follow-up

#### (1) Concrete structure

After the repair, it sometimes happens that the repaired surface is covered, and it becomes difficult to detect the sign of deterioration. Therefore, the observation after repairing is crucial to confirm the repair's effect and detect the sign of re-deterioration earlier. The follow-up inspection method according to the repair methods is shown in Table 5.10.1.

**Table 5.10.1 Follow-Up Inspection Items according to Repair Methods**

Repair method	Purpose	Expected effect	Inspection items
Crack injection method	Crack filling	Recovery of water tightness, integrity	– Crack opening, seepage water
Crack filling method	Prevention of water leakage, prevention of crack widening	Recovery of water tightness, covering cracks	– Deterioration of sealing material, peeling off of sealing material from concrete
Sectional repair method	Removal of deteriorated cover concrete and its recovery work	Quality assurance of cover concrete, corrosion protection of re-bars	– Cracks and flaking off of added concrete – Cracks along re-bars after the repair works of re-bars corrossions
Surface cover method	Intrusion prevention of outer deterioration factors, such as water, carbon dioxide	Deterioration prevention by eliminating deterioration factors	– Cracks, peeling off of cover materials, water seepage due to deterioration of cover materials – Be aware of the inside of concrete surface condition as it cannot be seen from outside. – Be aware of the color change of cover materials or rust juice color after the repair of re-bar corrossions – Be aware of partial bulging of cover material or gel seepage after the repair of ASR
Bridge deck surface waterproofing method	Prevention of water intrusion from the deck surface	Prevention of deterioration factors such as water	– Water seepage and free lime from the bottom of the bridge deck

(2) Steel structure

Typical defects of steel structures are the fatigue cracks and the corrosions resulting from the deterioration of the corrosion protection systems. The deterioration of the corrosion protection system and the corrosions are triggered by the chemical reaction so that the progress is comparatively slower. On the other hand, fatigue cracks can progress rapidly and considerably influence the safety of the bridge structure depending on the places of occurrence of cracks. This defect's characteristics should be fully understood. The follow-up inspection should be carried out with the appropriate intervals and appropriate places to find out the re-deterioration earlier after the repair.

The contents of the follow-up inspections for the steel bridges are shown below.

a) Cracks

Fatigue mainly causes cracks, but often many factors are related to the cause, such as the excessive amount of traffic, secondary stresses which have not been considered at the time of design, local deformations, improper welding. Therefore, the exact cause of the defect is sometimes unclear. Hence, around the places of repair, the re-occurrence of cracks and the following crack progress can happen after the emergency repair by the crack grinding out method, the cover plate method. To detect cracks earlier within two years of repair, the repaired places should be inspected to understand the condition. Two years correspond to the timing of the first inspection of the newly constructed bridges. The existence of cracks can be confirmed by eye inspection.

b) Corrosion

The re-painting method is mainly utilized to repair corrosion defects. Besides, if the evident thickness decrease, the pitting corrosions, the sectional decrease may influence the structural stress, the cover plate method is often adopted for the repair. In any case, the speed of re-deterioration is slow and the corrosions spread for a large area simultaneously, except for the cases of water leakage from the damaged expansion joints at the girder end. In these cases, only the girder end will be corroded. Therefore by the daily inspection, the occurrence of corrosions needs to be checked. The necessity of re-repair needs to be investigated based on the degree of corrosion.

c) Bolt loosening or falling off

Except for the defects shown in; a) cracks and b) corrosions, the bolt loosening or falling off is another defect of steel structures. The insufficient tightening causes this at the time of construction or by the corrosions, or by the delayed fracture of bolts.

If the cause is the corrosion, as explained in b), the earlier re-deterioration after the repair may not occur. The progress of corrosion should be observed by the daily inspection or the periodical inspection. In the case of the delayed fracture, the falling off may occur at any time after the repair, so that if the cause of the defect is judged to be the delayed fracture, the bolt falling off should be checked by the close eye inspection or the binoculars. The replacement of bolts should be investigated according to the condition of places of falling off and the number of falling off bolts.

---

## 6. BRIDGE RETROFITTING DESIGN

---

### 6.1 Bridge Retrofitting Policy

#### 6.1.1 Purpose and Target of Retrofitting

The retrofitting in this chapter aims to reinforce bridges to increase their strengths whose design standards become outdated and secure safety. The strengths of these bridges become insufficient due to the increase in the sizes of vehicles or the traffic amount.

In general, it is necessary to judge appropriately the necessity of reinforcement of bridges whose strength seems to be insufficient. However, reinforcing all of the older bridges will push up the cost and unrealistic because bridges might be utilized for the present traffic without any reinforcements. Besides this, there are the following reasons.

- if the bridges consequently have more affordance of its capacity because of the less actual traffic volume than the design
- if the strength of bridges is larger than the design calculation because of the influence of members such as curbs, which are not incorporated into the design calculations

Therefore do not reinforce the bridges uniformly just comparing the live loads of the old design standard and those of the current design standard. Instead, it is essential to investigate the condition of each bridge and judge the necessity of reinforcement.

The target structures of reinforcement are; 1) Steel bridge, 2) Concrete bridge, 3) RC bridge deck, 4) Concrete substructure.

#### 6.1.2 Applicable Standard and Points of Note

In principle, the current design standard should be followed for reinforcement, and the revised items of the new design standard must be checked and followed. However, it must be noted that if the reinforcement work is applied, afterward, the re-reinforcement work becomes very difficult. Furthermore, there are cases that the current design standard is followed and which results in excessively larger reinforcement, reduced durability, or a large influence on substructures.

Therefore, after enough investigation, it is necessary to determine the targeted performance level of bridges and select appropriate reinforcement methods.

When reinforcement methods are selected, the following points should be checked from the viewpoint of design and workability.

- a) When the degree of defects is large, the repair and reinforcement investigation, which reflects the influence of decrease of sectional performance of members due to the sectional loss or cracks, should be executed, and an appropriate method should be adopted.
- b) Do not injure the existing healthy members which support the present live loading and assure the present durability. When the repair and reinforcement methods are selected, the methods must not injure the existing members.

- c) When a comparatively long time may be needed before the commencement of the reinforcement works, temporary repair work to secure the durability depending on the condition of the defects should be investigated and executed.
- d) When the reinforcement methods are selected, not only the economy but also the workability should be investigated, and the selected method must fulfill the repair purpose. Future maintenance should be thoroughly investigated.
- e) The condition of traffic, the condition, and the bridge underside usage, the surrounding environment need to be investigated to decide the repair and reinforcement method.
- f) The traffic restriction needs to be established for the period of not only work but also concrete curing.

**Table 6.1.1 Classification of Reinforcement Method**

Method	Purpose of reinforcement
Bonding method	For steel members, cover plates will be added by high tension bolts or welding on the stress concentrated places, and the strength will be reinforced. (Welding should be avoided unless the welding specialist guidance exists.) For concrete members, the reinforcing materials will be bonded to restore or increase the strength on the concrete surfaces.
Wrapping method	For existing column members, which have insufficient strengths, the reinforcing materials are wrapped around the column members. The columns and the reinforcing materials are united, and the necessary strength will be achieved.
Member replacement method	By replacing a member partially or totally, the strength will be recovered or become higher.
Introduction of prestressing	The prestress will be added on a member through the outer cables, and the strength of the member will be recovered or will become higher.
Section thickness increase method	By adding concrete or mortar to a member and increasing the thickness, the strength of the member will be increased to the necessary level.
Member addition method	By adding additional members to the original structure, the dissipation of loads or the stresses can be achieved, and the strength of the structure can be recovered or can become higher.

**Table 6.1.2 Typical Reinforcement Method and Examples of Application Structures**

Kind of method	Reinforcement method	Steel bridge		Concrete bridge	RC bridge deck	Concrete substructure	
		Main girder	Secondary members			Column	Girder
Bonding method	Steel plate bonding method	Effective	Effective	Effective	Effective	Suitable	Suitable
	Continuous fiber sheet bonding method			Effective	Effective	Suitable	Suitable
	Continuous fiber plate bonding method	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable
Wrapping method	Steel plate wrapping method					Effective	Effective
	Continuous fiber sheet wrapping method					Effective	Effective
	RC wrapping method					Effective	Effective
Member replacement method	Re-concreting method			Effective	Effective		
Introduction of prestressing	Outer cable method			Effective			
Section thickness increase method	Plastering thickness increasing method				Effective	Suitable	Suitable
Member addition method	Supporting point addition method	Effective		Effective	Effective		
	Reinforcing member addition method	Effective	Suitable		Suitable		

### 6.1.3 Procedure of Retrofitting Design

The scale of reinforcement differs from one member to another so that the procedure of reinforcement method is decided according to each member.

The main girders need to be judged by the design calculation. Generally speaking, the live load is applied all over the road surface width including the side strips, over which vehicles may not run regularly. If the new design live load is applied only on the road lanes, not on the side strips, the total amount of new load may be smaller than the old load over the full width. Then there is a possibility that the main girders can withstand the new live load. For the main girders, this kind of calculation to confirm the effect of the new live load and to judge the necessity of the reinforcement is needed. If the design documents are unavailable, the actual stresses can be measured at the site.

Based on these calculations and measurements, together with the defect conditions and the traffic conditions, the necessity of reinforcement should be judged totally. If numerous defects are already found for other bridge elements, the bridges may need to be repaired and reinforced. In particular, the bridge decks that accept the wheel load directly, the defects may proceed rapidly, and the decks need to be checked carefully. The particular parts, such as a hinge section of a cantilever bridge or a girder end notched section, are susceptible to fatigue. Therefore, these parts should be reinforced even if there are no defects.

Typically, the countermeasure reinforcement of main girders may easily become a large-scale work. Therefore, the girder strength needs to be checked by the design calculation and the site loading tests so that it can be judged a large-scale reinforcement is needed or not. It is better to avoid a larger scale reinforcement work as far as possible.

The progress of defects is comparatively early because the RC bridge deck directly accepts the wheel loads. Therefore, it is necessary to understand the current progression status based on the result of inspection and diagnosis of its condition of defects and conduct the reinforcement design.

However, a dead load of RC bridge decks may increase due to the reinforcement. In this case, it is necessary to analyze not only the RC deck slab but also the substructure and the foundation.

The RC bridge decks can be retrofitted/reinforced comparatively easily by the carbon sheet bonding method, which is already well established. This method can decrease the dead load more than the deck slab thickness increasing method.

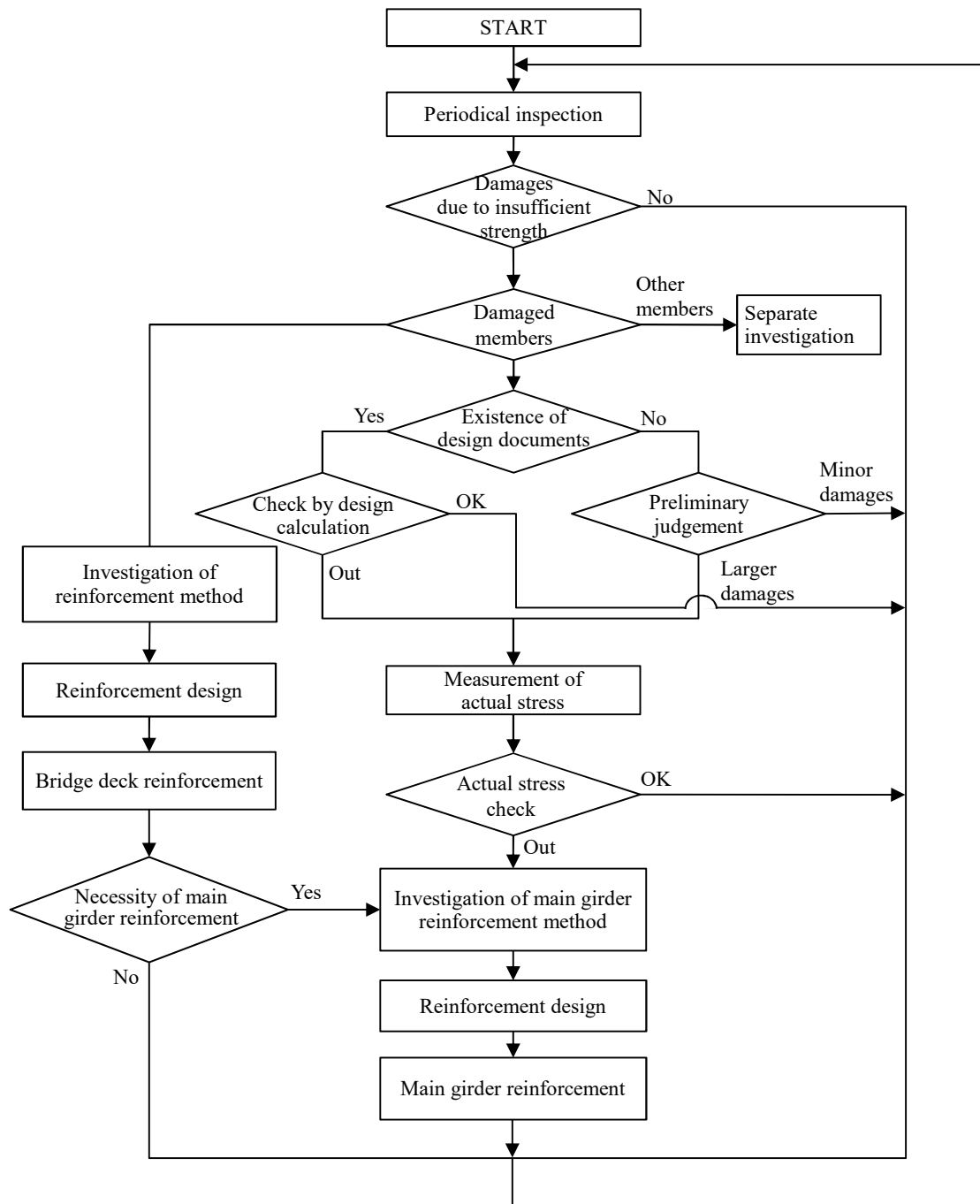


Figure 6.1.1 Reinforcement Design Flow

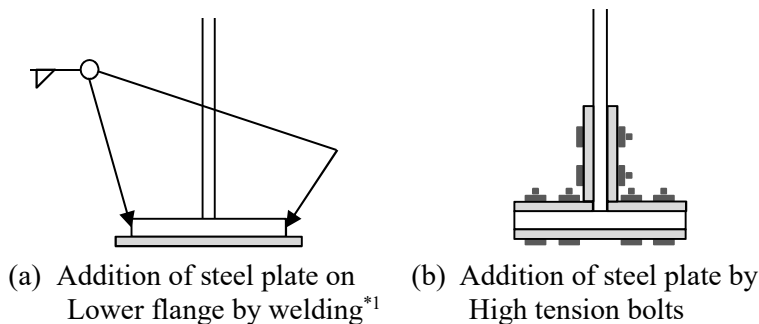
## 6.2 Retrofitting of Steel Bridge

The following major retrofitting methods of steel bridge are explained in this section.

### (1) The steel plate bonding method

The steel plate bonding method is applied to avoid cracks or prevent deformation due to stress concentration and increase strength.

The bonded steel plates will work only for the live load, which will work on the structure after the reinforcement. Therefore, when the dead load ratio is larger, the residual stresses of the existing members are larger. Consequently, the effect of the reinforcement becomes comparatively smaller and is not so effective. In these cases, the existing members should be jacked up and supported by temporary bents to reduce the initial stresses firstly. Then if the structure is reinforced, the reinforcement becomes more effective. However, when a structure is jacked up, the stress distribution of the structure changes. Thus, the reinforcement should be done carefully considering the influences on the existing members such as bridge decks.

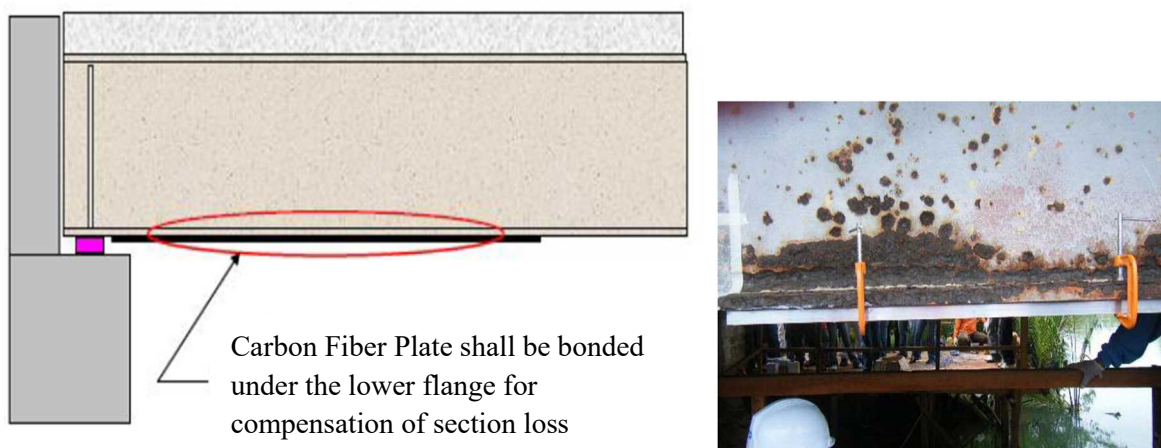


**Figure 6.2.1 Examples of Steel Bonding Method**

\*1: This method should be avoided unless specialist guidance exists.

### (2) The continuous fiber plates bonding method

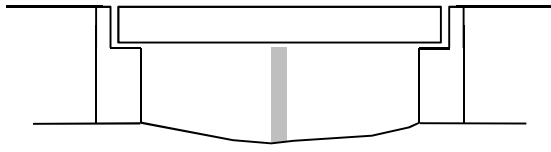
Continuous fiber plates are bonded to strengthen members or prevent the deformation of members. Lighter continuous fiber plates are comparatively easily bonded to the existing members by glues. However, if fiber plates need to be bonded over the cover plates fixed by high tension bolts, the bonding work becomes difficult.



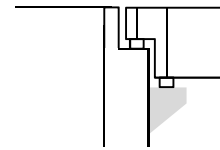
**Figure 6.2.2 Example of Bonding Continuous Fiber Plates**

(3) The additional supporting point method

By reducing span lengths, the abnormal deflection can be prevented, and the acting force can be redistributed, the strength can be increased. As the spans shorten, the bending strengths become larger. However, the utilization of the under girder space needs to be checked first to investigate this method.



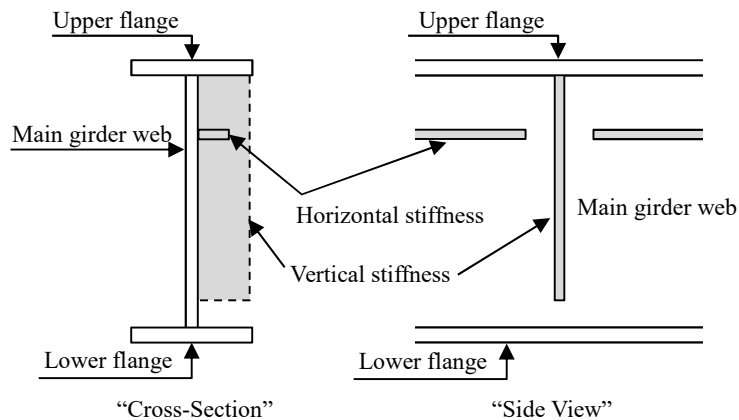
**Figure 6.2.3 Example of Span Reduction by Additional Pier**



**Figure 6.2.4 Example of Redistribution of Superstructure Reaction Force**

(4) The additional reinforcing member method

The reinforcing members are generally utilized to accept the live loads. The reinforcing members are added to increase the rigidity of the flanges of the main girders or to increase the strengths of main girders. When the welding connection is adopted, the welding technique becomes necessary. When the bolt connection is adopted, the sectional area reduction due to the bolt holes needs to be considered. The welding connection should be avoided unless the welding specialist guidance exists.



**Figure 6.2.5 Examples of Main Girder Reinforcement**

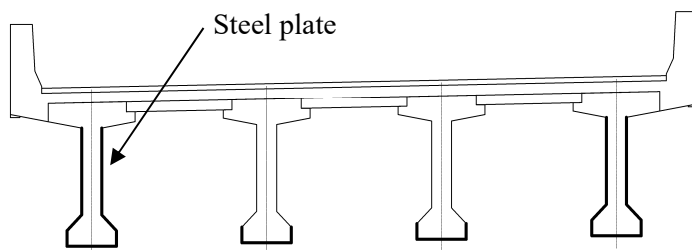
### 6.3 Retrofitting of Concrete Bridge

The causes of defects of the concrete bridge are often multiple, and the defect phenomenon is also complicated. To select the reinforcing method, it is necessary to fully understand the results of a detailed investigation and deterioration progress. When concrete bridges are reinforced, the defect conditions, the deterioration progress should be fully understood because the progress of deterioration may not be confirmed afterward due to the reinforcement works.

The major reinforcement method of concrete bridges are as follows.

#### (1) The steel plate bonding method

Steel plates are added to the tension side of concrete girders by epoxy resin glue. The existing concrete girders and the steel plates are united to increase the strength, and the rigidity of the united girders becomes larger and improves the deflection performance. The durability against cracks is also improved. However, the corrosion countermeasures of steel plates become necessary. When a whole concrete girder is covered by steel plates, to avoid the accumulation of intrusion water, the waterproofing of bridge decks should be executed simultaneously.



“Cross Section of PCT Girder”



“Picture”

**Figure 6.3.1 Examples of Steel Plate Bonding Method**

#### (2) The continuous fiber sheets bonding method

The continuous epoxy resin glue impregnated fiber sheets are added to the surface of tensile stress or diagonal tensile stress of concrete members. The united concrete members and fiber sheets will achieve higher strength. The reinforcement area should be decided to take into account the fixing length of the continuous fiber sheets. When the shear strength of larger height concrete girders is reinforced by this method, the fixing length of the continuous fiber sheets is difficult to be secured. It should be noticed beforehand. When a whole concrete girder is covered by continuous fiber sheets, to avoid the accumulation of intrusion water, the waterproofing of bridge decks should be executed simultaneously.



**Figure 6.3.2 Example of Shear Strength Reinforcement**

(3) The continuous fiber plates bonding method

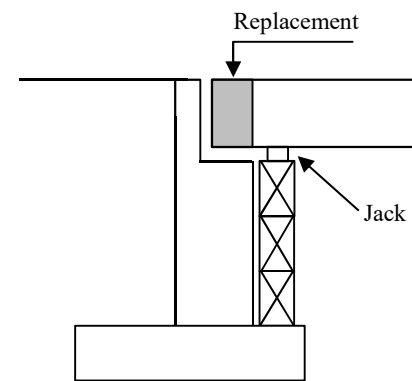
The continuous fiber plates, prefabricated at the factory, are attached to the tensile surface of existing girders. The girders and the fiber sheets are united by glue to achieve the higher strengths. The surface of existing girders needs to be cleaned by chipping, smoothed, and chamfered beforehand.



**Figure 6.3.3 Example of Continuous Fiber Plate Bonding Method**

(4) The re-concreting method

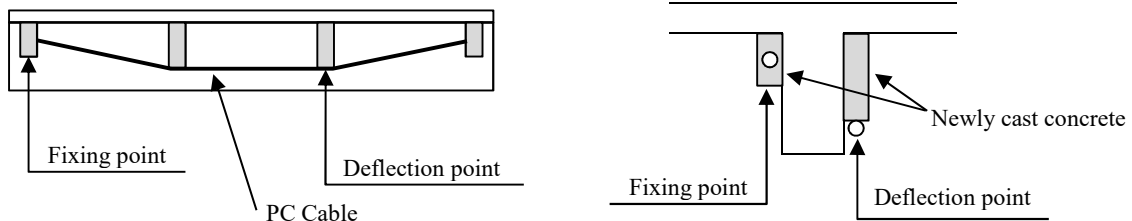
When a concrete member severely deteriorates and the strength becomes insufficient, a member is replaced partially or totally by a new concrete member. When a member is replaced partially, the treatment of construction joint between the new and old concrete, reinforcing rebar arrangement, the usage of high early strength cement to shorten the construction period, and shrinkage compensated cement need to be investigated.



**Figure 6.3.4 Replacement of the Main Girder End**

(5) The outer cable method

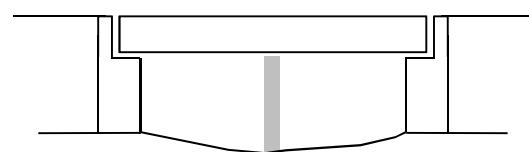
Outside of a concrete member, PC cables are added, and the concrete member is prestressed. By this effect, the bending strength will increase. By choosing the places of cable deflection, the improvement of the shear strength and the smaller girder deflection by the vertical component force of the prestress can be expected. Around the cable fixing points or the deflection points, the pressure, the splitting, the local stresses such as the tensile stress behind the girder end, the local bending, the local shear should be investigated, and the safety should be confirmed. The secondary stress due to the prestress may occur depending on the structure, which should be noted.



**Figure 6.3.5 Example of Outer Cable Method**

(6) The additional supporting point method

By shortening the span length of girders, preventing abnormal deflections, the redistribution of acting forces, the increase of strength can be achieved. If a supporting point is added, the performance of the existing girder needs to be checked as a continuous girder, and the stresses also need to be checked. After installing a pier, the ground displacement may occur due to the ground settlement, and the distribution of forces from the superstructure may change. These points should be investigated beforehand.



**Figure 6.3.6 Example of Additional Pier**

## 6.4 Retrofitting of RC Bridge Deck

The bridge deck accepts the repeated wheel load directly. Hence, the defects due to this influence are more often found than any other members. At the time of construction, the design standard, and the increase of traffic, especially the number of larger trucks, need to be understood. Then, it is necessary to judge that the causes of the defects are due to fatigue or due to some other causes, such as the environment, materials, construction works, structures. Based on this analysis, an appropriate reinforcement method suitable for the defect cause should be selected. It is crucial to eliminate or alleviate the cause of defects as far as possible when the bridge decks are reinforced. Table 6.1.1 shows typical causes of defects due to the live load.

**Table 6.4.1 Causes of Defects and Live Load Alleviation Measures**

Causes of defects	Alleviation countermeasures
Action of excessively heavy wheel load	Restriction of live load
Action of excessively larger impact	Maintenance of pavement and expansion joints
Action of excessively larger bending moment due to the path of moving wheel load	Adjustment of position of lanes (designation of lanes for larger vehicles)

The rainwater greatly influences the deterioration of bridge decks, and the leakage water from the bridge decks also influences other members below the bridge decks such as main girders. Therefore the adoption of waterproofing on the bridge deck should be investigated. Table 6.4.2 shows the degree of emergency reinforcement countermeasure according to the amount of cracks and the condition of cracks. Besides, Table 6.4.3 shows the reinforcement method according to the degree of emergency reinforcement countermeasures, which is judged based on the density of cracks and the condition of cracks. The time of execution of countermeasures should be decided based on the condition of cracks, the priority of maintenance.

**Table 6.4.2 Degree of Emergency Reinforcement Countermeasure according to Crack Condition and Density**

Amount of cracks "t" (m/m <sup>2</sup> )	t≤0.5	0.5<t≤2.0	2.0<t≤3.0	3.0<t≤5.0	5.0≤t
Crack condition					
All crack widths are below 0.1mm.	A	A	B	B	C
Partially 0.2mm cracks exist except for hair cracks.	A	A	B	C	D
About 0.2mm cracks are all over and partially 0.3mm to 0.4mm cracks exist.	A	B	C	C	D
About 0.3mm to 0.4mm cracks are all over.	A	B	C	D	D
About 0.3mm to 0.4mm cracks are all over. Partial grinding wear and crack corner spalling exist.	A	C	D	D	D

- A: No countermeasures are needed.  
 B: Follow-up periodical inspection is needed.  
 C: Earlier countermeasure is needed.  
 D: Emergency countermeasure is needed.

Table 6.4.3 Degree of Emergency (A,B,C,D) and Countermeasures

Degree of emergency \ Countermeasure	A	B	C	D
Steel plate bonding method		—————	—————	.....
Continuous fiber sheets bonding method		.....	.....	
Continuous fiber plates bonding method		.....	.....	
Re-concreting method			—————	—————
Concrete thickness increasing method		—————	—————	.....
Girder thickness increasing method		—————	—————	.....

Note) ————— : Permanent countermeasure      ..... : Emergency countermeasure

(1) The steel plate bonding method

Steel plates are added to the tension side of bridge decks. The existing concrete bridge decks and the steel plates are united to increase the strength. There are two methods to attach steel plates to the concrete bridge deck by epoxy resin glue. One is the pressing method, and the other is the injection method. Wider strips of steel plate or narrower strips of steel should be utilized separately depending on the situation of defects after the investigation. Although the steel plate bonding work can be done only from the bottom of bridge decks and is not necessary to stop the traffic, the restriction of the passage of larger vehicles is needed until the hardening of epoxy resin glue.

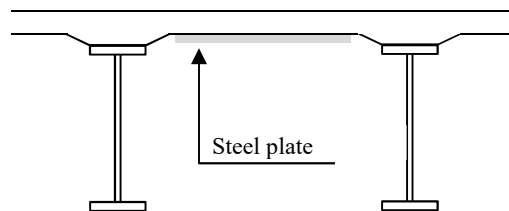


Figure 6.4.1 Example of Steel Plate Bonding Method

(2) The continuous fiber sheets bonding method

The purpose of this method is the same as that of the steel plate bonding method, but the material is lighter and softer so that the workability is much better. It is necessary to prepare the concrete surface well so that good adhesion can be achieved between the concrete and the fiber sheets and that the concrete and the sheets will be united to work together. If the sheets completely cover the surface entirely, it becomes difficult to inspect the condition of defects on the existing concrete afterward. Therefore sometimes, strips of fiber sheets are attached in a lattice shape.

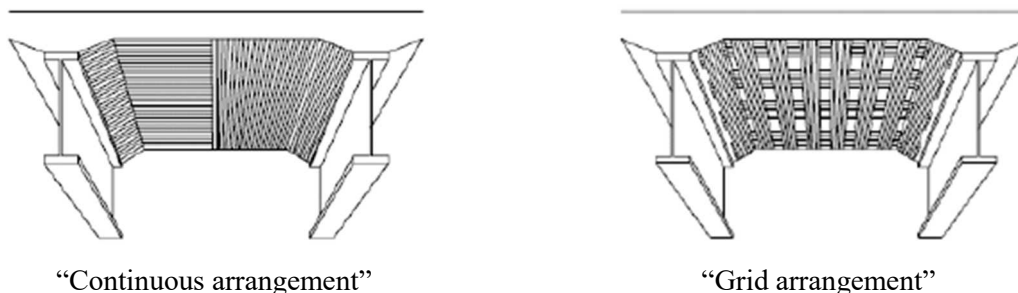


Figure 6.4.2 Example of Continuous Fiber Sheets Bonding Method

(3) The continuous fiber plates bonding method

Prefabricated continuous fiber plates are attached at the site by glue. Compared to the fiber sheets method with the multi-layer sheets, the construction period is shorter.

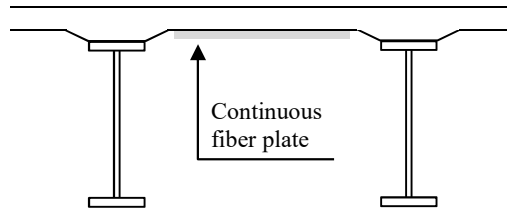


Figure 6.4.3 Example of Continuous Fiber Plates Bonding Method

(4) The re-concreting method

There are two methods. One is the partial re-concreting method, and the other, the total re-concreting method. When the partial re-concreting method is adopted, the connection between the new concrete and the old concrete must be carefully treated. When the total re-concreting method is adopted, the new bridge deck should be designed and constructed following the current design standard. If necessary, the lighter concrete should be utilized to alleviate the dead load. This method is very effective, but the traffic restriction is needed, and the investigation for the disposal of removed bridge decks is also needed.

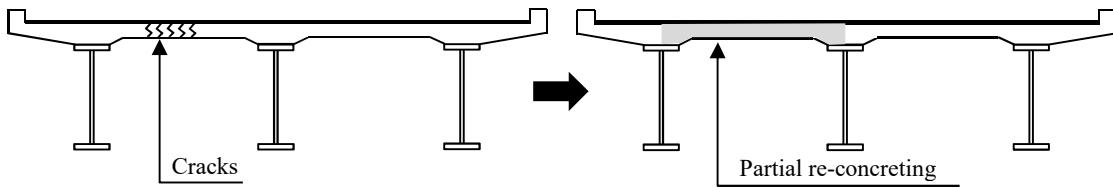


Figure 6.4.4 Example of Partial Re-concreting

(5) The upper surface thickness increasing method

Over the surface of the existing concrete bridge deck, the steel fiber reinforced concrete or the concrete with rebar or the concrete with rebar mesh is placed to increase the deck thickness. At the center of a span, the bending strength increases as the additional concrete is cast on the compression side. The punching shear resistance strength is also increased. Before the reinforcement work, the deteriorated section of the existing bridge deck needs to be removed completely. If the thickness of reinforcement is insufficient, the added reinforced concrete may be cracked and deteriorated again. The necessary thickness needs to be confirmed before the reinforcement work. This method involves the countermeasure to erase the height difference of road surfaces, the adjustment of expansion joints, a large-scale traffic restriction, the investigation of the bridge structure against the dead load increase.

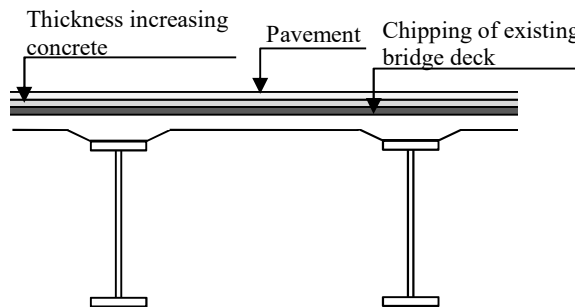
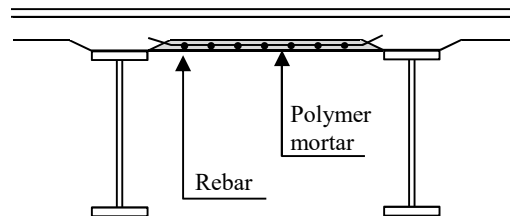


Figure 6.4.5 Example of Upper Surface Thickness Increasing Method

(6) The lower surface thickness increasing method

Grid-shaped woven rebars are fixed at the bottom surface of the bridge deck by anchor hole bolts, and then polymer mortar is placed over the rebars to unite with the existing bridge deck. The increase of tensile rebars and the concrete cover depth increase of rebars inside the existing bridge deck will enhance the strength of the bridge deck. The drying shrinkage of the polymer cement mortar is smaller than that of the cement mortar. The adhesive property of the polymer mortar is excellent so that if lighter type polymer cement mortar is utilized, scaffoldings for construction works are not needed.



**Figure 6.4.6 Example of Lower Surface Thickness Increasing Method**

## 6.5 Retrofitting of Substructure

When a substructure needs to be reinforced, causes and damage degrees, conditions at the time of construction need to be fully understood. The reinforcement method that considers the condition of under girder usage, the traffic restriction, the construction condition needs to be selected.

When a substructure itself is reinforced, the cross-section receives the live load and the dead load from the superstructure already, and the corresponding stresses exist. The additional reinforcement section will not support these stresses. Therefore, the countermeasure to release stresses of the existing structure or redistribute stresses needs to be investigated, and the scale of reinforcement needs to be decided.

(1) The steel plate bonding method

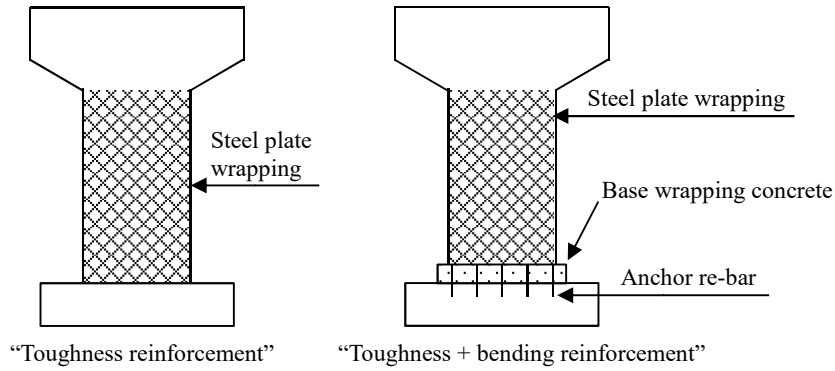
The reinforcing steel plates are bonded on the surface of substructures by epoxy resin glue. The dead load will be increased slightly, but the influence on the existing members is small.

(2) The continuous fiber sheet bonding method

Carbon fiber sheets are bonded on the surface of substructures by epoxy resin glue to achieve the bending reinforcement and the shear reinforcement. It has the advantage that the dead load slightly increases, and the influence on the existing members is also small. However, there is a limit to the number of sheets that can be utilized for the reinforcement. Therefore, when the scale of reinforcement is large, this method might not be adopted.

(3) The steel plate wrapping method

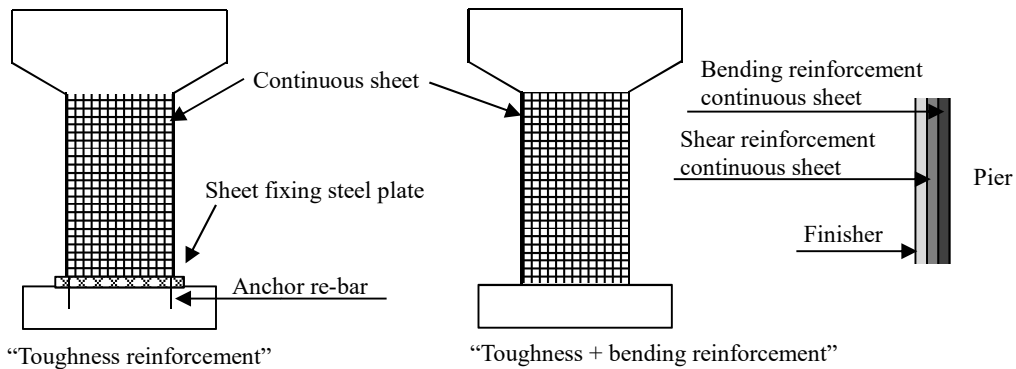
Steel plates are placed all around an existing pier with insufficient strength, and a composite structure with steel plates and a concrete pier will be formed to have sufficient strength. Steel plates need to be shaped to fit the existing piers, and they are connected at the site by welding or by high tension bolts.



**Figure 6.5.1 Example of Steel Plate Wrapping Method**

(4) The continuous fiber sheet wrapping method

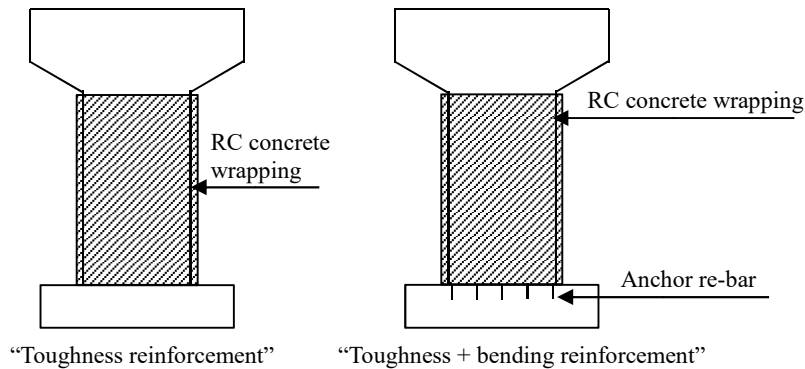
Continuous fiber sheets are placed all around an existing pier with insufficient strength. A composite structure with fiber sheets and a concrete pier will be formed to have sufficient strength. The materials are light so that they can be carried out by manpower. Even complicated surface shapes can be reinforced by this method. Protection against abnormal impacts such as vehicle collisions or rolling stone collisions is needed.



**Figure 6.5.2 Example of Continuous Fiber Sheet Wrapping Method**

(5) The RC concrete wrapping method

Rebars are placed around an existing pier, and concrete is cast to increase the sectional area. By this method, the necessary strength can be added. It is a popular method, but the chipping work of existing pier surfaces is needed.



**Figure 6.5.3 Example of RC Concrete Wrapping Method**

## **6.6 Important Points of Retrofitting Work**

As the strength reinforcement is to add some member to an existing structure, appropriate care is needed for the construction work. Without appropriate care, construction failures, damages to the existing structures, initial defects in the new members could happen.

- a) Check items to avoid construction failures
  - Confirmation of dimensions of existing structures
  - Investigation of rebar positions of existing structures
  
- b) Check items to avoid damages to existing structures
  - Investigation of rebar positions of existing structures
  
- c) Check items to avoid initial defects of new members
  - Appropriate supervision of hole-in anchor construction work
  - Appropriate supervision of construction work to ensure the good adhesion between an old member and a new member
  - Avoidance of concrete cracks due to the drying shrinkage when the concrete member thickness increasing method is applied. (A care should be taken for the method and duration of curing and the rebar arrangement.)
  
- d) Other
  - When steel girders are reinforced, site construction works are often adopted. For the connection of steel members, the high tension bolt connections are often adopted because of the construction conditions or the easiness of the construction supervision. If the quality of steel materials is unknown, and it is difficult to ensure the welding quality, it is recommended to adopt high tension bolt connections avoiding the welding connections.  
When an existing member, which is planned to be reinforced, has a defect of cracks or a sectional loss already before installing new members, an appropriate method of treatment of the existing member should be planned beforehand.