



BRIDGE MAINTENANCE CAPACITY BUILDING IN ZAMBIA

BRIDGE REPAIR GUIDEBOOK

2024

Road Development Agency
Japan International Cooperation Agency

FOREWORD

The Road Development Agency (RDA) is responsible for the entire classified road network of 67,671 kilometres, including bridges and culverts. However, owing to limited resources, the Agency identified a rationalised network of 40,454 kilometres deemed as the Core Road Network (CRN). The CRN is defined as “the minimum network which when improved will spur socio-economic development and contribute to poverty reduction.”

The CRN has over 460 bridges, most of which were constructed over 40 years ago, and have reached a critical stage, in need of repair. In an effort to implement bridge inspection, repair and maintenance, Guidebooks and Guidelines were produced under the Japan International Cooperation Agency (JICA), Technical Cooperation Project (TCP) on Bridge Maintenance Capacity Building in Zambia. These are the Bridge Repair Guidebooks, Bridge Routine Maintenance Guidelines and Bridge Inspection Guidebooks.

These Guidebooks and Guidelines will assist the officers in carrying out bridge inspections and maintenance activities and also offer repair Methods, which will in turn allow for the continued long-term use of the existing bridges.

Our profound gratitude goes to JICA for the technical and financial assistance and the RDA personnel that worked tirelessly to formulate and publish the Guidebooks and Guidelines.

I implore all those charged with the responsibility to inspect, repair and maintain bridges to utilise the Guidebooks and Guidelines as they undertake their work.

April, 2024



Eng. Grace Mutembo
Director and Chief Executive Officer
ROAD DEVELOPMENT AGENCY

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ABBREVIATIONS

ASTM	:	American Society for Testing and Materials
AASHTO	:	American Association of State Highway and Transport Officials
BMS	:	Bridge Management System
BPB	:	Sealed Rubber Bearing Plate
BS	:	British Standard
CF	:	Concrete Failure
CFP	:	Carbon Fiber Plate
CFS	:	Carbon Fiber Sheet
HTB	:	High Tension Bolt
HWL	:	High Water Level
JHS	:	Japan Highway Standard
JICA	:	Japan International Cooperation Agency
JIS	:	Japan Industrial Standard
JRA	:	Japan Road Association
KPa	:	Kilo-Pascal
MPa	:	Mega-Pascal
PC	:	Prestressed Concrete
PCM	:	Polymer Cement Mortar
PTFE	:	Polytetrafluoroethylene (Teflon)
PVC	:	Polyvinyl Chloride
RC	:	Reinforced Concrete
SABS	:	South African Bureau of Standards
SIS	:	Swedish Standards Institute
TWG	:	Technical Working Group
US\$:	United States Dollar
W/C	:	Water and Cement Ratio

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE

The purpose of this guidebook is to describe and introduce standard repair methods for defects commonly found in bridges owned and maintained by RDA. The following distinctive features are considered in view of standardizing the bridge repair guidebook:

- This serves as a guide for personnel responsible in selecting and implementing appropriate repair methods. This guidebook covers only the repairs of damaged bridge components. Reconstruction, total replacement and retrofitting requiring structural design, are not included in this guidebook
- The standard bridge repair methods are selected in consideration with structurally and practically acceptable methods in Zambia.
- The knowledge and experiences gained from projects are also incorporated in this guidebook. This is an effective means of knowledge transfer to the maintenance engineers.

This guidebook serves as a guide for the repair works undertaken by RDA.

1-2 TARGET USERS

This guidebook is intended for:

- RDA Engineers who are responsible for bridge repair projects;
- Contractors involved in bridge repair works through RDA;
- Suppliers of bridge repair materials.

1-3 STRUCTURE

The guidebook basically presents an introduction and standard bridge repair procedures. The composition of the manual is as follows:

- Chapter 1: Introduction
- Chapter 2: Major Maintenance Repair
- Chapter 3: Repair of Concrete Deck Slab
- Chapter 4: Repair of Concrete Bridge Superstructure
- Chapter 5: Repair of Steel Bridge Superstructure
- Chapter 6: Repair of Concrete/Steel Bridge Substructure
- Chapter 7: Repair of Bridge Expansion Joint
- Chapter 8: Repair of Bridge Bearing
- Chapter 9: Repair of Protection Works

CHAPTER 2 MAJOR MAINTENANCE REPAIR

2-1 TYPES OF DEFECTS AND CAUSES

Types of defects and causes are classified based on the condition rating criteria combined with the relevant stipulations in the Bridge Inspection Guidebook. The rating criteria classifies the bridge component into four conditions based on the results of the condition inspection namely: Good, Fair, Poor and Bad. The types of defects and causes are classified for each of the following bridge components:

- Concrete Bridge, Superstructure
- Steel Bridge, Superstructure
- Concrete/Steel Bridge, Deck Slab
- Concrete/Steel Bridge, Substructure
- Bridge Accessories such as Expansion Joint and Bearing
- Protection Works

In the Inspection Guidebook, the defects are focused on fair, poor or bad classifications, with corresponding causes identified.

2-2 PROCEDURE FOR SELECTING REPAIR METHOD

2-2-1 Selecting Repair Method

The repair methods suggested in this guidebook are prepared based on the condition rating criteria of the Bridge Inspection Guidebook. The different repair methods are selected according to the type of defects found on the bridge structure. The selection of repair methods however gives priority to bridges that will remain structurally sound after the repair and to those with defects which can be practically repaired, considering local conditions in Zambia. For major repairs where the bridge exhibits different combinations of defects, corresponding repair measures shall be simultaneously carried out using the appropriate repair methods.

Prior to using this guidebook, the following should be considered to determine the appropriate repair method:

(1) Necessary Strength Based on Original Design

Repair methods included in this guidebook aim to maintain the capacity of the bridge based on its original design and not to further enhance its serviceability strength to meet the latest design requirements. Nevertheless, it is noted that even if the full design load capacity is achieved, slight overstressing due to the defect may be accepted for certain serviceability limits. Engineering judgment is also vital in selecting the appropriate repair method in order to minimize cost. For example, repair of the full flange area of a simply-supported steel girder may not be necessary near its end span since bending moment at this

location is expected to be minimal.

(2) Bridge Service Life and Characteristic of Defects

The proposed repair methods are limited to realizing the corresponding repair costs, and not the value of the bridge's life cycle cost. Bridge inspection team of RDA need to also consider the following factors in determining the appropriate repair methods:

- The service life of steel bridges is governed by the fatigue life of a steel section. It is not practical to spend largely on repairs if the bridge is close to its predicted fatigue life (50 ~ 100 years), hence, replacement is a better option.
- In concrete structures, defects such as corrosion of reinforcement may not be visible. However, such defects are known to occur in the form of concrete cracking or spalling.
- It is not practical to spend on repairs for some localized defects if more extensive defects are expected to appear in the near future. For such case, detailed inspection using NDT (Non-destructive testing) equipment should be conducted for the complete structure prior to implementation of costly repairs of localized concrete defects.

(3) Detailed Evaluation/Assessment

This guidebook does not provide assessment of the cost of repairs against its possible benefits, which could be the basis in deciding between repair and reconstruction. It should be noted that reconstruction is not covered in this guidebook. However, an engineering assessment for the necessity of reconstruction is explained in "Implementation Plan of Bridge Repair and/or Replacement".

(4) Partial Replacement of Bridge

In case a primary bridge component exhibit defects that appear to spread widely and have continuously progressed, partial replacement of the component could be considered. This may involve replacement of damaged bracing members, stiffeners, stringers, cross girders, but not to the extent of completely replacing the components. (Total replacement of girder or deck slab is not included in this repair guidebook.)

(5) Total Repair Cost for Defects

The repair costs refer to the unit cost of each repair. The total cost for implementing repair should also include the following items for each bridge, with due consideration of the scale and location (terrain) of the subject bridge:

- Transportation cost of materials and equipment
- Scaffolding, staging and other temporary facilities
- Detour road or detour bridge if necessary
- Management cost (Overhead and profit)

(6) Adverse Problems on the Structure and Traffic

Consider the following issues that may cause adverse problems during the implementation of the bridge Repair:

- Detour road or bridge for rerouting traffic flow.
- Reduction of traffic load clearances during overlay or jacking-up of girder
- Structure becomes more vulnerable to damage or deterioration during repair
- Other potential defects that may be observed

2-2-2 Cracking on Concrete Structure

Generally, fine and stable cracks with up to 0.3 mm width have no adverse effect if concrete cover to reinforcement is adequate. These cracks are generally harmless and need not be repaired.

Defective cracks with over 0.3 mm width develop due to carbonation, chlorination, alkali aggregate reaction, rebar corrosion, overloading of structure, foundation movement and lack of adequate cover. It is important to identify the presence of these causes. All defective cracks have to be repaired as shown in Figure 2-1 to Figure 2-3. The repair methods for cracks are classified according to crack width, based on the Condition Rating Criteria of the Bridge Inspection Guidebook.

(1) Deck Slab

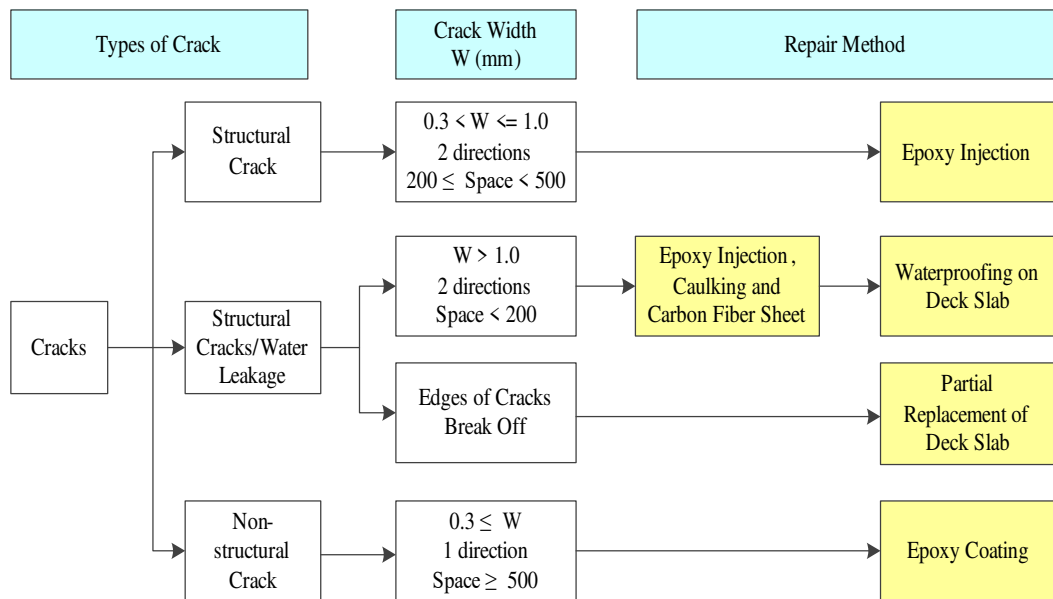


Figure 2-1 Selection Procedure of Repair Method for Deck Slab Due to Cracks

(2) Superstructure

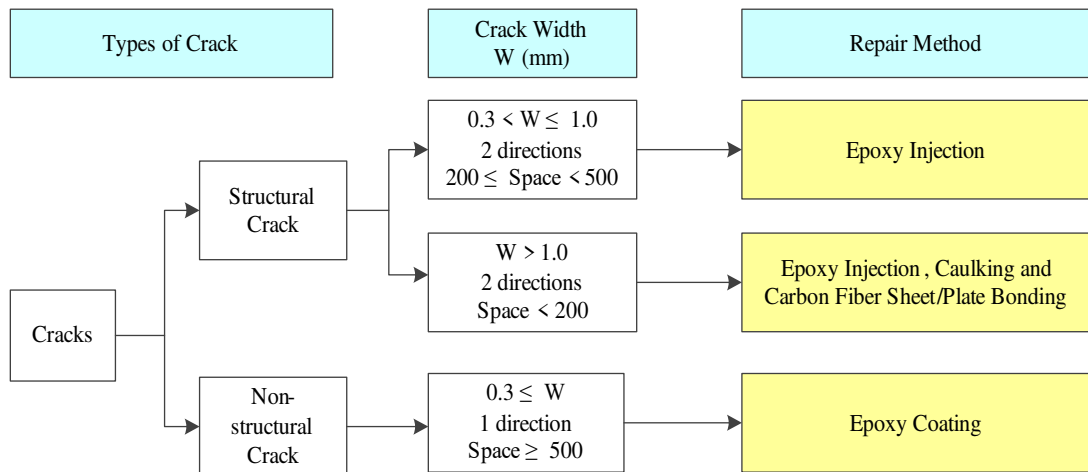
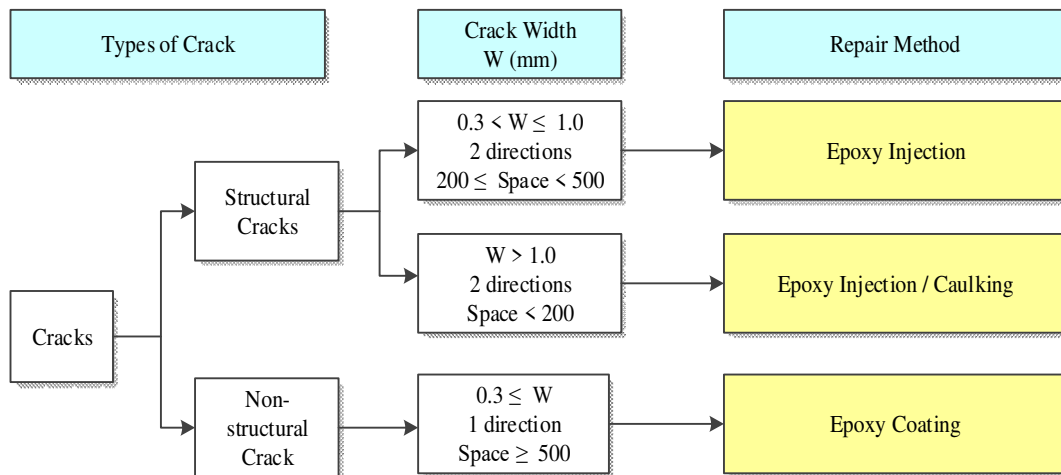


Figure 2-2 Selection Procedure of Repair Method for Girder Due to Cracks

(3) Substructure



Remark: Epoxy injection repair shall be similar to the epoxy injection for superstructure.

Figure 2-3 Selection Procedure of Repair Method for Substructure Due to Cracks

2-2-3 Spalling, Scaling and Disintegration on the Concrete Structure

Spalling is defined as a depression resulting from detachment of a large fragment of concrete. On the other hand, disintegration is a depression resulting from detachment of small fragment. The major cause of spalling is expansion resulting from corrosion of reinforcement. Spalling caused by impact can weaken the structure locally and expose the reinforcement to corrosion.

Scaling of concrete surfaces is defined as local flaking or peeling away of concrete near the surface. As the deterioration continues, coarse aggregate particles are exposed and eventually become loose.

All defects have to be repaired based on the flowchart shown in Figure 2-4 to Figure 2-6.

The repair method for spalling is classified according to width and depth damaged, while that for scaling is only according to the width of damage on the concrete. This is based on the Condition Rating Criteria of the Bridge Inspection Guidebook.

(1) Deck Slab

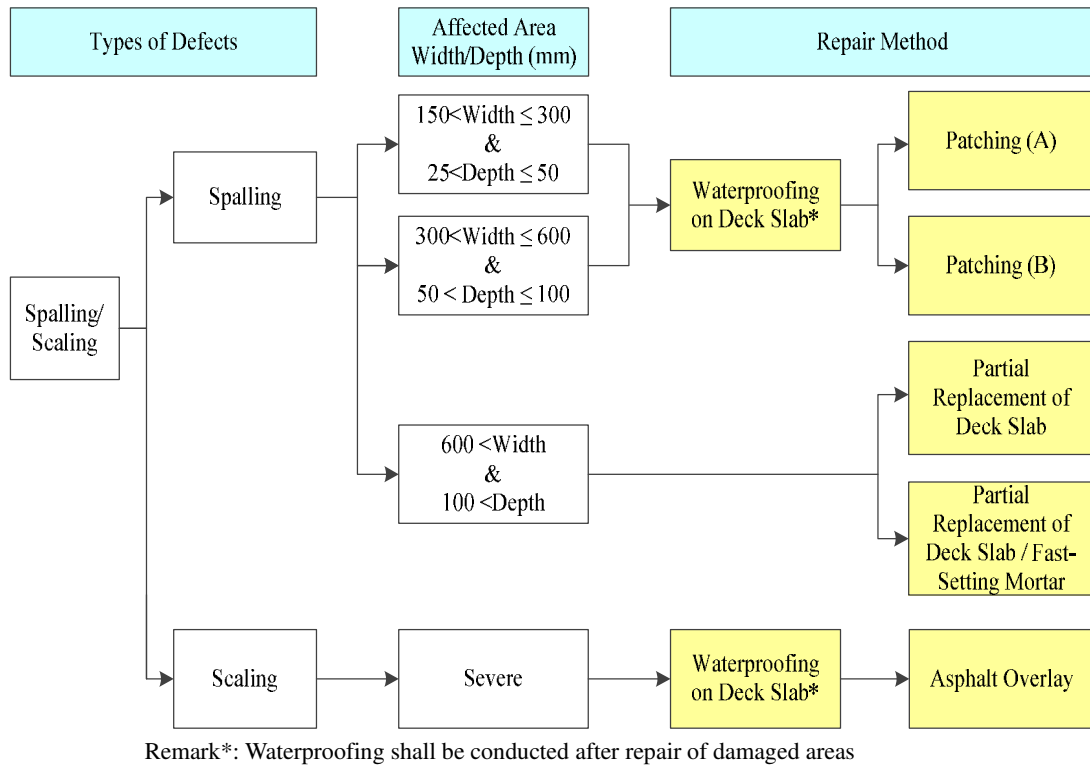


Figure 2-4 Selection Procedure of Repair Method for Deck Slab due to Spalling and Scaling

(2) Superstructure

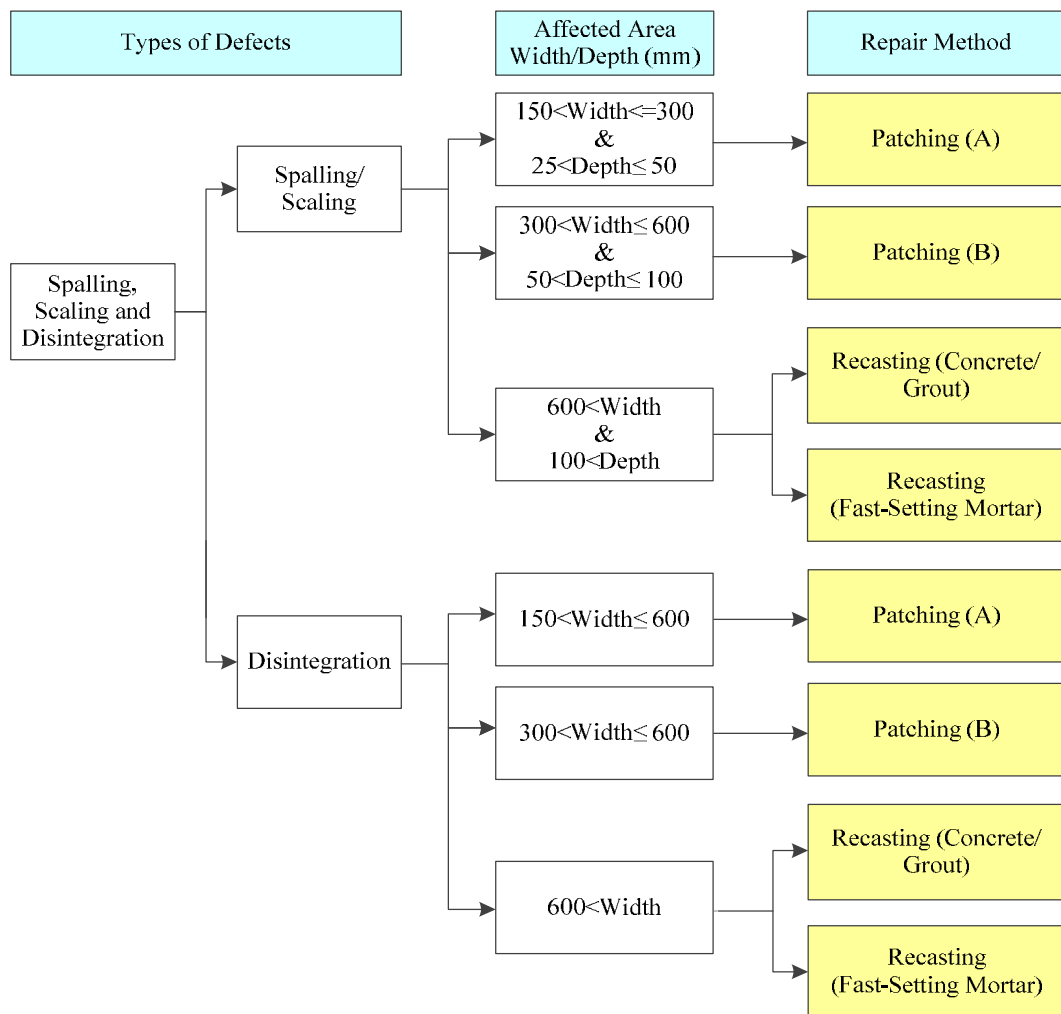
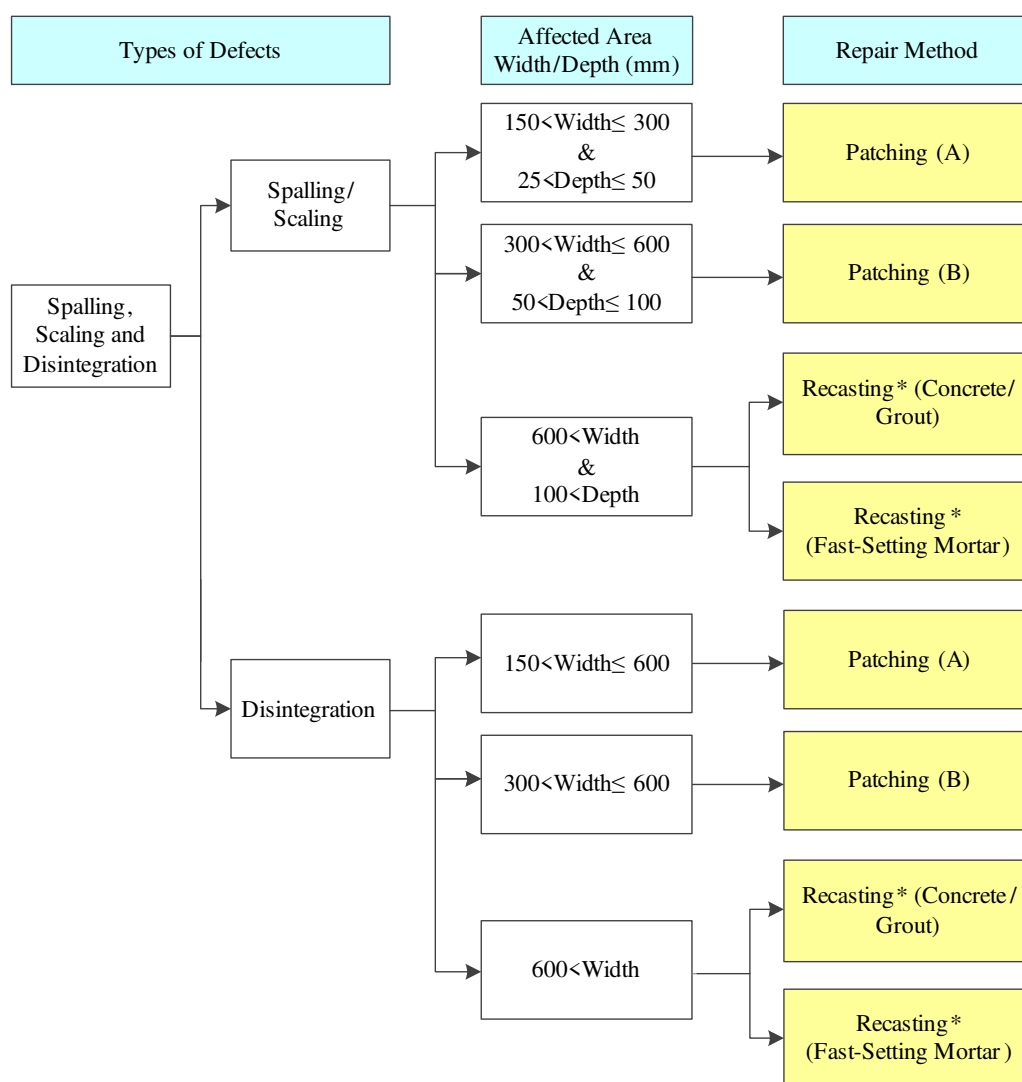


Figure 2-5 Selection Procedure of Repair Method for Superstructure Due to Spalling, Scaling and Disintegration

(3) Substructure



Remark*: For pile bents, repair method is applied with concrete jacket

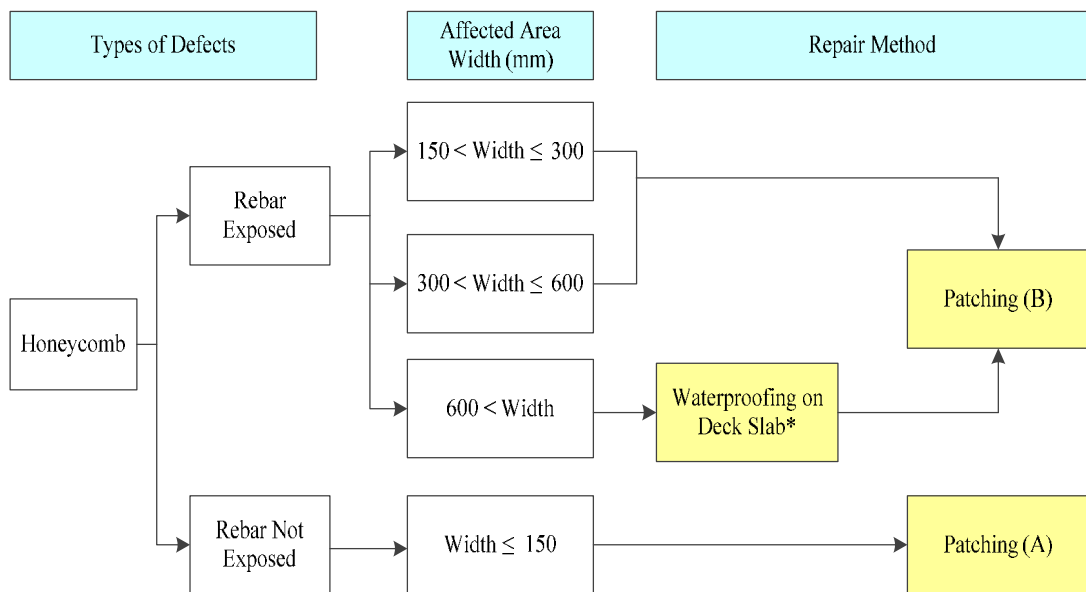
Figure 2-6 Selection Procedure of Repair Method for Substructure due to Spalling, Scaling and Disintegration

2-2-4 Honeycomb on Concrete Structure

Honeycomb is formed due to lack of mortar in the spaces between coarse aggregate particles. It is caused by insufficient compaction or vibration during the placement of concrete, resulting in a porous and weak reinforced concrete. The voids will allow ingress of water, oxygen and corrosive agents such as carbon dioxide, chlorides and sulfates that will eventually cause corrosion of the steel reinforcement.

Honeycomb defects have to be repaired based on the flowcharts shown in Figure 2-7 to Figure 2-9.

(1) Deck Slab



* Water proofing shall be applied after deck repair

Figure 2-7 Selection Procedure of Repair Method for Deck Slab Due to Honeycomb

(2) Superstructure

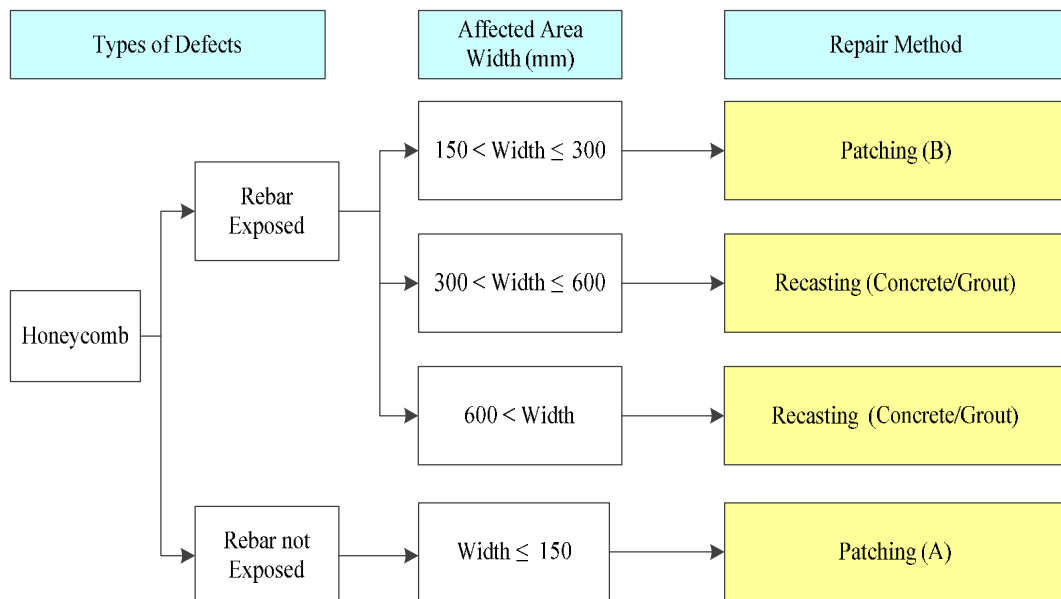


Figure 2-8 Selection Procedure of Repair Method for Superstructure Due to Honeycomb

(3) Substructure

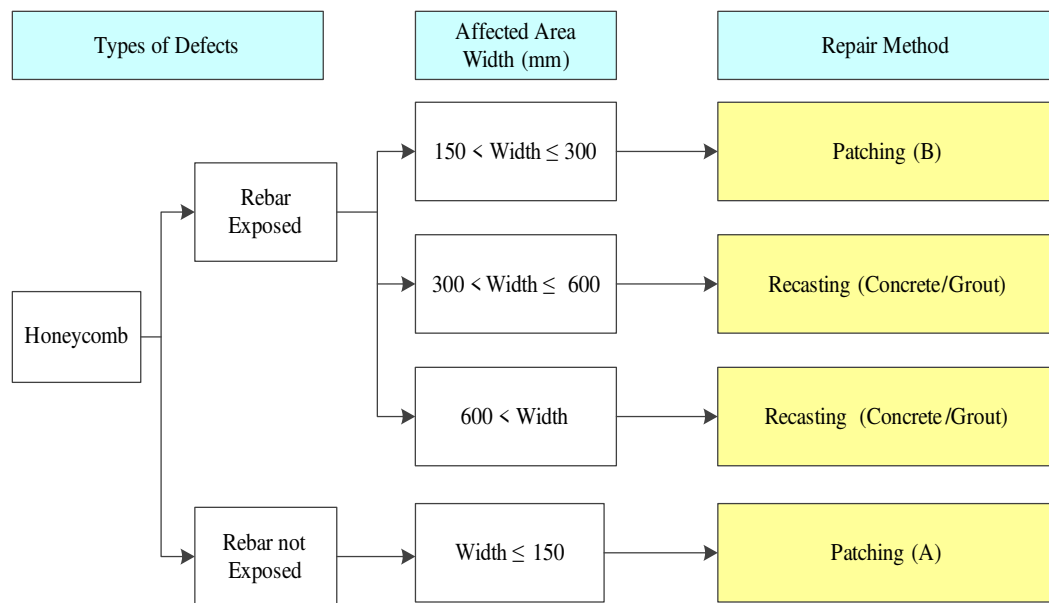


Figure 2-9 Selection Procedure of Repair Method for Substructure Due to Honeycomb

2-2-5 Rebar Exposure on Concrete Structure

During initial occurrence of defects such as spalling, scaling and delamination, exposure of rebars to air is limited, hence, does not significantly affect the strength and serviceability of the bridge structure. In severe cases where rebars are widely exposed and loss of section seem progressive strength and serviceability of the bridge is consequently reduced.

All defects have to be repaired based on the flowchart shown in Figure 2-10 to Figure 2-12. The applicable repair method for rebar exposure is determined according to the width of defective area on the concrete.

(1) Deck Slab

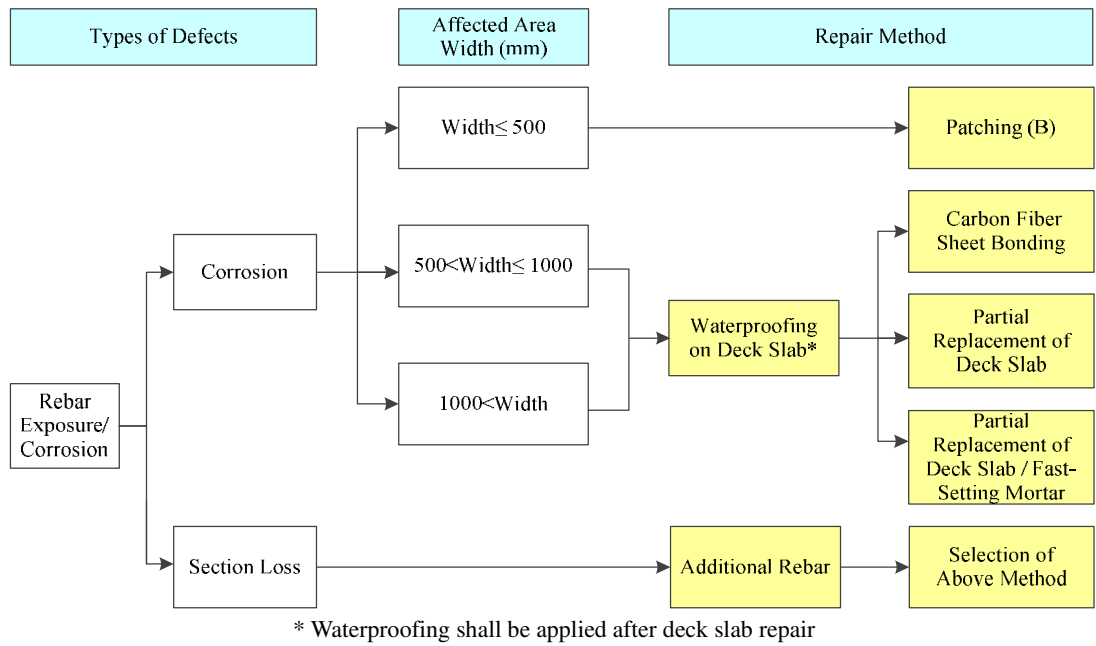


Figure 2-10 Selection Procedure of Repair Method for Deck Slab Due to Rebar Exposure

(2) Superstructure

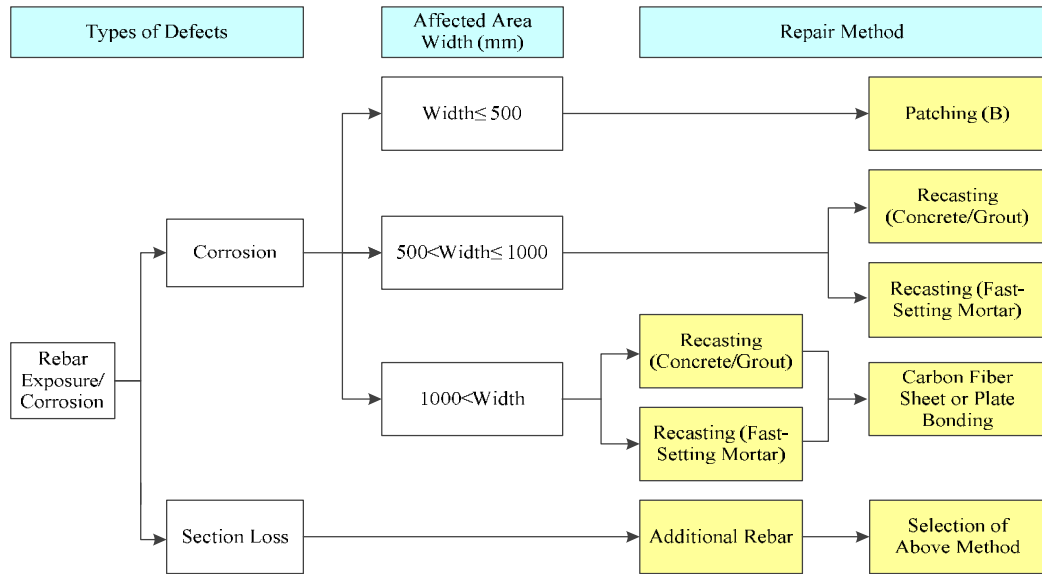


Figure 2-11 Selection Procedure of Repair Method for Superstructure Due to Rebar Exposure

(3) Substructure

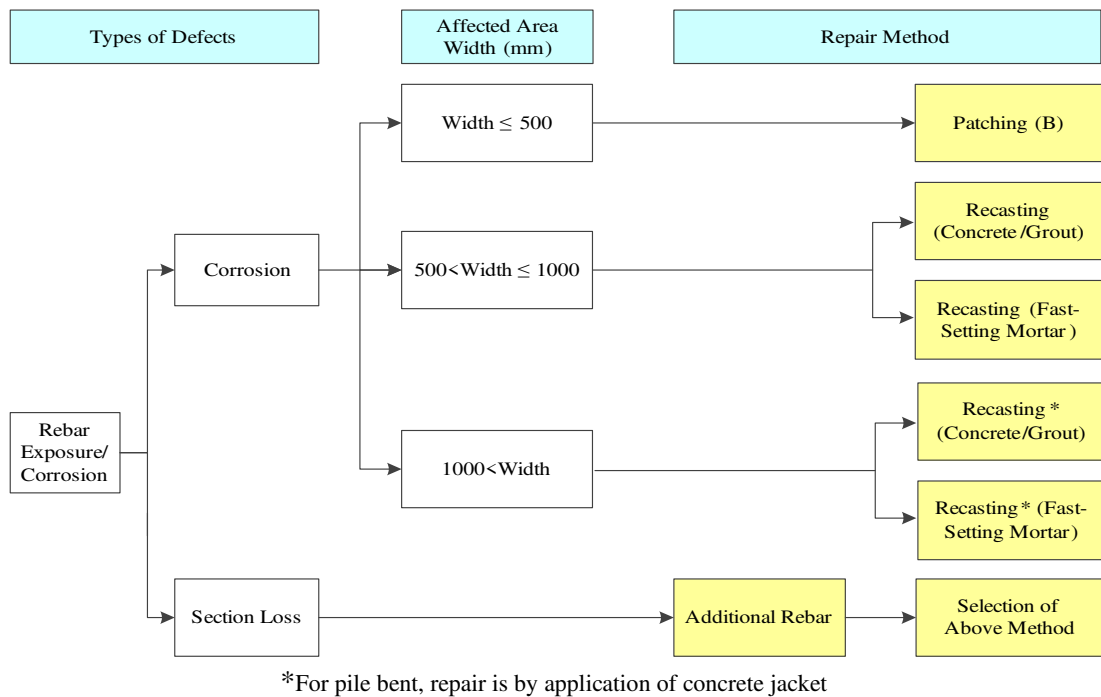


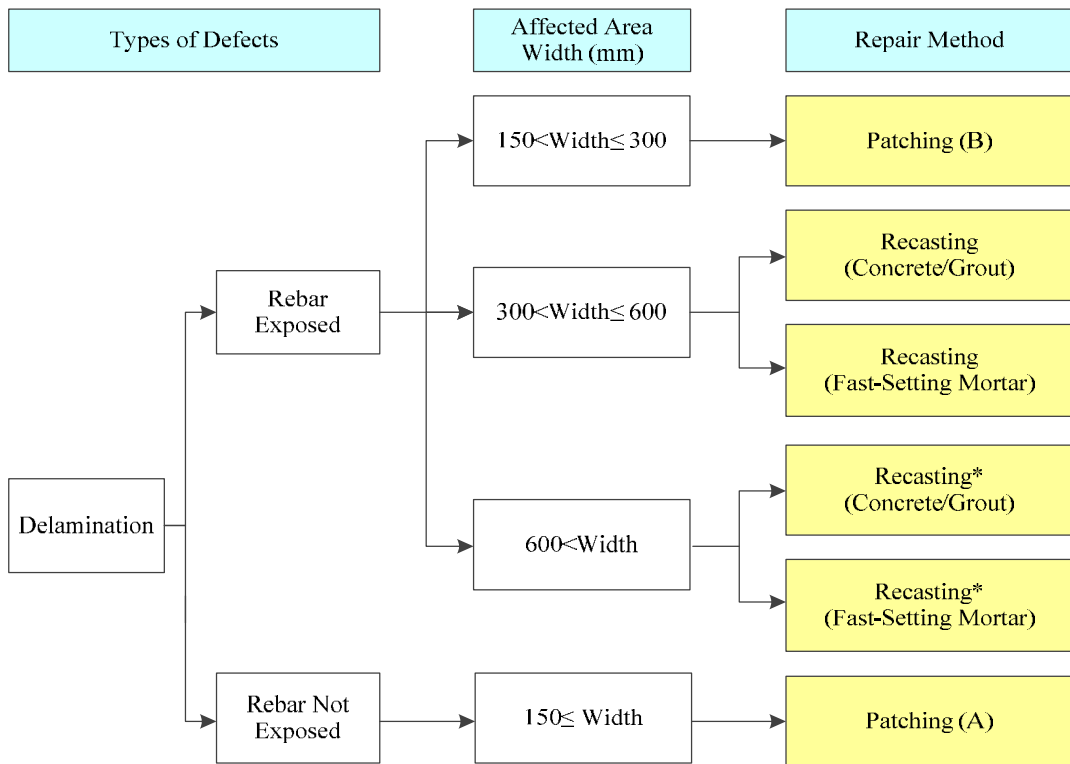
Figure 2-12 Selection Procedure of Repair Method for Substructure Due to Rebar Exposure

2-2-6 Delamination on Concrete Structure

Delamination is the separation of concrete from the reinforcing bar. Delamination may not be identified visually since the defect is beneath the concrete surface. Sound tapping on the surface allows accurate identification of the affected area on the concrete surface. To confirm the delaminated areas, hammer shall be used to break the inspected surface. It should be realized that if the corresponding repair is not successful, the concrete will eventually spall off.

All defects have to be repaired based on the flowchart shown in Figure 2-13 and Figure 2-14.

(1) Superstructure



Remark: If there is section loss of rebar, repair method with mark * is applied with carbon fiber sheet/plate bonding after recasting

Figure 2-13 Selection Procedure of Repair Method for Delamination in Superstructure

(2) Substructure

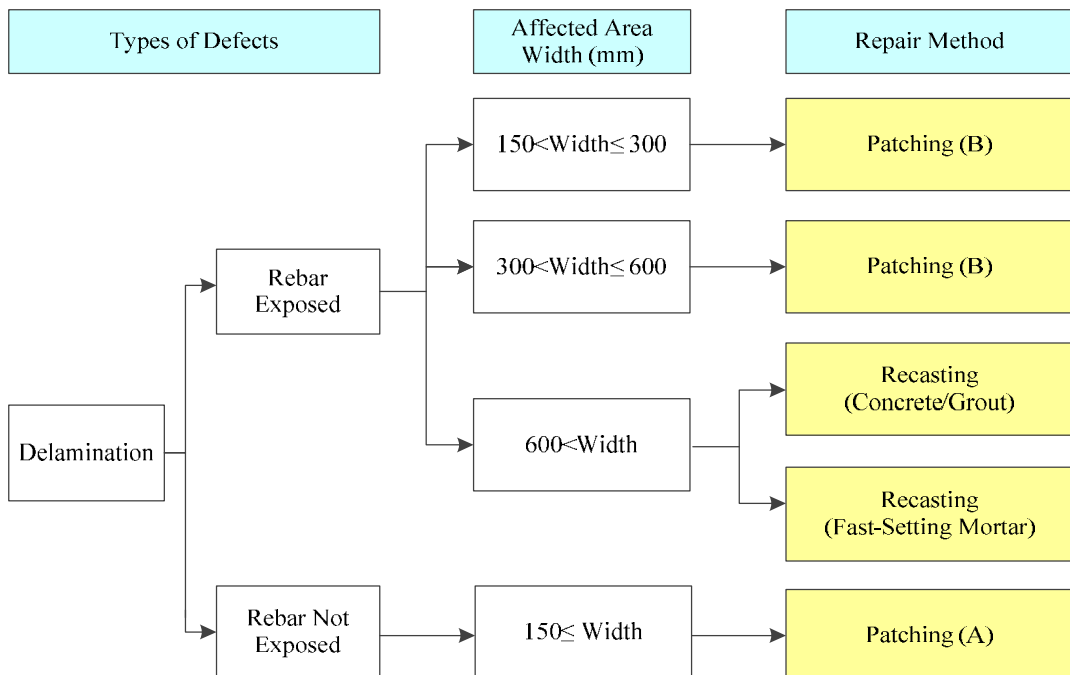


Figure 2-14 Selection Procedure of Repair Method for Delamination in Substructure

2-2-7 Corrosion on Steel Structure

Repainting may be the only repair measure required against rusting and corrosion of steel members. It may also be implemented to supplement other repair measures for strengthening section loss. The most effective method against corrosion is to apply abrasive blast cleaning prior to the proper application of a high quality paint system and touch-up painting as routine maintenance. Heavy corrosion with section loss often appears at the end of lower flanges, thus, adequate paint material should be applied to avoid progressive corrosion. The repair method for rust/corrosion is classified according to the severity of the condition and the percentage of section loss, based on the Condition Rating Criteria in the Bridge Inspection Guidebook.

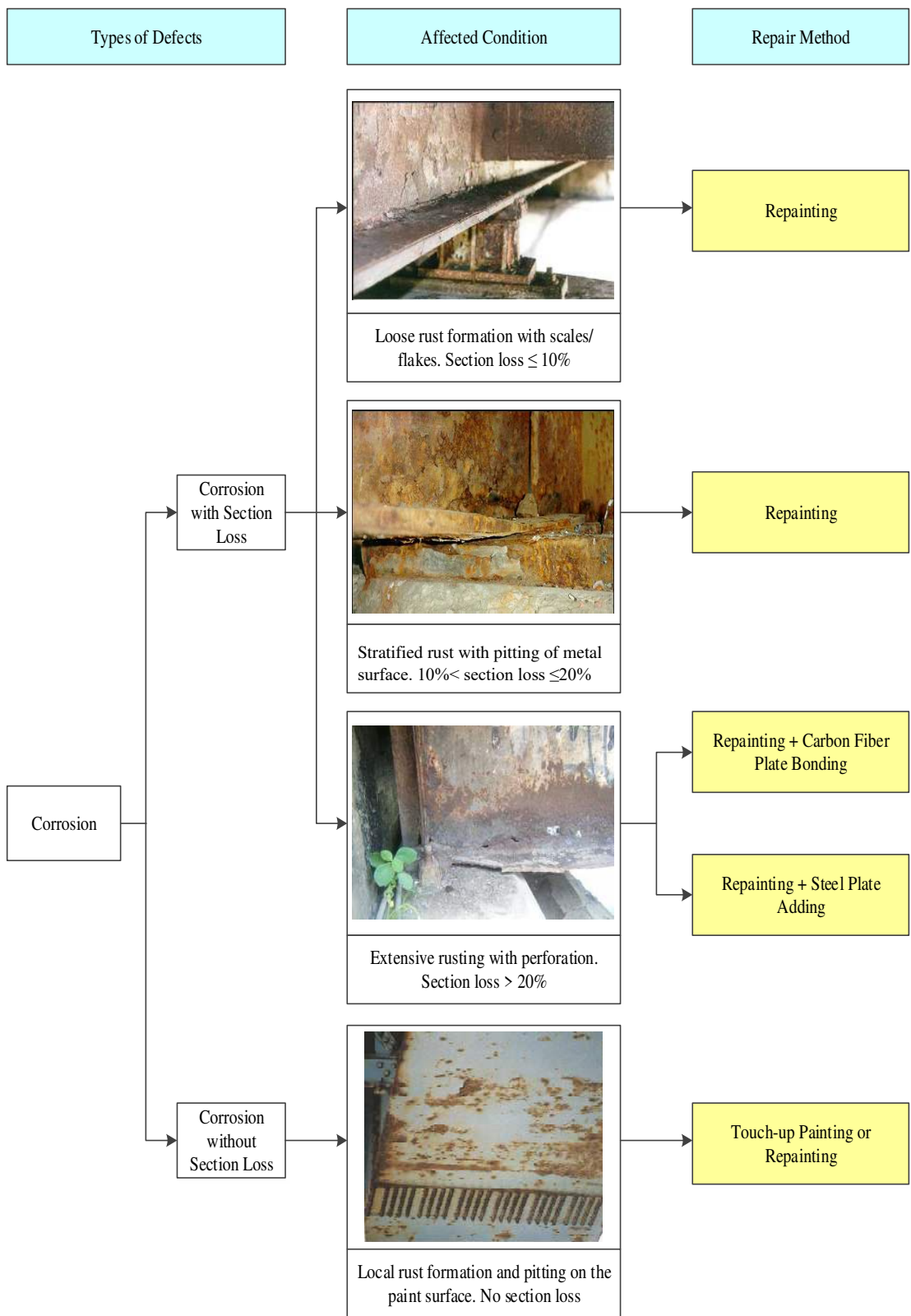


Figure 2-15 Selection Procedure of Repair Method for Steel Due to Corrosion

2-2-8 Paint Peel-off of Steel Structure

Touch-up painting is initially required to supplement the repainting repair for corrosion protection. This shall be applied to the steel structure, prior to final application of paint coating intended to restore the uniform appearance of the bridge. The repair method for paint peel-off is classified according to the percentage of affected surface area, based on the Condition Rating Criteria in the Bridge Inspection Guidebook.

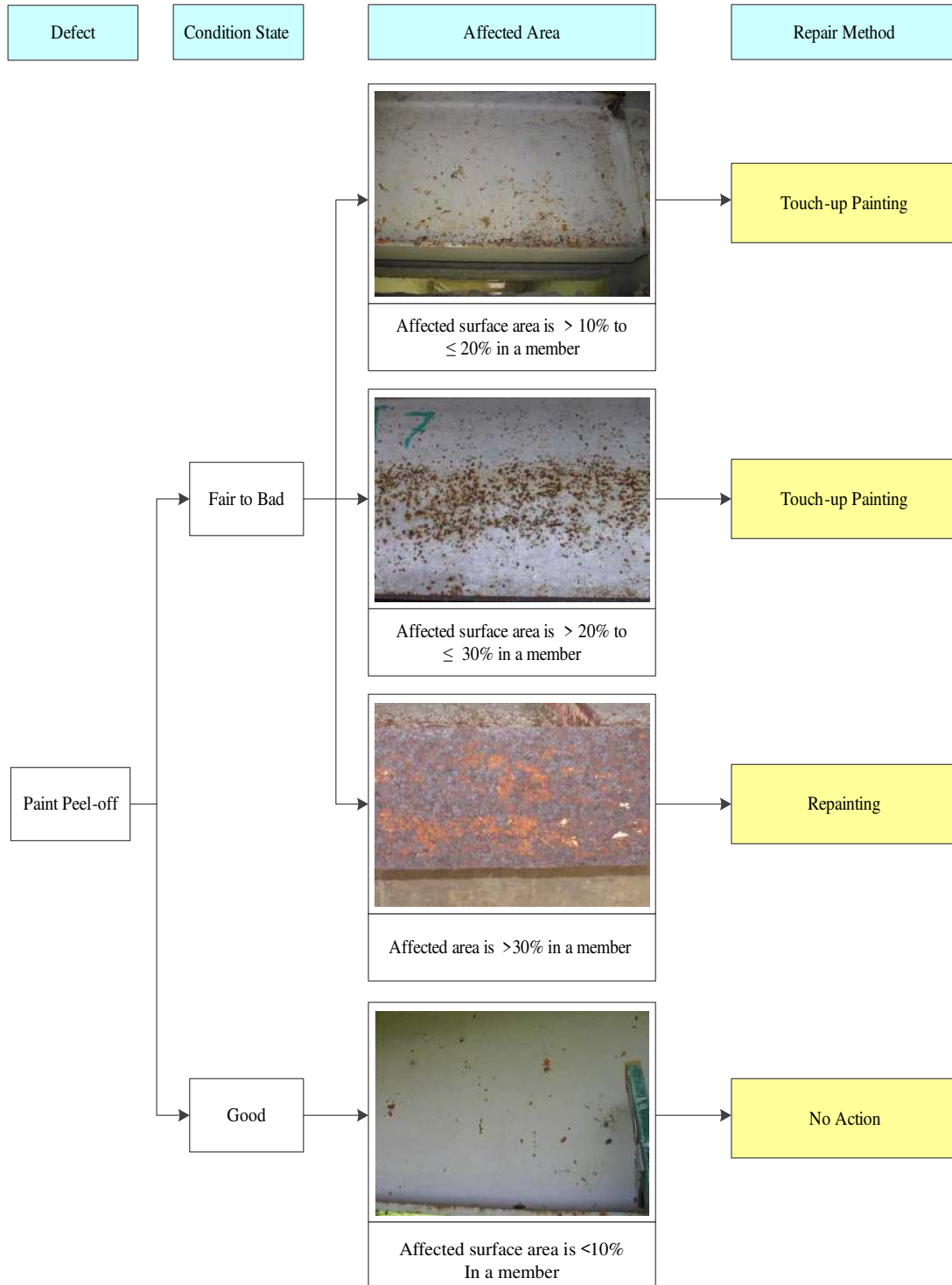


Figure 2-16 Selection Procedure of Repair Method for Steel due to Paint Peel-off

2-2-9 Loose Bolt Connection

Bolts at joints connecting the steel members are sometimes loosened or missing. There were cases where these are merely replaced with ordinary bolts instead of High Tension Bolts (HTB) or steel fasteners. Such conditions subject the bridge to risk of collapse. Repair for loose bolt connection is by resetting or retightening of HTB. The repair method for this defect is classified according to the percentage of loose fasteners and numbers of bolts that fell off from its connection, based on the Condition Rating Criteria in the Bridge Inspection Guidebook.

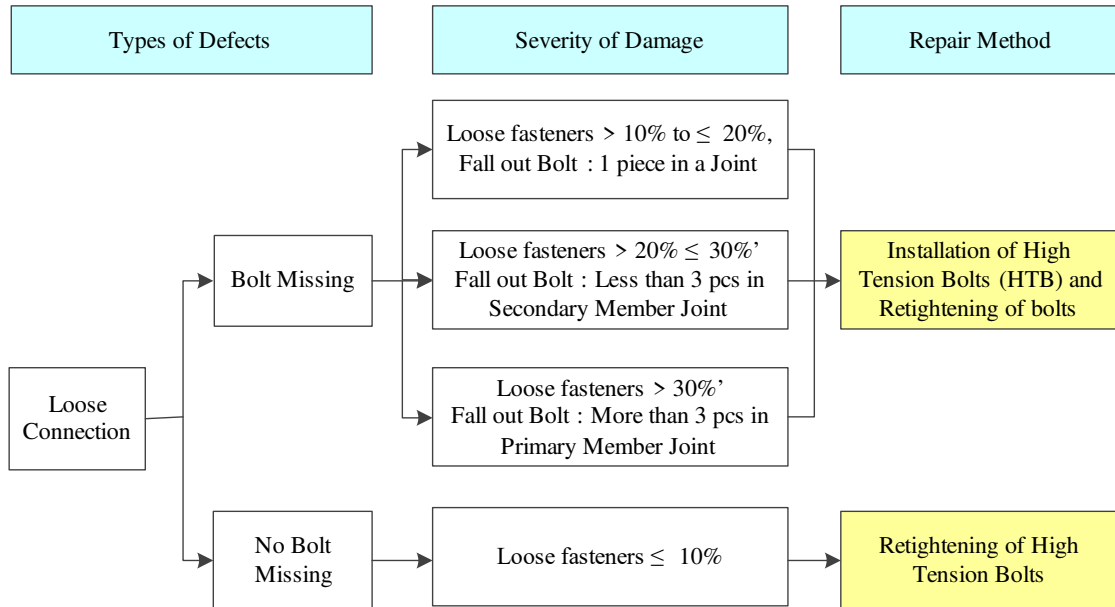


Figure 2-17 Selection Procedure of Repair Method for Steel Due to Loose Bolt Connection

2-2-10 Repair of Bridge Accessories

(1) Expansion Joint

The three major types of expansion joints used for bridges in the country include sealant, rubber and steel joints. These are often damaged because of rain water leakage. Said leakage causes many other damages on the bridge such as degradation of bearings and corrosion of steel girder. Damaged expansion joint should be replaced with seamless joint or a new type of rubber and steel joint with under drain function. The repair method for expansion joint is classified according to the extent of the damage, based on the Condition Rating Criteria in the Bridge Inspection Guidebook.

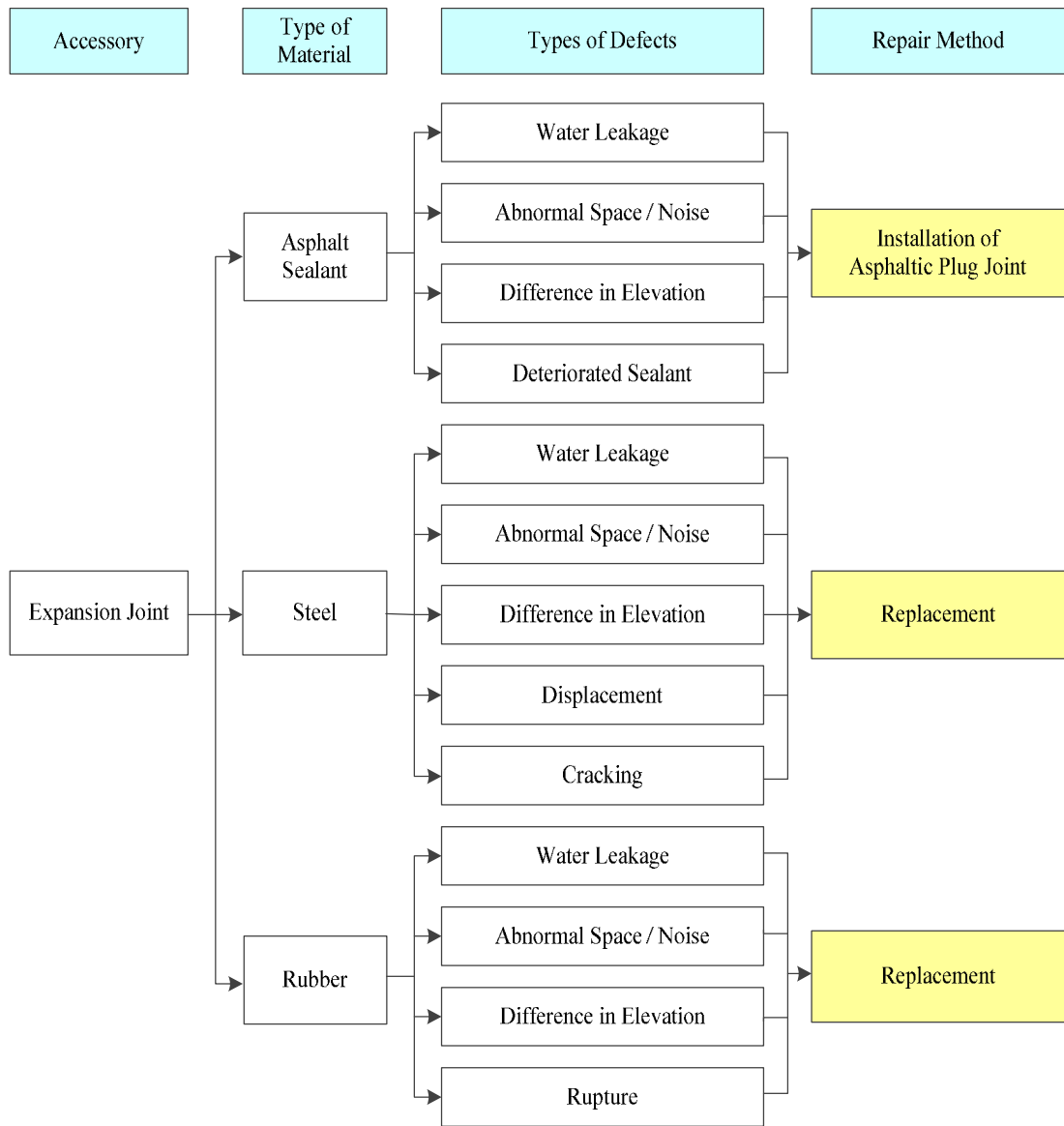


Figure 2-18 Selection Procedure of Repair Method for Expansion Joints

(2) Bearings

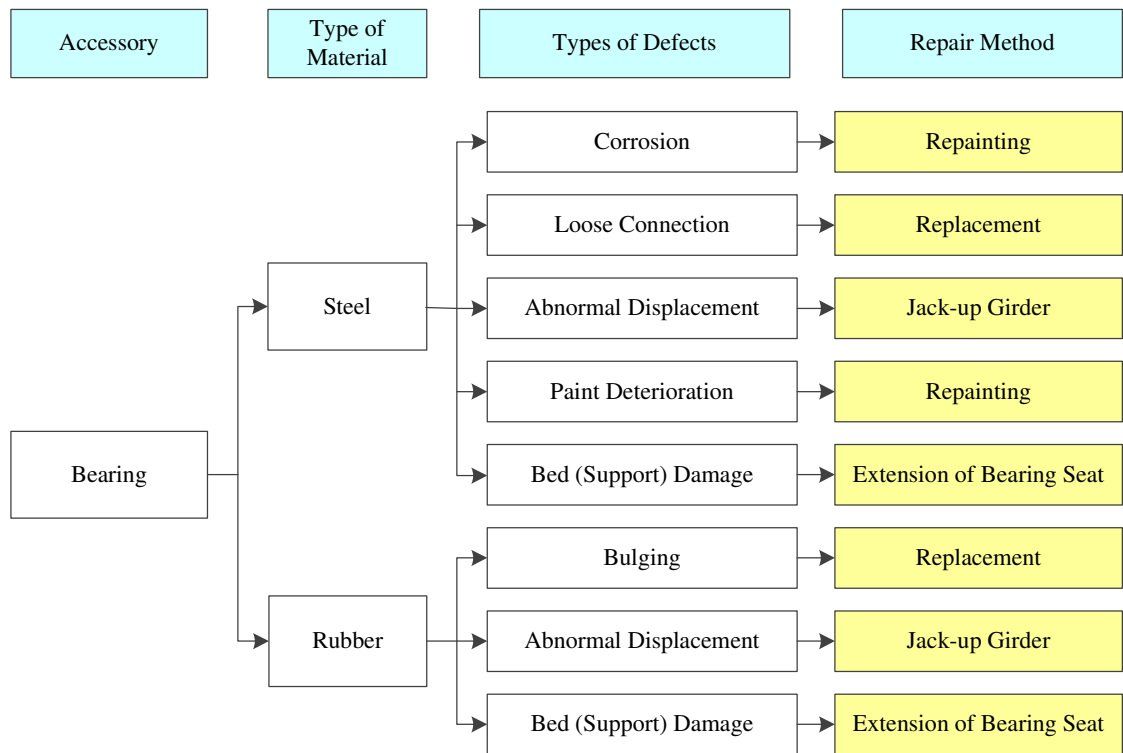
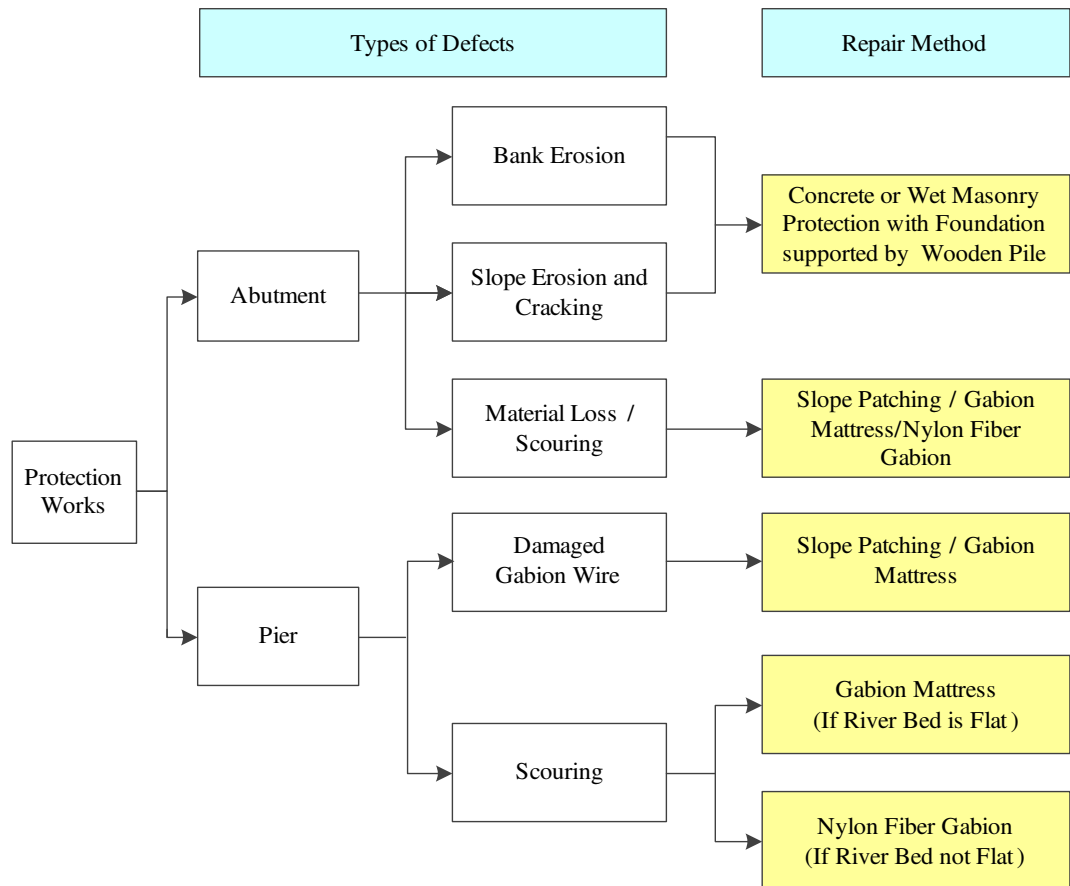


Figure 2-19 Selection Procedure of Repair Method for Bearings



Note: Each damage ranked with "Bad" in Condition of Rating Criteria will be repaired based on recommended Repair Method.

Figure 2-20 Selection Procedure of Repair Method for Protection Works

2-3 CONSIDERATION ON REPAIR ACTIVITIES

2-3-1 Concrete Repair Activities

The most important consideration in repairing any structure is to ensure adequate strength and stability of the bridge at all times. This is particularly relevant for repairs to reinforced concrete elements, where significant areas of concrete are to be removed or to be subjected to repair. In such cases the strength or stability of the structure where a portion of concrete is removed should be checked by a structural engineer, before commencing appropriate repairs. Moreover during repair activities, load restrictions should be imposed and the structure temporarily supported as necessary.

In repair of concrete structures, knowledge on the following is essential prior to implementation of related activities:

- 1) Types of defects which can occur due to deterioration, e.g. cracks, spalls, delamination, scaling, honeycombing etc.,
- 2) Causes of cracks such as carbonation, alkali - aggregate reaction, shrinkage and thermal effects, foundation movements etc.,
- 3) Test methods for assessing the severity of deterioration.
- 4) Selection of appropriate repair materials, from ordinary Portland cement to synthetic polymers, epoxy resins and carbon fiber sheet/plate according to particular requirements of a repair method,
- 5) Selection of appropriate repair procedure

The details for items 1) and 2) were discussed in the previous sections, while items 3) to 5) will be covered in Chapter 4. However, these exclude complex and advanced repair methods (except for carbon fiber sheet/plate bonding and waterproofing on the deck) as this guidebook is intended only for structures that will remain structurally sound after the repair and to those with defects which can be practically repaired, considering local conditions in Zambia.

Furthermore, the repair methods are suitable only to reinforced and plain concrete, and not to pre-stressed concrete.

2-3-2 Steel Repair Activities

Activity on steel repair mainly involves repainting for rusted and corroded steel structures, and touch-up painting as part of routine maintenance.

Regarding defects concerning section loss in steel bridges, which resulted from heavy corrosion, it is evident that its original condition cannot be restored. Similarly, restoring physically damaged steel to its original condition is often difficult. Corresponding repairs therefore involve fitting new steel or carbon plates to compensate for the section loss, in order to restore original strength and serviceability.

The two standard methods for connecting new steel plates are welding and mechanical fastenings (bolts, etc.). Among these, mechanical fastenings exhibit the least potential problems, although welding is usually more convenient and less costly.

The two main potential problems with field welded connections are as follows:

- 1) Satisfactory welds may be difficult or impossible to achieve for steel of older bridges due to their metallurgical properties; and
- 2) Fatigue life of the structure may be adversely affected by welding.

Considering these, mechanical fastening (HTB) should be adopted as the standard repair method.

2-3-3 Bridge Accessory Repair Activities

2-3-3-1 Expansion Joint

Deck slab for Concrete Girder Bridge is commonly provided with a joint sealant between the bridge deck and abutment, and at gaps above intermediate supports (in case of multiple span superstructure). A damaged joint sealant, usually unprotected, allows water and debris to pass through the joint. As a result, debris is accumulated around the bearings on top of abutments and piers. Consequently, the leaking water becomes contaminated and flows to the river under the bridge. This eventually will have an adverse effect to the environment. Corrosion meanwhile could accelerate on the provided steel bearings. Such joints should therefore be replaced with a seamless type, as shown in Figure 2-21.

Deck slabs for steel and Pre-stressed Concrete Girder bridges are commonly provided with sliding plate joints, as shown in Figure 2-22. The damage that usually occur on the sliding plate joint involves missing cover plate due to detached set bolts. The resulting situation is then similar to that described above for damaged joint sealant. Simultaneous to application of new waterproofing and asphalt overlay to the damaged deck slab, expansion joints should be replaced with a rubber or steel expansion joint.

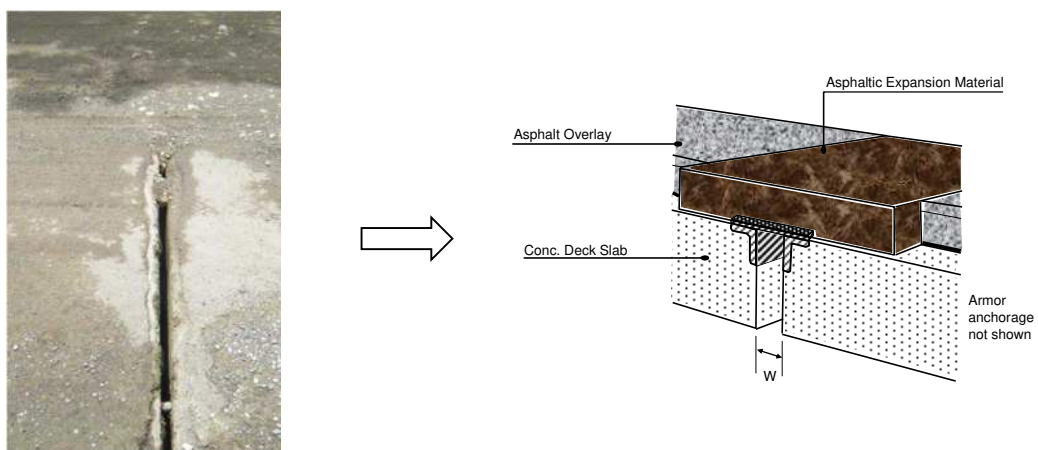


Figure 2-21 Asphaltic Plug Joint

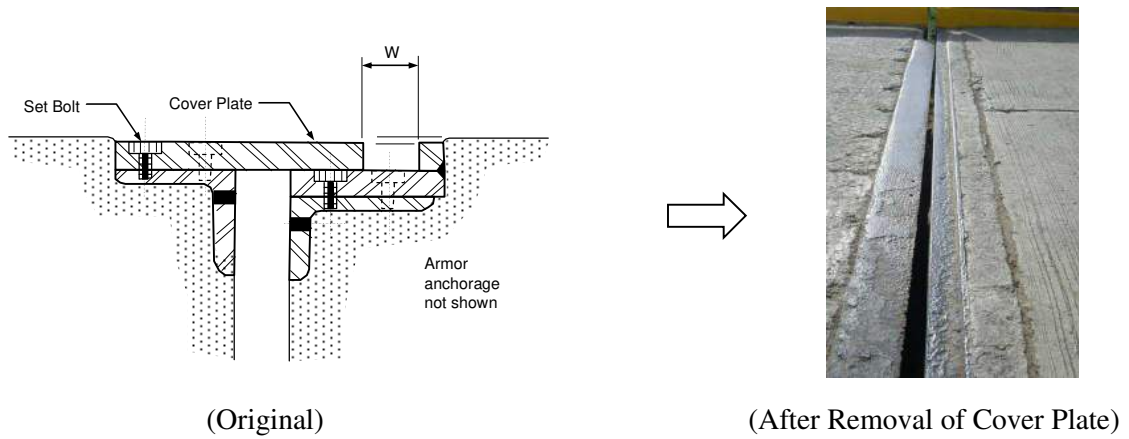


Figure 2-22 Sliding Plate Type Expansion Joint

2-3-3-2 Bridge Drainage

Deck slab drains in most bridges are not efficiently functioning due to lack of drain pit and small and short drain pipe size. It causes the drain pit to clog and girders to rust. This will eventually cause standing rain water to remain on the deck for some time. This rain water will then cause deterioration of the deck slab. Therefore, these clogging pipes should be replaced with large and long PVC drain pipes, fitted into gently sloped drain pits.

2-3-3-3 Bridge Bearing

Concrete Girder Bridges are commonly found not supported with bearings and are placed directly on top of abutment and pier coping. This cause damage to the bottom portion of the girder ends, considering that the superstructure is subjected to traffic impact and thermal movement of the concrete girder. For trunk and main roads where heavy traffic occurs frequently, bridge bearings are necessary to ease traffic impact and to allow for movement without overstressing the concrete girder.

Meanwhile, steel girder and truss bridges are commonly supported by steel sliding bearings and rocker bearings, respectively. Both types of steel bearing are usually observed to be heavily corroded and no longer functioning. For short span steel bridges, rubber bearings as shown in Figure 2-23, may be applicable in Zambia considering its weather conditions such as rainfall occurrences.

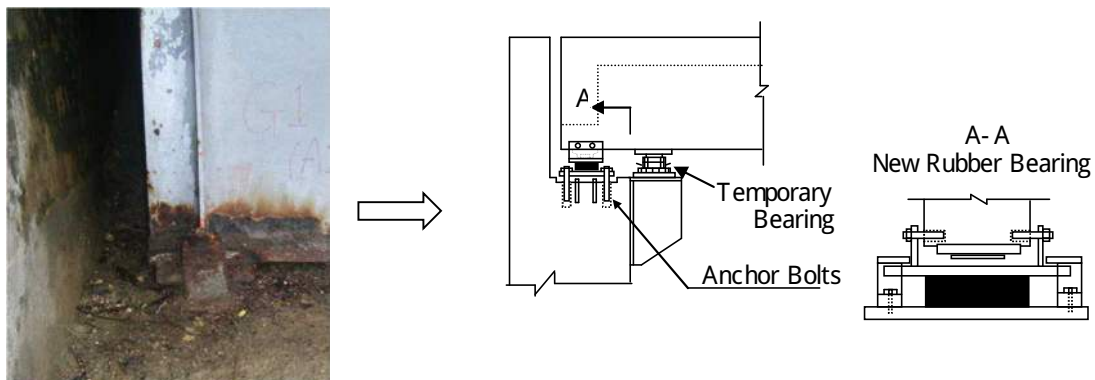


Figure 2-23 Replacement of Bearing

2-3-4 Protection Works Activities

2-3-4-1 Slope Protection/Bank Erosion

Most slope protections at riverside and around abutments are made up of stone pitch filled with mortar along the slope. The slope protection is not commonly supported on footing, thus, sliding and settlement of the slope occur due to local scouring at its toe. At places where slope protection is severely damaged, durable alternative such as concrete or wet masonry protection with footing supported on piles is necessary as repair measure. Concrete protection is more costly than the other methods. Types of abutment protections are determined based on the following:

- 1) Concrete protections are considered where water velocity is high;
- 2) Wet masonry is usually considered as abutment protection and at other sections;
- 3) Gabions are provided where settlement and deformation of riverside protection occur
- 4) Gabions are also considered between the unprotected riverside and the protected riverside (wet masonry or concrete).

2-3-4-2 Local Scouring

Local scouring occurs around piers and toe of abutments due to high river flow velocity. According to survey results on hydraulic conditions and riverbed materials, protection to scouring depth around the bridge piers should be provided. The riverbed protections around the piers and abutments should be sufficient to ensure safety of the bridge piers against maximum scour depth. Gabion mattress apron is suitable to protect local scouring in flexible structures. Also, Nylon Fiber Gabion is more appropriate to protect scouring, if river bed is not flat.

2-4 CONSIDERATION ON DESIGN, MATERIAL AND CONSTRUCTION

2-4-1 Design

Prior to implementation of the bridge repair, verify the damage condition based on the bridge inspection result. Next, conduct a detailed investigation to identify the cause of the damage and know the scale and degree of progress of the damage.

Then, based on the result mentioned above, carry out the following repair design items:

(1) Selection of Repair Method

Based on the cause, scale and degree of the damage which are obtained from the bridge inspection and the detailed investigation, study the repair method and select the best one (refer to relevant sections in 2-2 above).

(2) Design Drawings and Construction Procedure of the Bridge Repair

Prepare the design drawings which include the repair location, repair method, repair materials and construction equipment. Then prepare the construction procedure of repair work.

(3) Construction Quantity and Construction Costs

Calculate the construction quantity, including materials and construction equipment, taking into consideration the design drawings and construction procedure of the bridge repair. Then, estimate the construction costs with the calculated construction quantity.

2-4-2 Material and Construction

If the construction company in Zambia is unable to procure the materials and construction equipment of the determined repair method, it is necessary to consider to procure them from foreign countries like South Africa.

In addition, if construction companies in Zambia don't have the construction technology of the determined repair method, it is necessary to consider the introduction of foreign construction companies (such as companies in South Africa).

CHAPTER 3 REPAIR OF CONCRETE DECK SLAB

3-1 EPOXY COATING

3-1-1 Description of Repair Method

This work item is applicable to repair of vertical or overhead cracks, with widths less than 0.3 mm.

Epoxy coating, made up of epoxy compounds with high strength and non-solvent two-component material, is characterized by its excellent adhesion to both dry and wet concrete.

It should be noted that epoxy coating is not a repair method, but a protective or preventive application to prolong the bridge service life. The coating, applied using a roller brush, should be capable of penetrating overhead, downward and vertical. This measure is one of the most appropriate maintenance activities.



Photo 3-1 Epoxy Coating Penetrating into the Crack

3-1-2 Application Criteria

Cracks with widths less than 0.3 mm are acceptable if the cause is non-structural and has no adverse effect on the structure. However, it is difficult to evaluate whether the crack is stable or developing due to such factors as carbonation, chlorination, corrosion, overloading of structure, insufficient reinforcement or inadequate concrete cover.

As a protective or preventive measure, epoxy coating should be applied on surfaces of concrete structures, with cracks of less than 0.3 mm width, regardless if crack formation is structural or non-structural. Subsequently, the regional office should regularly monitor the cracks for future repair, if necessary.

3-1-3 Procedures

(1) Preparation of Concrete Surface

Concrete surfaces adjacent to the crack shall be cleaned by air jet, and free from laitance and contaminants such as grease and oil.

(2) Application of Epoxy Sealant

Apply approximately 50 mm width strips of epoxy sealant coating to concrete surfaces along the crack, as recommended by the manufacturer.

(3) Curing

After application, perform until the epoxy coating hardens.

(4) Monitoring of Crack width

The cracks coated with sealant shall be monitored by a designated maintenance staff of the Regional Office, to determine whether it is progressing or not.

3-1-4 Required Materials and Tools/Equipment

(1) Required Materials

- Epoxy Sealant

(2) Required Equipment/Tools

- Brush or Paint Roller

3-2 EPOXY INJECTION

3-2-1 Description of Repair Method

This method involves crack repairs to concrete structures, particularly to deck slab as shown in Figure 3-1. The works include preparation of concrete surface, installation of injection ports bonded with adhesive, injection of epoxy, curing and conducting performance test.

Epoxy injection for concrete cracks requires highly skilled process and its effectiveness depends mostly on the proficiency of the certified applicator. Said applicator should be qualified based on his previous work records, and approved by the Engineer.

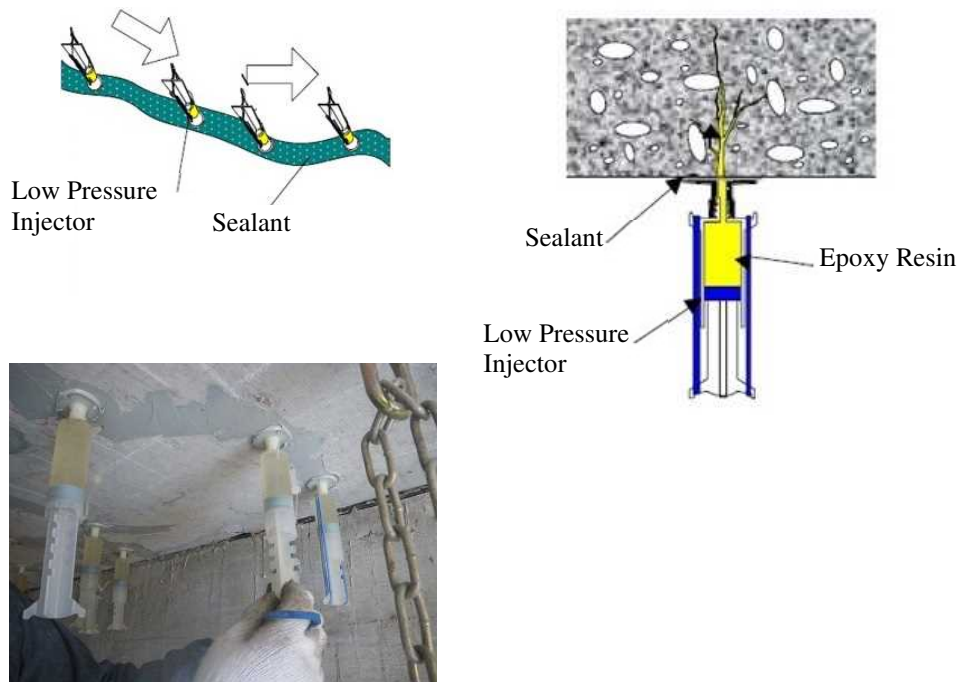


Figure 3-1 Crack Injection Method

3-2-2 Application Criteria

Epoxy injection is used to restore structural soundness of structures exhibiting inactive cracks. Cracks with more than 0.3 mm up to 3.0 mm widths can be bonded and sealed by injecting low-viscosity epoxy.

3-2-3 Procedures

Cleaning of Cracks

1. Adhesion of Injection Ports
2. Sealing of Cracks and Injection of Epoxy
3. Curing of Injected Material and ports removed

a: Concrete Surface, b: Crack, c: Injection Port
d: Sealant

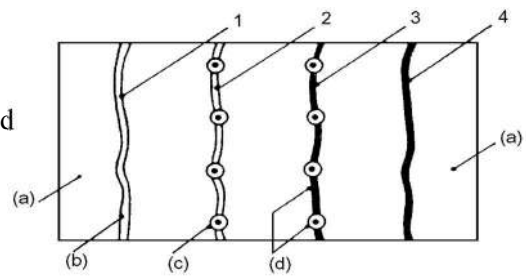


Figure 3-2 Sequence of Operation

(1) Cleaning of Cracks

All loose debris such as dirt, concrete fine particles and contaminants (oil, grease, etc) are removed from the cracks using high-pressure water, or special and effective solvent. Remove residual water or solvent in the crack with filtered (dust and oil free) compressed air and allow adequate time for drying.



(2) Adhesion of Injection Ports

Injection ports are bonded with adhesive to the crack center for injecting epoxy. Spacing of the ports varies between 150mm to 500 mm, depending on the width and depth of the cracks.



(3) Sealing of Cracks at the Surface

Using a 5 cm width strip, epoxy sealant is applied on the area around the ports and cracks, allowing it to harden.



(4) Fitting of Injector

Connect the terminal of the injector to the port.



(5) Injection of Epoxy

Epoxy shall be injected using low pressure injector, injection gun or other injection devices as shown in Figure 3-3. Injection is performed on the injection port. Duration of the injection operation shall be in accordance with the supplier's instruction.

For horizontal cracks, epoxy injection is carried out from one end of the crack to the other. And for vertical cracks, epoxy injection is carried out from the top end of the crack to other.



Automatic Low Pressure Injector



Injection Gun

Figure 3-3 Crack Injection Equipment

(6) Curing of Injected Material

After the crack has been injected, the projecting injection ports shall be removed and holes shall be filled with an epoxy sealant. Surface coating will be applied if required in the repair process.



3-2-4 Required Materials and Tools/Equipment

(1) Required Materials

- Epoxy Resin
- Epoxy Sealant
- Injection Port

(2) Required Equipment/Tools

- Epoxy Injector or Gun
- Power Disc Grinder/Cutter
- Portable Generator
- Brush, etc.

3-3 CAULKING

3-3-1 Description of Repair Method

Active cracks are treated as movement joints and repaired with flexible sealants as shown in Figure 3-4. The sealant is generally applied in a wide recess cut along the crack. The dimensions of the recess (width and depth) depend on the total crack movement and the cyclic movement capability of the joint sealant used. For selection of sealant material, crack movement should be calculated taking into account the applied loads, shrinkage and temperature variations.

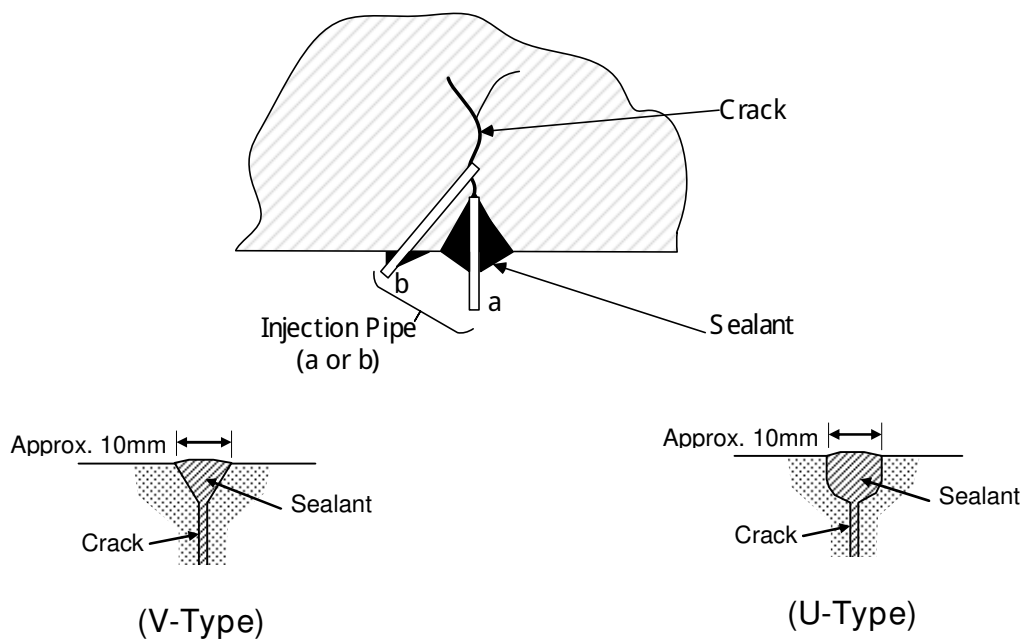


Figure 3-4 Type of Caulking

3-3-2 Application Criteria

Crack widths could be more than 3.0 mm with depth of less than 300 mm. In this case, the top surface edges should be chipped or sawn to form V-type or U-type groove, in order to provide a caulking for inlet of gravity flow of resin into the crack by injection pump.

Cracks wider than 3.0 mm generally require epoxy-based injection material.

3-3-3 Procedures

(1) Cleaning of cracks

Remove all loose debris such as dirt, concrete fine particles and contaminants (oil, grease, etc.) from the cracks using high-pressure water, or special and effective solvent. Remove the residual water or solvent in the crack with filtered (dust and oil free) compressed air and allow adequate time for drying.



(2) Preparation of Caulking

Using a concrete saw, hand tools or pneumatic tools, a V-groove or U-groove, approximately 10 mm in width and in depth, is prepared at the surface along the crack. The groove shall then be partially sealed with a sealant.



(3) Drilling of Holes and Fixing of Injection Pipes

Port holes are drilled near the crack or in the groove. Injection pipes are then fixed at the tip of the groove. Spacing between ports varies between 150 mm to 500 mm, generally depending on the width and depth of the cracks.



The groove is then completely sealed with sealant.

(4) Injecting the Epoxy Resin

Epoxy resin can be injected using injection pumps, or air-activated caulking guns. Duration of injection process shall be in accordance with the supplier instructions.

For horizontal cracks, the injection is carried out from the injection pipe at the end of the crack to the other end.



(5) Curing of Injected Material

After the crack is sealed, the projecting injection pipes are cut and the holes are filled with epoxy sealant. If surface coating or carbon fiber sheet will be applied, the portions with sealant and tip of cut pipe should be grinded to form a smooth surface.



3-3-4 Required Materials and Tools/Equipment

(1) Required Materials

- Epoxy Resin
- Epoxy Sealant
- Injection Pipe

(2) Required Equipment and Tools

- Grout Injection Pump or Gun
- Power Disc Grinder/Cutter
- Portable Generator
- Brush

3-4 PATCHING

3-4-1 Description of Repair Method

Patch repair is performed to restore small areas where sound concrete is damaged by spalling, scaling and impact. This method of repair is generally applied using trowel and require none or minimum formworks. The patch thickness is limited to a maximum of 100 mm depth of hollow surface.

Type A Patching is for defects without exposed rebars while Type B Patching is applied to surfaces with exposed rebars.

Non-shrinkage polymer cement mortar is used for the patch repair.

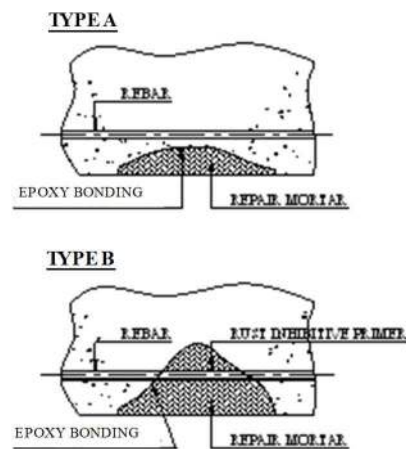


Figure 3-5 Types of Patching

3-4-2 Application Criteria

Patch repair is classified into two types as shown in Figure 3-5 considering defective area and surface. Type-A is applicable to surfaces without exposed rebars having defective widths of up to 300 mm and depth of up to 50 mm. Type-B is for surfaces with exposed rebars with defective widths between 300 mm and 600 mm, and up to 100 mm depth.

Non-shrinkage polymer cement mortar is used for Type-A and Type-B patching.

3-4-3 Procedures

(1) Removal of Defective Concrete

Remove all defective, unsound and contaminated concrete and prepare the edges for the patch area. If local corrosion in reinforcement with section loss is found, which would require additional bars, remove only the damaged area of concrete including the length needed to bond the new reinforcement as shown in Figure 3-6.

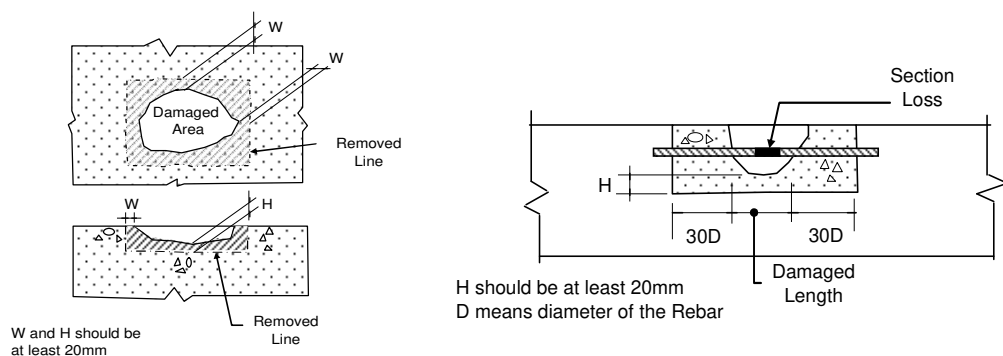


Figure 3-6 Limits of Removal of Damaged Concrete

(2) Cleaning of Surfaces of Concrete and Rebar

Remove loose particles and dust using high pressure water or vacuum cleaner. Concrete surfaces to be bonded have to be free from dirt, oil, grease, asphalt. Corrosion has to be removed before placing the new mortar. If deterioration is due to chloride contamination or if the reinforcement is covered with loose corrosion elements and has developed pits, use water abrasive blasting until all the rust is removed



(3) Applying Epoxy Bonding Coats to Concrete and Rebar

Epoxy bonding coats are applied to dry and clean concrete surfaces in order to bond firmly. Specially formulated resins are also available for damp surfaces. Apply the epoxy bonding coat to steel bars with a brush working vigorously to ensure that they are evenly covered all around.

As notes, depending on the type of mortar, the bonding coat to the concrete surface may not be needed.



(4) Placing Mortar

The mortar should be placed in layers of about 20 mm thick. Compact each layer thoroughly over the entire surface using a wooden trowel or hammer. Generally, there should be no time delays between the placing and compaction of layers.

The patching to the surrounding concrete is performed using a form material, and then hammered using a mallet, wood floating or steel trowel.



(5) Curing

All types of cement repairs need thorough and continuous curing to develop strength and impermeability, and to minimize drying shrinkage while bond strength is developing.



3-4-4 Required Materials and Tools/Equipment

(1) Required Materials

Polymer Cement Mortar (PCM)

- PCM Powder

- Water

- Concrete Nail

- Bonding Agent to Concrete

(Epoxy Resin Adhesive)

- Bonding Agent to Rebar

(Zinc Rich Primer)

(2) Required Equipment

- Chisel

- Portable Generator

- Wire Brush

- Small Hammer

- Mortar Mix Bucket

- Safety Goggles

- Trowel

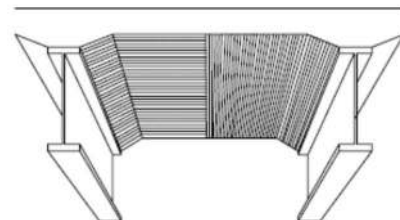
- Scaffolding or Inspection Vehicle

3-5 CARBON FIBER SHEET BONDING TO DECK SLAB

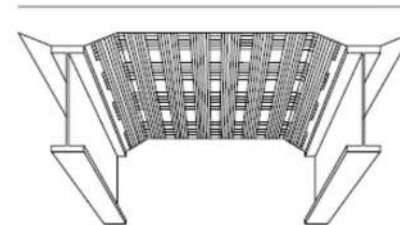
3-5-1 Description of repair Method

Carbon fiber sheet for reinforced concrete repairs and strengthening systems consists of a combination of carbon fiber reinforcing material and adhesive resin such as epoxies and other materials. This composite product is intended to enhance the capacity of the concrete deck slab and extend its service life. The function of the resin is to serve as an adhesive bond onto the concrete surface and facilitate the transfer of stresses to and from the carbon fiber sheet.

The works shall consist of furnishing and installing two types of Carbon Fiber Sheets as shown in Figure 3-7 for concrete strengthening systems in accordance with the plans and specifications. The systems shall be designed to strengthen and stiffen concrete bridge deck slab and tested by the Engineer to verify performance.



Continuous Arrangement



Grid Arrangement

Figure 3-7 Arrangements of Carbon Fiber Sheet

3-5-2 Application Criteria

The related strengthening system for the concrete deck slab shall generally consist of woven carbon fiber sheet (CFS) reinforcing layers, bonded to the concrete surface with epoxy adhesive.

The continuous arrangement is commonly used during the early stage of CFS bonding application at the bottom of the deck slab. However, in most of the cases observed, entrapped air which could not be easily released, was found in the installed CFS. These air voids reduce bond strength between CFS and concrete surface and has to be squeezed out by a roller. Meanwhile, in the grid arrangement, CFS does not totally cover the required surface. Instead, the CFS is installed in strap-type method in both directions. According to experimental results, effectiveness of the second system is almost same as the continuous arrangement. Moreover, entrapped air in the second system can be squeezed out easily using a roller. Thus, in this guidebook, the grid arrangement is recommended considering its ease of application, least cost and acceptable effectiveness. The carbon fiber sheet should be applied as two layers in both the longitudinal and transversal directions, as shown in Figure 3-8.

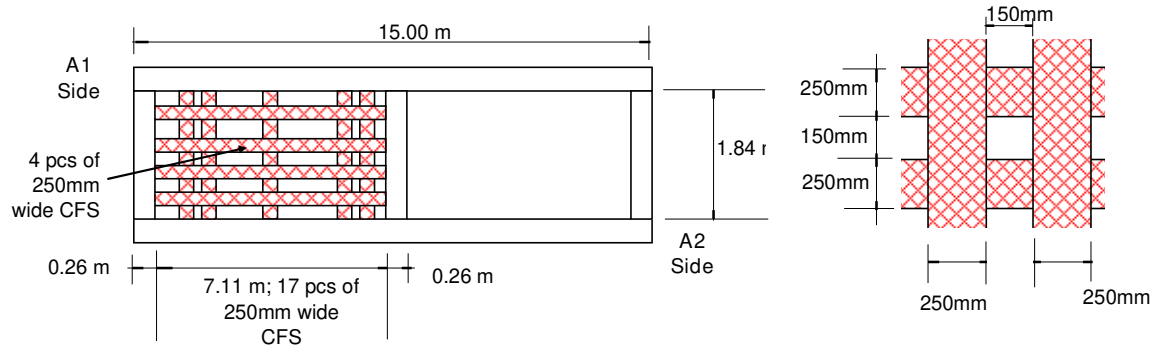


Figure 3-8 Arrangement of CFS (For Reference)

3-5-3 Procedures

(1) Preparation of Concrete

Disc grinder or abrasive sandblasting is used to clean and smoothen the concrete surface.



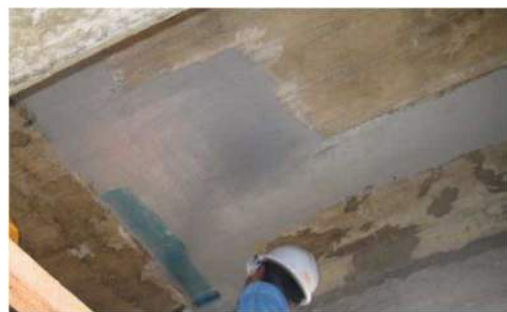
(2) Application of Primer

The surface is coated with a primer resin to increase the strength of concrete surface and improve its bonding with CFS.



(3) Adjustment of Unevenness with Sealant

Any concave, pores, gaps on the concrete surface has to be smoothened using epoxy sealant.



(4) Application of Epoxy Resin for Undercoat

When the epoxy sealant becomes tack-free, the epoxy resin is applied to the concrete, acting as an adhesive to bond the CFS. The molded composite is achieved as the resin permeates into the CFS.



(5) Installation of Longitudinal Layer CFS

Properly aligned CFS strips are installed in longitudinal direction to the adhesive coated concrete surface.

Press the carbon fiber sheet by using plastic roller starting from the center toward the edge.



(6) Installation of Transversal Layer CFS

Properly aligned CFS strips are installed in transversal direction to the adhesive coated concrete surface.

Press the carbon fiber sheet by using plastic roller starting from the center toward the edge.



(7) Squeezing out of Entrapped Air

For complete impregnation, entrapped air is squeezed out of the strips using a roller, before the adhesive sets. Do not apply the roller against the direction of the placed CFS to avoid damaging the material



(8) Surface Protection

For safety purposes, fire proof protection coating may be applied to the finished surface.



3-5-4 Required Materials and Tools/Equipment

(1) Required Materials

Carbon Fiber Products

- CFS (Strap Type)

Epoxy Materials

- Epoxy Primer
- Epoxy Sealant
- Epoxy Resin Adhesive for CFS

(2) Required Equipment

- Abrasive Sandblaster
- Air Compressor
- Disc Grinder
- Portable Generator
- Paint Roller/Brush

3-6 STEEL PLATE BONDING

3-6-1 Description of Repair Method

The technique of bonding steel plates to concrete deck slab using epoxy adhesives has been used on a number of bridges to enhance their load carrying capacity in Japan and other countries. The viability of this technique for a particular structure should be considered carefully due to its sensitivity to standards of workmanship and need for regular in-service inspection. Economical evaluation should be carried out in order to compare this technique with other methods of strengthening. The effect of bonding a plate to the tension face of a reinforced concrete section is to increase the depth from the compression face to the neutral axis and the area of effective reinforcement, thus, increasing the moment of resistance of the section.

The steel plate bonding has two types, namely, wide plate and narrow plate as shown in Figure 3-9. Wide plates are used for strengthening the slab in both the main reinforcing bar and distribution bar directions. Narrow plates are used for strengthening the slab in one direction only.

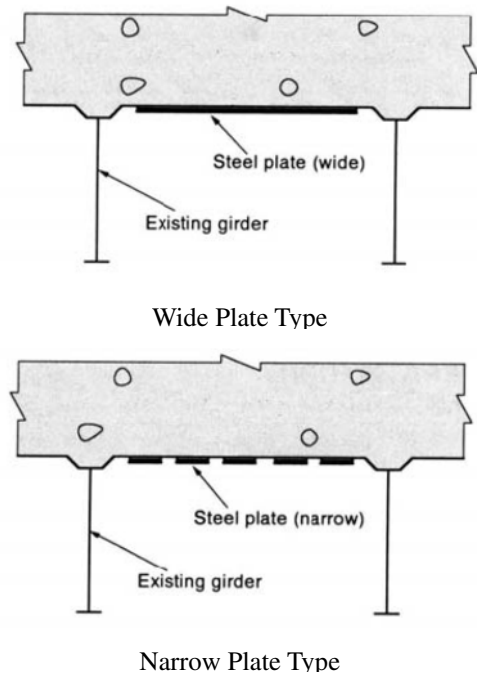


Figure 3-9 Types of Steel Plate Bonding

3-6-2 Application Criteria

Type of steel plate bonding (wide and narrow steel plates) to be applied shall be according to the direction of the damaged rebar of the deck slab, as discussed above. The bonding of steel plates to concrete members has been undertaken considering two methods as follows:

Injection Method

This method involves single plates of required thickness, with gaps sealed at the edges between the steel and the concrete. Resin is then pumped ensuring that no voids occur between the plate and the concrete as shown in Figure 3-10.

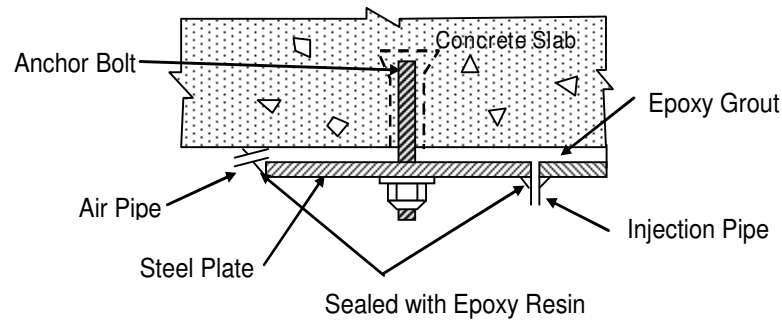


Figure 3-10 Detail of Injection Method Sealing with Epoxy Adhesive

Pressure Attaching Method

Similar to injection method, this requires single plates of required thickness with gaps sealed at the edges between the steel and the concrete. However, epoxy resin in this method is injected to ensure that no voids occur between the plate and the concrete.

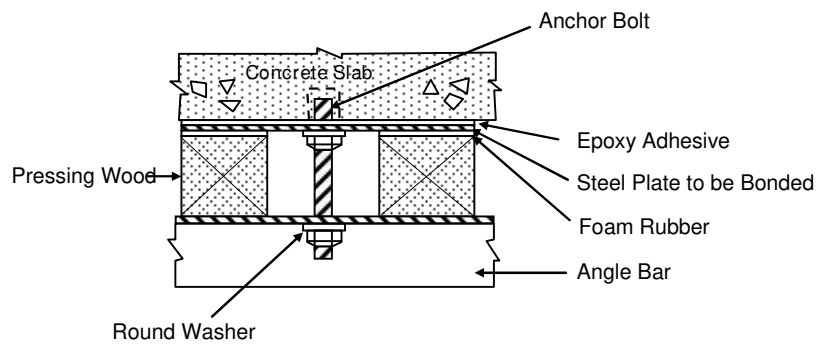


Figure 3-11 Detail of Pressure Attaching Method by Anchor Bolts

Injection method should be applied for wide plate type while pressure attaching method for narrow plate type, with due consideration to the extent of surface preparation of both concrete and steel plate.

3-6-3 Procedures

3-6-3-1 Injection Method

(1) Surface Preparation

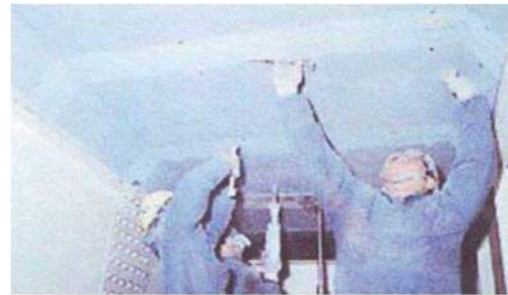
Bottom surface of slab to be bonded with steel plate shall be cleaned. Any surface irregularities shall be leveled using a disc grinder.

The surface of the steel to be bonded has to be completely free of any mill scale, rust, grease or other contaminants. The primer should be applied on the surface which is compatible with the adhesive.



(2) Setting of Steel Plate on the Slab

Injection pipes are attached to the steel plate. Anchor bolts shall be provided to temporarily support steel plates (placed below the slab surface with an average gap of 5 mm) in the event that the deck slab settles. Joints between steel plates are welded at site.



(3) Sealing of Steel Plate

The periphery of the steel plate is sealed with epoxy sealant as well as the area surrounding the injection holes.



(4) Injection of Epoxy Resin

Mixing is continuously done during the injection. Inject the epoxy resin through injection pipes to fill the gap between the plate and the concrete.



(5) Curing and Painting

A suitable chamfer/fillet could also be formed in the adhesive around the edge of the plates and the concrete surfaces. Steel plates and all its components shall be adequately painted for corrosion protection.



3-6-3-2 Pressure Attaching Method

(1) Surface Preparation

Bottom surface of slab bonded with steel plate shall be cleaned. Any surface irregularities shall be leveled using a disc grinder.



The surface of the steel to be bonded has to be completely free of any mill scale, rust, grease or other contaminants. The primer should be applied on the surface which is compatible with the adhesive.



(2) Application of Epoxy Resin Adhesive

The adhesive shall be thicker along the center of the steel plate than at the sides. The use of plastic spacers maintains minimum adhesive thickness of 1- 2 mm



(3) Pressure Attachment of Steel Plate

The epoxy resin adhesive is applied to the steel plate which is set at the required position of the deck slab, and pressed using the anchor bolts wedging off with the temporary stiff wood and steel angle bar.



(4) Curing and Painting

A suitable chamfer/fillet could also be formed in the adhesive around the edge of the plates and the concrete surfaces. Steel plates and all its components shall be adequately painted for corrosion protection.



3-6-4 Required Materials and Tools/Equipment

(1) Required Materials

Injection Method

- Steel Plate
- Epoxy Primer
- Epoxy Resin Adhesive for Injection
- Epoxy Sealant
- Anchor Bolts

Pressure Attaching Method

- Steel Plate
- Epoxy Primer
- Epoxy Resin Adhesive for Steel Bonding
- Epoxy Sealant
- Anchor Bolts
- Wood and Angle for Fitting

(2) Required Tools/Equipment

Injection Method

- Disc Grinder
- Welder
- Electric Drill
- Epoxy Injection Pump with Accessories
- Wire Brush

Pressure Attaching Method

- Disc Grinder
- Welder
- Electric Drill
- Epoxy Injection Pump with Accessories
- Wire Brush

3-7 PARTIAL DECK SLAB REPLACEMENT

3-7-1 Description of Repair Method

Partial replacement of slab is carried out to replace portion of the concrete that has been severely damaged. If damaged portion is not removed, as shown in Photo 3-2, further deterioration is expected, which could impair the strength, stability and serviceability of the structure. The cause of such damage could be corrosion of reinforcement, fracturing, spalling, delamination, honeycomb or water leakage.



Photo 3-2 Severely Damaged Deck Slab

Recasting generally involves removal of the deteriorated concrete, cleaning up the substrate and reinforcement, setting up formwork and placement of new concrete as shown in Figure 3-12.

If the bridge cannot be closed to traffic during repair, it is suggested to use Fast-setting mortar instead of Portland cement concrete.

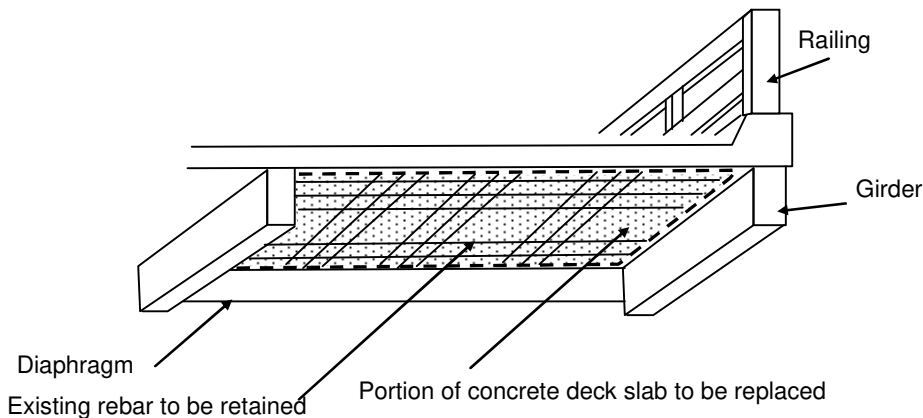


Figure 3-12 Detail of Partial Deck Slab Replacement

3-7-2 Application Criteria

The method of placement of concrete slab depends largely on particular situation. Nevertheless, it should be ensured that well compacted concrete completely fills all the voids. The works generally include complete removal of defective concrete and its adjacent surfaces to its full depth, setting formworks, cleaning the existing rebars (and additional rebars, if required) and placing new concrete. Alternatively, only partial depth of the defective concrete will be removed, while the soffit formwork can be extended to provide a series of hoppers at its open sides, to allow for filling of super plasticized "flowing" concrete.

Said alternative method (Partial Depth) is similar to the recasting method for repair to girder and substructure, discussed in separate sections in this guidebook. However, it is not expected to be as effective considering the wide area and limited thickness of deck slab, subjected to repeated loadings due to traffic. In this guidebook, the first method (Full Depth), which is replacement of concrete by defect section or panel, is recommended for repair of severely damaged deck slab.

3-7-3 Procedures

(1) Support of Existing Structure

The existing structure shall be properly supported to safeguard against instability and deformation during the repair work.

(2) Removal of Concrete Deck Slab

All deteriorated or damaged concrete surface are cut by saw, forming vertical edges, and then removed using breaker and chisel. Rebars are examined for loss of section due to corrosion. If cross sectional area of the reinforcement has reduced by more than 20%, additional reinforcement is required and necessary.



(3) Preparation of Old Concrete and Rebar

A suitable bonding agent for concrete and reinforcement should be selected taking into consideration the limited working time available for fixing the formworks and placing the new concrete. Concrete should be placed immediately after application of the bonding coat to the faces of the old concrete and rebars.



(4) Setting of Formworks

Soffit formworks for re-casting deck slab have to be very rigid and well-supported to prevent the new concrete from sagging due to its own weight.



(5) Cutting of Existing Rebars and Addition of New Rebars

Deteriorated old rebars are cut up to the required lap length. New bars to be provided shall be of same or bigger diameter than the existing, considering the current loading condition. The lap length is calculated as 30 times the new rebar diameter. The new rebars shall be tied to the existing bars using tie wires or by welding.

(6) Placing of Concrete

Concrete is placed in the soffit formworks through a suitable method and compacted well using internal or external vibrators. Finish unformed surfaces by broom, wood float, or steel trowel to match the adjacent existing concrete.



(7) Curing and Removal of Formworks

Continuous water curing with wetted cotton mat is always preferable to slow down drying.

Formworks for load bearing structural members shall remain in position until at least 80% of the 28 day compressive strength of the new concrete is achieved.

3-7-4 Required Materials and Tools/Equipment

(1) Required Materials

- Portland Cement
- Silica Fume
- Rebar (Reinforcing bar)
- Epoxy Resin Adhesive (Bonding Coat for Concrete)
- Zinc Rich Primer (Bonding Coat for Rebar)

(2) Required Tools/Equipment

- Sawing Equipment
- High Pressure Water Blasting
- Handy Concrete Breaker or Jackhammer
- Handy Power Chisel
- Concrete Mixer 30 liters
- Vibrator
- Troweling tools

3-8 WATERPROOFING ON DECK SLAB

3-8-1 Description of Repair Method

Concrete is naturally alkaline and therefore protects the steel. However, the effect of its contact with water and corrosive materials reduces the alkaline environment and allows an electrolytic process to start, thus corroding the rebar. The result of the corrosion and rusting is to expand the rebar which then damages and eventually destroys the surrounding concrete of the deck. The primary protection against this destructive damage is through installation of waterproofing membrane on the deck slab.

The bridge deck waterproofing includes the sheet system and liquid (Membrane) system. The sheet system is widely applied in European countries by a qualified contractor. However, it is difficult to implement this system in Zambia since, at present, no qualified contractor has an experience in the related work methods.

On the other hand, liquid system involves a simple procedure similar to painting method. In this repair guidebook, Asphalt Compound Membrane System (Photo 3-3) is introduced.



Photo 3-3 Asphalt Compound Membrane System

3-8-2 Application Criteria

Asphalt Compound Membrane system involves less costly materials. However, equipment costs such as kettle and heating tool, including its inland transport cost tends to somehow increase related construction cost. In this guidebook, this system is recommended considering ease of application and low cost as well as its good performance.

3-8-3 Procedures

Asphalt Compound membrane is composed of layers as shown in Figure-3-13.

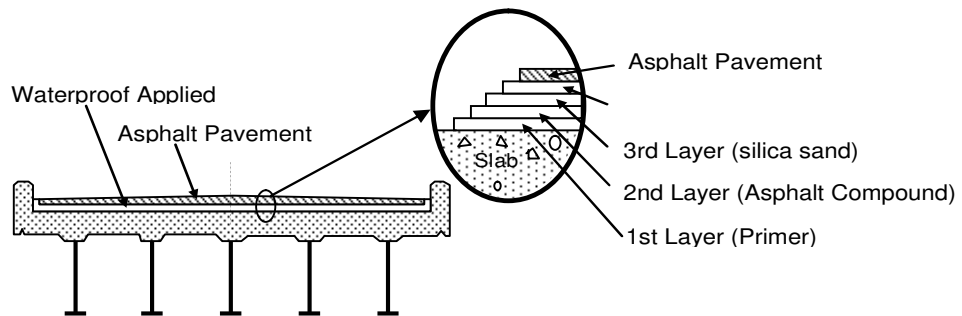
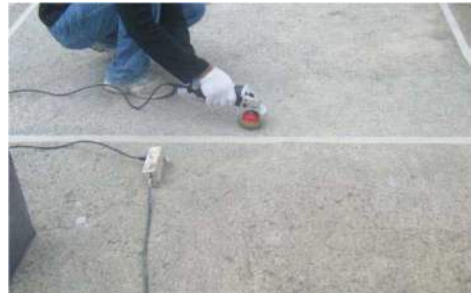


Figure 3-13 Composition of Layer for Asphalt Compound Membrane

(1) Preparation of Surface

Existing asphalt pavement is stripped off and removed totally. The deck surface shall be cleaned using a wire brush, removing oil, asphalt and concrete chips and dust that will affect adhesion to the substrate. The substrate shall be kept dry during the waterproofing works



(2) Primer Coating

Primer coat shall be applied once or twice on the cleaned substrate using a roller brush. The coating is approximately 0.2 kg/m² and natural dried for more than 30 minutes until tack-free. (Refer also to Manufacture's instruction).



(3) Melting Asphalt Compound

Asphalt membrane shall be melted in the mechanically agitated heating process and mixed in a kettle. This unit shall keep the contents continuously agitated until the material can be drawn free flowing and lump-free from the mixing unit, at a temperature recommended by the Manufacturer.



(4) Application of Asphalt Compound

The asphalt membrane shall be applied using a rubber brush within the temperature range recommended by the Manufacturer to the clean, primer-coated concrete deck, forming a uniform film with equal thickness (Approximately 1.2kg/m²). The laying operation shall eliminate discontinuities in the membrane.



(5) Application of Silica Sand for Protection

Silica sand shall be scattered on the waterproofing layer while the membrane is still hot. The silica sand to be used shall be approximately 0.7 kg/m². (Refer to the Manufacture's instruction).



(6) Curing/Asphalt Pavement

Curing has to be carried out until waterproofing membrane is cooled down to normal temperature. Excess silica sand shall then be removed using a broom. Asphalt overlay is then finally applied.



3-8-4 Required Materials and Tools/Equipment

(1) Required Materials

- Epoxy Primer
- Asphalt Compound Membrane
- Silica Sand No.4

(2) Required Equipment/Tools

- Kettle with Heater
- Roller Brush or Hair brush
- Rubber Brush

3-9 FAST SETTING MORTAR FOR DECK SLAB

3-9-1 Description of Repair Method

If the deck slab is required to be replaced partially or entirely, fast setting mortar is used to minimize the construction time.

This method is effective when construction is done one lane at a time without stopping the traffic.

3-9-2 Application Criteria

The works generally include complete removal of defective concrete and its adjacent surfaces to its full depth, setting formworks, cleaning the existing rebars (and placing additional rebars) and placing fast-setting mortar.

If ordinary concrete is used for continued deck slab, it is necessary to observe enough curing time to reach the 28 days design compressive strength of concrete prior to opening to traffic,

In order to shorten curing time, fast-setting mortar shall be used. The material is allowed to reduce curing time to only a few days for shorter traffic disruption. Premixed type of fast-setting mortar should be poured without vibrator.

This method is similar for repair to girder and substructure, discussed in separate sections in this guidebook. It is expected to be effective in conditions where the structure is subjected to repeated loadings.

3-9-3 Procedures

(1) Removal of Concrete Deck Slab

Concrete surface is cut by saw, forming vertical edges, and then removed using breaker and chisel. Rebars are examined for loss of section due to corrosion. If cross sectional area of the reinforcement has reduced by more than 20%, additional reinforcement is required and necessary.

(2) Setting of Formworks

Soffit formworks for re-casting deck slab have to be very rigid and well-supported to prevent the fast-setting mortar from sagging due to its own weight.

(3) Addition of Longitudinal/Transverse Rebars

Longitudinal and transverse rebars to be provided shall be of the same or bigger diameter than the existing, considering the current loading condition.

Spacing of rebars should be less than 150mm for durability and to avoid occurrence of bending cracks.

The new rebars shall be tied to the existing bars using tie wires or by welding.

(4) Clean Up Inside of Forms

After placement of additional rebars and formworks are completed, clean up inside the forms using vacuum cleaner.



(5) Apply Epoxy Resin to Existing Concrete Surface for Proper Bonding to Fast-setting Mortar

Epoxy resin shall be applied on all exposed sections of existing concrete. Fast-setting mortar shall be poured within hardening time of epoxy resin.



(6) Keep the Forms in Wet Condition

After cleaning inside of the forms, water should be spread to keep it in wet condition prior to placing mortar.



(7) Mix with Water

The material consists of special cement of pre-mixed type and sand for fast setting and non shrink performance. One (1) bag of material which weighs 25kg and 4.5 liters water shall be mixed by steel-bladed electric mixer. One (1) bag of mixing will produce 13 liters of fast-setting mortar. Minimum mixing time shall be 2 minutes.



(8) Pour from Lower to Higher Portion

Fast setting mortar is very flowable. Vibrator should not be used for spreading. The sequence of placing should start from the lowermost portion to the highest portion in one direction. If a mass of mortar like lump is found during placing of mortar, it should be remixed immediately. It is a sign of insufficient mixing.



(9) Finishing of Surface, Curing

After placing 1m length of fast-setting mortar, finishing of surface should be started.

Finish unformed surfaces by broom, wood float, or steel trowel to match the adjacent existing concrete.



Continuous water curing with wetted cotton mat is always preferable to slow down drying. Because fast setting mortar is non-shrink and non-bleeding type, curing should be started within two hours after beginning of placing mortar.

3-9-4 Required Materials and Tools/Equipment

(1) Required Materials

- Premixed type fast setting mortar
- Clean water
- Epoxy Resin Adhesive (Bonding Coat for Concrete)
- Zinc-rich Primer (Bonding Coat for Rebar)

(2) Equipment/Tools

- Sawing Equipment
- High Pressure Water Blaster
- Handy Concrete Breaker or Jackhammer
- Handy Power Chisel
- Electric Mixer with steel blade
- Water container
- Generator
- Hydraulic Pump system
- Brush

3-9-5 Fiber Cement Mortar on Surface of Deck Slab (Reference)

When concrete for the top surface of deck slabs is replaced, fiber cement is often used to improve the strength of the surface layer.

This material is an extremely dense cementitious material reinforced with fibers to increase the load-bearing capacity and durability of the slab. Reinforcing fibers include polypropylene and steel.



Polypropylene Fiber



Steel Fiber

Figure 3-14 Fiber Reinforce Materials

The method of installation is similar to the mortar placement described above, but it is necessary to ensure that the reinforcing fibers are sufficiently mixed in the mortar and that the fibers do not protrude vertically at the surface. If the fibers protrude in the vertical direction, they may damage the pavement on the upper surface of the slab.

CHAPTER 4 REPAIR OF CONCRETE BRIDGE SUPERSTRUCTURE

4-1 EPOXY COATING

4-1-1 Description of Repair Method

This work item is applicable for repair of vertical or overhead cracks, with widths less than 0.3 mm.

Epoxy coating, made up of epoxy compounds with high strength and non-solvent two-component material, is characterized by its excellent adhesion to both dry and wet concrete.

It should be noted that epoxy coating is not a repair method, but a protective or preventive application to prolong the bridge service life. The coating, applied using a roller brush, should be capable of penetrating overhead, downward and vertical. This measure is one of the most appropriate maintenance activities.



Photo 4-1 Epoxy Coating Penetrating into the Crack

4-1-2 Application Criteria

Cracks with widths less than 0.3 mm, is acceptable if the cause is non-structural, and has no adverse effect on the structure. However, it is difficult to evaluate whether the crack is stable or developing due to such factors as carbonation, chlorination, corrosion, overloading of structure, insufficient reinforcement or inadequate concrete cover.

As a protective or preventive measure, epoxy coating should be applied on surfaces of concrete structures, with cracks of less than 0.3 mm width, regardless if crack formation is structural or non-structural. Subsequently, the regional office should regularly monitor the cracks for future repair, if necessary.

4-1-3 Procedures

(1) Preparation of Concrete Surface

Concrete surfaces adjacent to the crack shall be cleaned by air jet, and free from laitance and contaminants such as grease and oil.

(2) Application of Epoxy Sealant

Apply approximately 50 mm width strips of epoxy sealant coating to concrete surfaces along the crack, as recommended by the manufacturer.

(3) Curing

After application, perform until the epoxy coating hardens.

(4) Monitoring of Crack width

The cracks coated with sealant shall be monitored by a designated maintenance staff of the district office, to determine whether it is progressing or not.

4-1-4 Required Materials and Tools/Equipment

(1) Required Materials

- Epoxy Sealant

(2) Required Equipment/Tools

- Brush or Paint Roller

4-2 EPOXY INJECTION

4-2-1 Description of Repair Method

This method involves crack repairs to concrete superstructures as shown in Figure 4-1. The works include preparation of concrete surface, insertion of pipe fittings bonded with adhesive, injection of epoxy, curing and conducting performance test.

Epoxy injection for concrete cracks requires highly skilled process and its effectiveness depends mostly on the proficiency of the certified applicator. Said person should be qualified based on his previous work records, and approved by the Engineer.

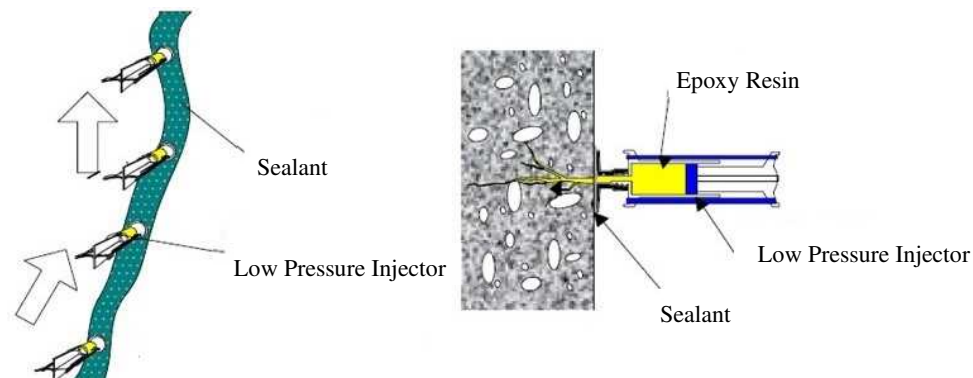


Figure 4-1 Crack Injection Method

4-2-2 Application Criteria

Epoxy injection is used to restore structural soundness of structures exhibiting inactive cracks. Cracks with more than 0.3 mm up to 3.0 mm widths can be bonded and sealed by injecting low-viscosity epoxy.

4-2-3 Procedures

1. Cleaning of Cracks
 2. Adhesion of Injection Ports
 3. Sealing of Cracks and Injection of Epoxy
 4. Curing of Injected Material and ports removed
- a: Concrete Surface, b: Crack, c: Injection Port
d: Sealant

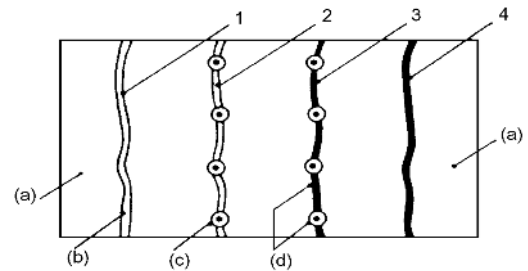
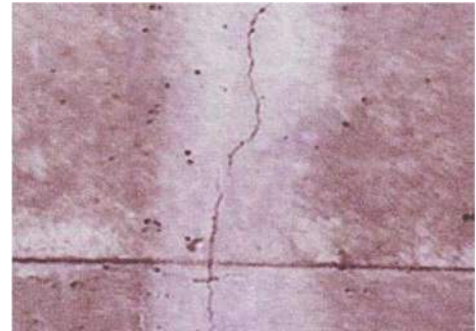


Figure 4-2 Sequence of Operation

(1) Cleaning of Cracks

All loose debris such as dirt, concrete fine particles and contaminants (oil, grease, etc.) should be removed from the cracks using high-pressure water or special and effective solvent. Remove the residual water or solvent in the crack with filtered (dust and oil free) compressed air and allow adequate time for drying.



(2) Bonding of Injection Ports

Injection ports are bonded with the adhesive to the crack center for injecting epoxy. Spacing of the ports varies between 150 mm to 500 mm depending on the width and depth of the cracks. The first and last ports are set at or near the bottom and top, respectively.



(3) Sealing of Cracks at the Surface

Using a 5 cm width strip, epoxy sealant is applied on the area around the injection ports and cracks, allowing it to harden.



(4) Fitting of Injector

Connect the terminal of the injector to the port.



(5) Injection of Epoxy

Epoxy shall be injected using low pressure injector, injection guns or other injection devices as shown in Figure 4-3. Injection is performed on the injection port. Duration of the injection operation shall be in accordance with the supplier's instruction.

If the crack is vertical, commence the injection of epoxy at the lowest injection port, until the epoxy exudes from the injection port above. For horizontal cracks, epoxy injection is carried out from one end of the crack to the other, in a similar manner.

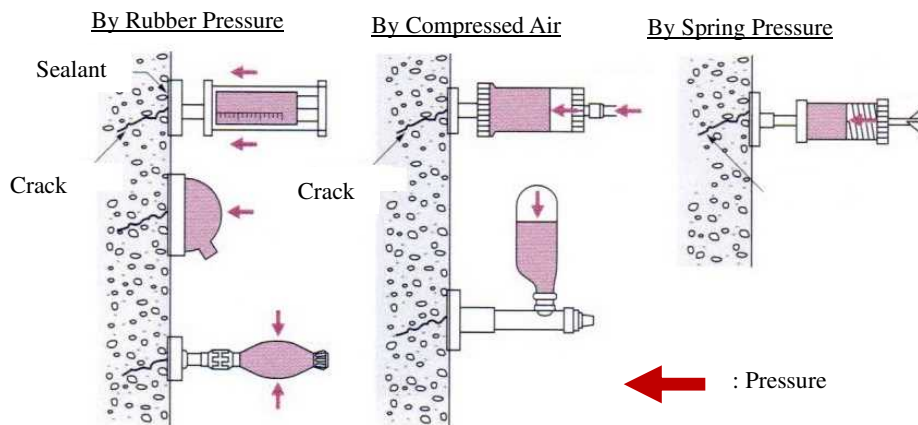


Figure 4-3 Crack Injection Method

(6) Curing of Injected Material

After the crack has been sealed, remove the projecting injection port and fill holes with an epoxy patching compound. Surface coating will be applied, when required in the process



4-2-4 Required Materials and Tools/Equipment

(1) Required Materials

- Epoxy Resin for Injection
- Epoxy Sealant
- Set of Injection Tool

(2) Required Equipment/Tools

- Epoxy Injector or Gun
- Power Disc Grinder/Cutter
- Portable Generator
- Brush etc.

4-3 CAULKING

4-3-1 Description of Repair Method

Active cracks are treated and repaired with flexible sealants as shown in Figure 4-4. The sealant is generally applied in a wide recess cut along the crack. The dimensions of the recess (width and depth) depend on the total crack movement and the cyclic movement capability of the joint sealant used. For selection of sealant material, crack movement should be calculated taking into account the applied loads, shrinkage and temperature variations.

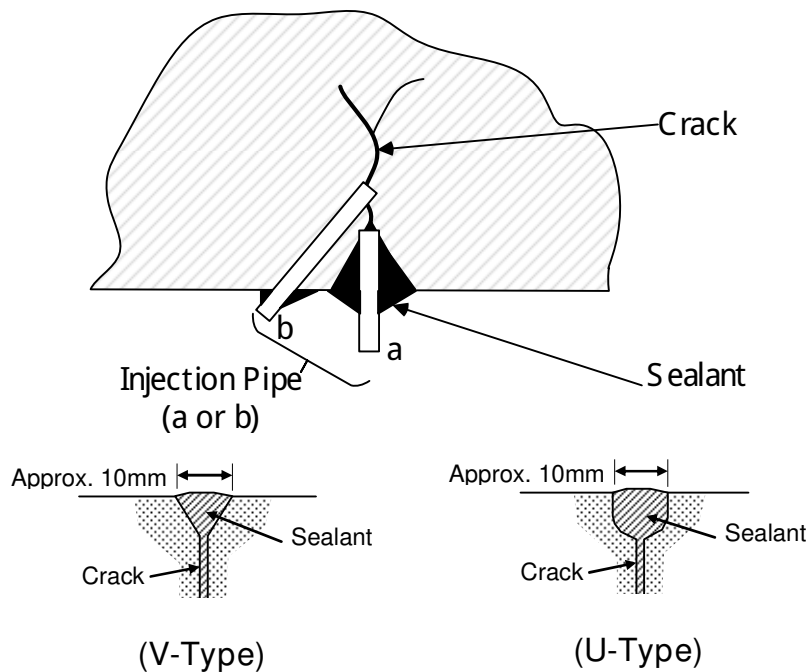


Figure 4-4 Types of Caulking

4-3-2 Application Criteria

Crack widths could be more than 3.0 mm with depth of less than 300 mm. In this case, the top surface edges should be chipped or sawn to form a V-type or U-type groove, in order to provide a caulking for inlet of gravity flow of resin into the crack by injection pump.

Cracks wider than 3.0 mm generally require epoxy based injection material.

4-3-3 Procedures

(1) Cleaning of the cracks

Remove all loose debris such as dirt, concrete fine particles and contaminants (oil, grease, etc.) from the cracks using high-pressure water or special and effective solvent. Remove the residual water or solvent in the crack with filtered (dust and oil free) compressed air and allow adequate time for drying.



(2) Preparation of Caulking

Using a concrete saw, hand tools or pneumatic tools, a V-groove or U-groove, approximately 10 mm in width and in depth, is prepared at the surface along the crack. The groove shall then be partially sealed with a sealant.



(3) Drilling Holes and Fixing the Injection Pipes

Port holes are drilled near the crack, or in the groove. Injection pipes are then fixed at the tip of the groove. Spacing between ports varies between 150 mm to 500 mm, generally depending on the width and depth of the cracks.

The groove is then completely sealed with sealant.



(4) Injecting Epoxy Resin

Epoxy resin can be injected using injection pumps, or air-activated caulking guns. The duration of injection process shall be in accordance with the supplier's instructions.

If the crack is vertical, commence the injection of epoxy at the lowest pipe fitting, until the epoxy exudes from the pipe fitting above. For horizontal cracks, the injection is carried out from the injection pipe at end of the crack to the other end.



(5) Curing of Injected Material

After the crack is sealed, the projecting injection pipes are cut and the holes are filled with epoxy patching compound. If surface coating or carbon fiber sheet will be applied, the portion with sealant and tip of the cut pipe should be grinded to form a smooth surface.



4-3-4 Required Materials and Tools/Equipment

(1) Required Materials

- Epoxy Resin
- Epoxy Sealant
- Injection Pipe

(2) Required Equipment and Tools

- Epoxy Injection Pump
- Power Disc Grinder
- Portable Generator
- Brush

4-4 PATCHING

4-4-1 Description of Repair Method

Patch repair is performed to restore small areas where concrete is damaged by spalling, scaling and impact. This method of repair is generally applied using trowel and require none or minimum formworks. The patch thickness is limited to a maximum of 100 mm depth of hollow surface.

Type A Patching is for used for defects without exposed rebars while Type B Patching is applied to surfaces with exposed rebars.

Non-shrinkage polymer cement mortar is used for the patch repair.

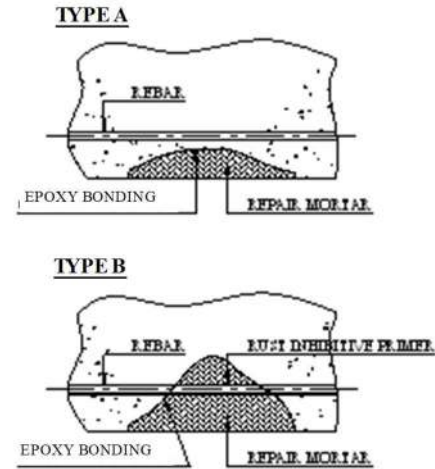


Figure 4-5 Types of Patching

4-4-2 Application Criteria

Patch repair is classified into two types as shown in Figure 4-5 considering defective area and surface. Type-A is applicable to surfaces without exposed rebars having defective widths of up to 300 mm and depths of up to 50 mm. Meanwhile, Type B is used for surfaces with exposed rebars with defective widths between 300 mm and 600 mm, and up to 100 mm depths.

Non-shrinkage polymer cement mortar is used for Type-A and Type-B patching.

4-4-3 Procedures

(1) Removal of Defective Concrete

Remove all defective, unsound and contaminated concrete and prepare the edges for the patch area. If local corrosion in reinforcement with section loss is found, which would require additional bars, remove only the damaged area of concrete including the length needed to bond the new reinforcement as shown in

Figure 4-6.

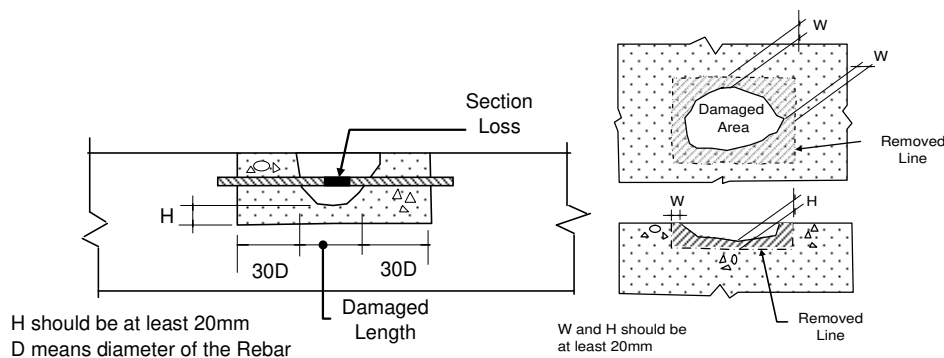


Figure 4-6 Limits of Removal of Damaged Concrete

(2) Cleaning of Concrete and Rebar

Remove loose particles and dust using high pressure water or vacuum cleaner. Concrete surfaces to be bonded have to be free from dirt, oil, grease, asphalt. Corrosion has to be removed before placing the new mortar. If deterioration is due to chloride contamination or if the reinforcement is covered with loose corrosive elements and has developed pits, use water abrasive blasting until all the rust are removed.



(3) Applying Bonding Coats to Concrete and Rebar

Epoxy bonding coats are applied to dry and clean concrete surfaces to bond firmly. Specially formulated resins are also available for damp surfaces. Apply the selected bonding coat to steel bars with a brush working vigorously to ensure that they are evenly covered all around.

As notes, depending on the type of mortar, the bonding coat to the concrete surface may not needed.



(4) Placing of Mortar

The mortar should be placed in layers of about 20 mm thick. Compact each layer thoroughly over the entire surface using a wooden trowel or hammer. Generally, there should be no time delays between the placing and compacting of layers.

Patching to the surrounding concrete is performed using a form material, and then hammered using a mallet, wood or steel trowel.



(5) Curing

All types of cement repairs need thorough and continuous curing to develop the desirable strength and impermeability, and to minimize drying shrinkage while



bond strength is developing.

4-4-4 Required Materials and Tools/Equipment

(1) Required Materials

- Polymer Cement Mortar (PCM)
 - PCM Powder
 - Water
 - Concrete Nail
 - Bonding Agent to Concrete (Epoxy Resin Adhesive)
 - Bonding Agent to Rebar (Zinc Rich Primer)

(2) Required Equipment

- Chisel
- Portable Generator
- Wire Brush
- Small Hammer
- Mortar Mix Bucket
- Safety goggles
- Trowel
- Dust mask

4-5 RECASTING CONCRETE/GROUT

4-5-1 Description of Repair Method

Recasting Method which involves casting of the damaged area by placing concrete or grouting mortar on the formworks, is usually most suitable for severely damaged concrete or for largely damaged areas with densely spaced rebars as shown in Figure 4-7. If concrete placing by vibration is a problem, grout and free flowing self-compacting concrete should be used to minimize the vibration required.



AFTER

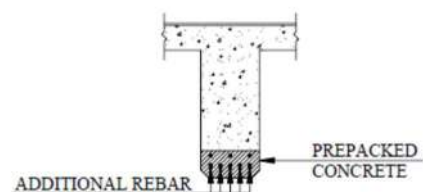


Figure 4-7 General View of Recasting

4-5-2 Application Criteria

Recasting Concrete/Grout is divided into two methods namely, concrete placing and mortar grouting types. Further, the mortar grouting type has two categories depending on materials used, i.e., Portland cement and non-shrink cement.

Considering the position and scale of damages defined in Figure 4-8, the application of the recasting concrete and grout are classified according to the formwork types, such as the “Envelope Type” and “Mail Box Type,” shown in Figure 4-9. Envelope type formwork is open at the top for pouring concrete while the mail box type formwork consists of holes or slit at its side for purposes of grouting or pumping mortar. Mail box type formwork is further classified based on concrete volume, applied area and rebars arrangement as shown in Figure4-8, with due consideration to cost performance.

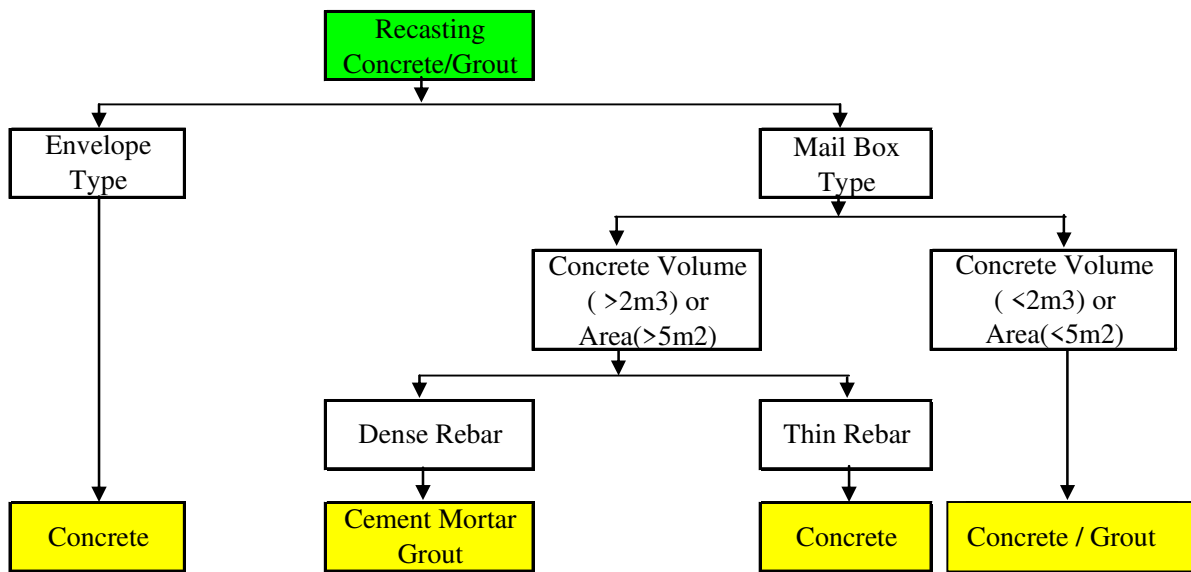


Figure 4-8 Flowchart of Selecting Material for Recasting

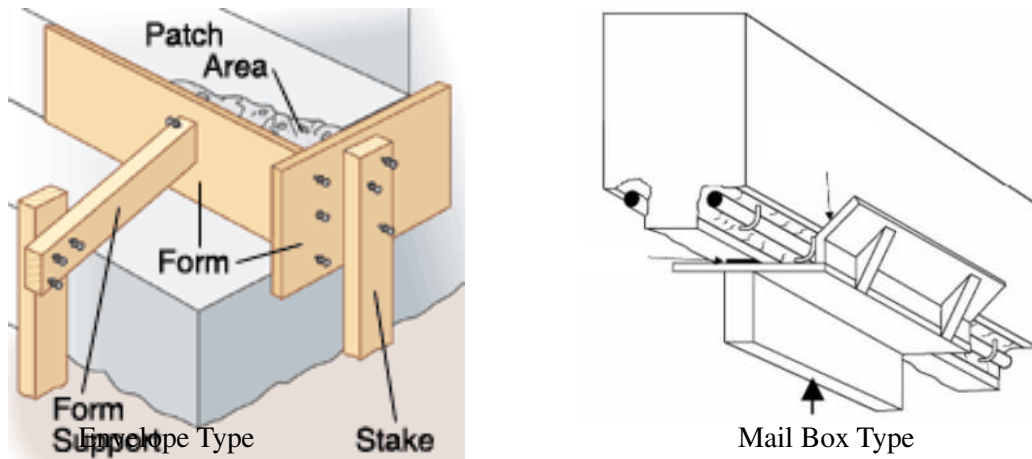


Figure 4-9 Type of Formwork of Recasting

4-5-3 Procedures

The procedure of concrete mixing, pouring and curing is in accordance with Section 3-7-3 of “PARTIAL DECK SLAB REPLACEMENT”. The following procedure is only for cement mortar grout.

(1) Removal of Girder Concrete

All deteriorated or damaged concrete are cut using saw to form the vertical edges, and then removed using a breaker and chisel. Rebars are examined for loss of section due to corrosion. If cross sectional area of the reinforcement has been reduced by more than 15%, provide extra reinforcements, as necessary.



(2) Preparation of Old Concrete and Rebars

A suitable bonding agent for concrete and reinforcement should be selected taking into consideration limited working time available for fixing the formworks and placing the new concrete. Concrete should be placed immediately after applying bonding coat to the faces of old concrete and anti-corrosion primer to rebars.



(3) Cutting of Deteriorated Rebars and Adding New Rebars

Deteriorated old rebars are cut up to the required lap length. New bars to be provided shall be of same or bigger diameter than the existing, considering the current loading condition. The lap length is calculated as 30 times the new rebar diameter. The new rebars shall be tied to the existing bars using tie wires or by welding.



(4) Setting Formworks

Formworks for re-casting the girder have to be very rigid and well-supported to prevent the new concrete from sagging due to its own weight.



(5) Mixing of Mortar

Cement mortar grout shall be composed of one part cement, three parts sand and a minimum amount of water necessary for the mixture to flow under its own weight, and then mixed using a grout mixer.



(6) Mortar Grouting

The mortar has to be carefully placed to avoid the entrapment of air. Pumping is usually employed for the mail box type formwork which can be used for smaller pours. When pumping is used, the delivery hose should be at a low position while pouring, to allow the air to be displaced.



(7) Curing and Removal of Formworks

Continuous water curing by spraying is always preferable as membrane cure, which helps slow down drying process.

Formworks for load bearing structural members shall remain in position until at least 80% of the 28 day compressive strength of the new concrete is achieved.



4-5-4 Required Materials and Tools/Equipment

(1) Required Materials

For Concrete

- Portland Cement
- Silica fume
- Aggregate/Sand
- Rebar (Reinforcing bar, Grade 60)
- Bonding Coat for Concrete (Epoxy Resin Adhesive)
- Anti-corrosion Primer for Rebar (Zinc Rich Primer)
- Cotton mat (Curing)

For Mortar

- Portland Cement (Cement Mortar)
- Admixture for consistency
- Reinforcing steel bar
- Bonding Coat to Concrete (Epoxy Resin Adhesive)
- Anti-corrosion Primer to Rebar (Zinc Rich Primer)

(2) Required Tools/Equipment

- Sawing Equipment
- High Pressure Water Blasting
- Handy Concrete Breaker or jackhammer
- Handy power Chisel
- Concrete Mixer 30 liters
- Mortar Mixer with Pump (For Mortar)
- Vibrator
- Troweling tools

4-6 CARBON FIBER SHEET/PLATE BONDING TO CONCRETE GIRDER

4-6-1 Description of Repair Method

Carbon fiber sheet/plate for reinforced repair and strengthening systems are combination of carbon fiber sheet/plate material and resins such as epoxies and other adhesive materials, acting as a composite material to enhance the capacity and extend the life of concrete structures as shown in Figure 4-10. The role of the resin is to serve as adhesive bond to the concrete surface and facilitate the transfer of stresses to and from the carbon fiber sheet.

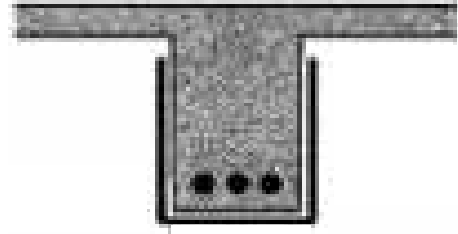


Figure 4-10 Carbon Fiber Sheet/Plate Bonding

4-6-2 Application Criteria

The first system for concrete girder shall generally consist of woven carbon fiber sheet (CFS) reinforcing layers bonded to the concrete surface with epoxy. The second system shall generally consist of carbon fiber plate (CFP) bonded to the concrete with epoxy.

As shown in Figure 4-11, the section of 1/4 in span from both ends is applied with CFS for protection against shear cracks (Photo 4-2) while the center section of 1/2 in span is applied with CFP for protection against flexural cracks (Photo 4-3) caused by live load.

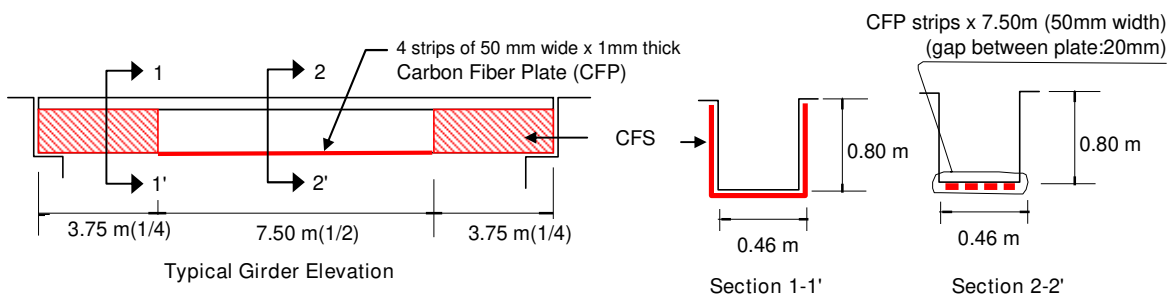


Figure 4-11 Arrangement of Carbon Fiber Sheet/Plate (For Reference)

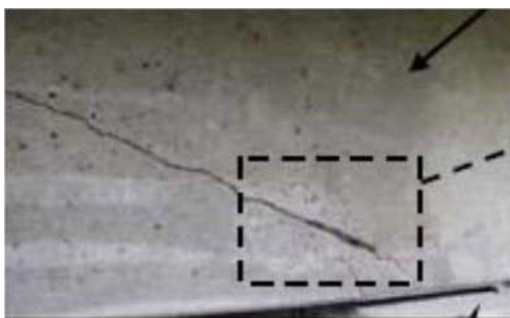


Photo 4-2 Shear Cracks at Both Ends

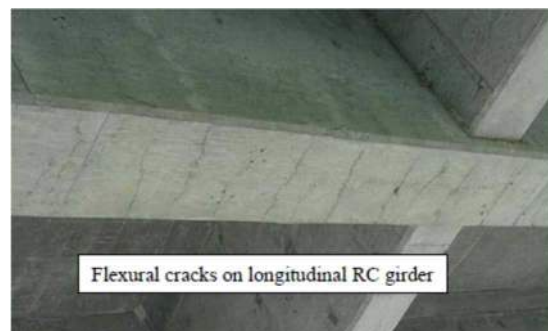


Photo 4-3 Flexural Cracks at the Center Portion

4-6-3 Procedures

4-6-3-1 For CFS

(1) Preparation of Concrete

Disc grinder or abrasive sandblasting is used to clean the concrete and to ensure that the surface roughness is even and smooth. To avoid pollution impact to soil and water, dust, cement, paint and other contaminants were contained by covering the bridge with plastic sheeting.



(2) Application of Primer

Primer resin soaks into the surface of concrete, resulting in increased strength of the concrete surface and improves bonding with CFS.



(3) Adjustment of Unevenness with Sealant

Any concave, pores, gaps on the concrete surface has to be smoothed using epoxy sealant. After the sealant becomes tack-free, it is required to roughen the surface with sandpaper, then cleaned.



(4) Application of Epoxy Resin for Undercoat

Using a roller, epoxy resin is applied to the concrete as adhesive to bond with the CFS. It forms a molded composite by permeating into the CFS.



(5) Installation of CFS (1st layer)

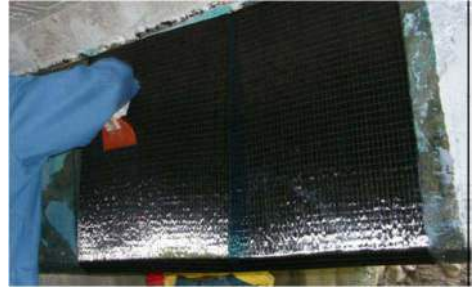
Properly aligned CFS are installed to the resin coated concrete surface to strengthen the section.

Press the CFS using deformed roller, starting from the center toward the edges.



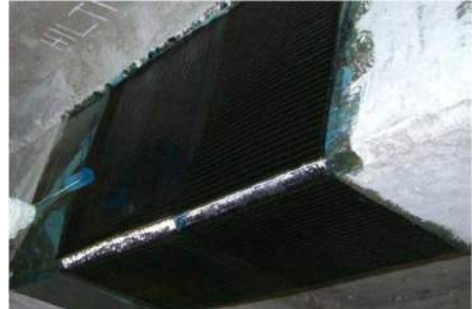
(6) Squeezing Out of Entrapped Air

For complete fusion, entrapped air is squeezed out of the carbon sheets using a roller, before applying the adhesive sets.



(7) Over Coating Resin Application

Epoxy resin is roller-applied to the 1st layer of CFS as adhesive to bond to 2nd layer, and to form a molded composite by permeating into the CFS.



(8) Installation of CFS (2nd layer)

Properly aligned CFS strips (2nd layer) are installed to the resin over coated surface to further strengthen the section.

Press the CFS using deformed roller starting from the center toward the edges.



(9) Surface Protection

For safety purposes, fire proof protection coating may be applied to the finished surface.



4-6-3-2 For CFP

(1) Preparation of Concrete

Disc grinder or abrasive sandblasting is used to clean the concrete and to ensure that concrete surface is even and smooth.



(2) Application of Primer

Primer resin soaks into the surface of concrete, resulting in increased strength of concrete surface and improves the bonding with CFP.



(3) Adjustment of Unevenness with Sealant

Any concave, pores, gaps on the concrete surface has to be smoothed with epoxy sealant. After the sealant becomes tack-free, it is required to roughen the surface with sandpaper, then cleaned.



(4) Application of Epoxy Resin on CFP

In order to reduce the formation of voids, epoxy based adhesive is applied to the CFP with molder to bond, forming a curved profile measuring approximately 3 mm in the center and 1 mm on the edges.



(5) Installation of CFP

Properly aligned CFP is installed longitudinally to the adhesive coated concrete surface.



Press the carbon fiber plate manually using deformed roller, starting from the center toward the edges.



(6) Squeezing Out of Entrapped Air

For complete impregnation, entrapped air is squeezed out of the CFP using a roller before applying the adhesive sets.



(7) Pressure Attachment of CFP

Set at position of the girder, then press using wooden anchor frame and set bolts for curing.

4-6-4 Required Materials and Tools/Equipment

(1) Required Materials

Carbon Fiber Products

- Carbon Fiber Sheet
- Carbon Fiber Sheet Strip
- Carbon Fiber Plate

Epoxy Materials

- Epoxy Primer
- Epoxy Sealant
- Epoxy Resin Adhesive for CFS/CFP

(2) Required Equipment

- Abrasive Sandblaster
- Air Compressor
- Disc Grinder
- Portable Generator
- Paint Roller/Brush

4-7 STEEL PLATE BONDING TO CONCRETE

4-7-1 Description of Repair Method

Steel plate is bonded with epoxy resin at the bottom or side face of existing girders. Bonded steel plate provides the same effect as that for installing additional rebar to existing girder.

This method is adopted for strengthening the slab or girder against bending moment as well as shear. Due to ease of application, this method as shown in Figure 4-12 is widely used. This measure is often performed for girders since it does not require restriction to traffic. However, in case where the deterioration of the concrete surface is too severe, other measures to improve the quality may be considered.



Figure 4-12 Repair of Concrete Girder by Steel Plate Bonding

4-7-2 Application Criteria

Steel plate bonding involves use of narrow steel plates installed in the longitudinal direction of the concrete girder. The bonding of steel plates to concrete members is achieved using pressure attachment method as discussed below.

Pressure Attachment Method

This method requires single plates of required thickness with gaps sealed at the edges between the steel and the concrete. Epoxy resin is injected to ensure that no voids occur between the plate and the concrete.

Pressure attaching method is normally adopted for narrow plate type considering the extent of surface preparation of both concrete and steel plate as shown in Figure 4-13.

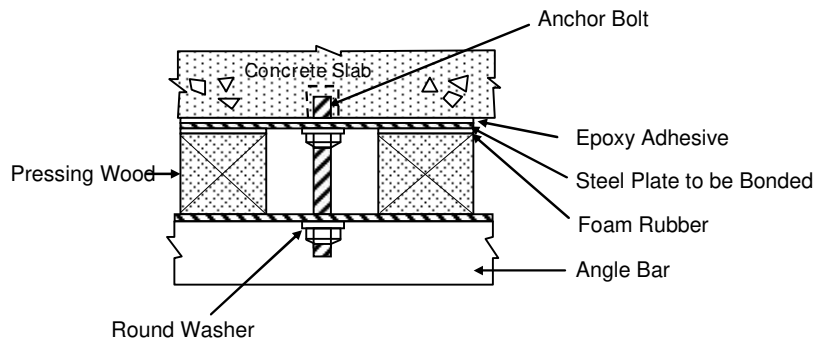


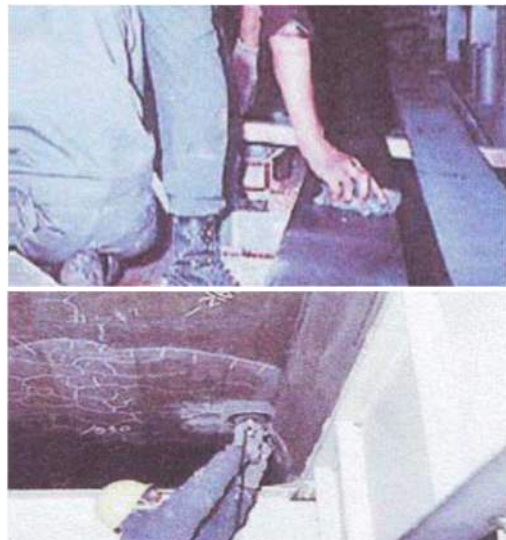
Figure 4-13 Detail of Pressure Attachment Method by Anchor Bolts

4-7-3 Procedures

(1) Surface Preparation

Bottom surface of concrete girder to be bonded with steel plate shall be cleaned. Any surface irregularities shall be leveled using a disc grinder.

The surface of the steel to be bonded has to be completely free of any mill scale, rust, grease or other contaminants. The primer should be applied on the surface which is compatible with the adhesive.



(2) Application of Epoxy Resin

The adhesive shall be thicker along the center of the steel plate than at its sides. The use of plastic spacers maintains minimum adhesive thickness of 1- 2 mm.



(3) Pressure Attachment of Steel Plate

The epoxy resin adhesive is applied to the steel plate which is set at the required position of the girder, and pressed using the anchor bolts wedging off with the temporary stiff wood and steel angle bar.



(4) Curing and Painting

A suitable chamfer/fillet could also be formed in the adhesive around the edge of the plates and the concrete surfaces. Steel plates and all its components shall be adequately painted for corrosion protection.



4-7-4 Required Materials and Tools/Equipment

(1) Required Materials

- Steel Plate
- Epoxy Primer for Steel Plate Bonding
- Epoxy Resin Adhesive
- Epoxy Sealant
- Anchor Bolts
- Wood and Angle for Fitting

(2) Required Equipment/Tools

- Disc Grinder
- Welder
- Electric Drill
- Epoxy Injection Pump with Accessories
- Wire Brush



CHAPTER 5 REPAIR OF STEEL BRIDGE SUPERSTRUCTURE

5-1 REPAINTING

5-1-1 Description of Repairing Method

The service life of steel bridges could be expected to exceed 50 years if its surface is kept in good condition and properly protected using suitable paint coating. However, if corrosion occurs, repainting is the only restoration and effective method for steel structures. Repainting is carried out for Rust Condition 1st and 2nd degree.

Table 5-1 Type of Repainting

Degree	Type of Paint	Photo	Rust Condition
1 st Degree	Organic Zinc Rich Primer, Epoxy Minacious Oxide Intermediate and Polyurethane Acrylic Coating		Corrosion is very severe on steel surface and coating film is not visible due to corrosion. Affected surface area is over 30%.
2 nd Degree			Corrosion is severe on steel surface and coating film is visible but almost deteriorated due to corrosion. Affected surface area is over 30%.

Before repainting, degreasing, abrasive blasting and soluble salts/chlorides test are necessary as the surface preparation.



5-1-2 Application Criteria

This repair method shall be applied when affected surface area is over 30% (Rust condition: 1st and 2nd Degrees).

The 3rd and 4th degree rust conditions are not recommended for repainting.

For the 3rd and 4th rust degree bridges, the repair is performed by touch-up paint as needed in the routine maintenance.

Table 5-2 3rd and 4th Degree Rust Conditions

Degree	Photo	Rust Condition
3 rd Degree		Corrosion is partially severe on steel surface and coating film is almost visible but partially deteriorated due to corrosion. Affected surface area is 20% to 30%.
4 th Degree		Corrosion is partially visible but not severe. Peel-off of coating film is partially visible. Affected surface area is 10% to 20%.

5-1-3 Procedures

(1) Scaffoldings

Scaffoldings for safe and efficient repainting works shall be provided for the whole bridge. Chain or wire ropes shall be attached to bottom flanges or stiffeners to tie the supporting timber or steel pipes, which serve as framing for the wooden planks. Steel girder shall be covered with plastic sheet to avoid pollution impact to surrounding soil and water for the sand blasting.



(Scaffolding)



(Environmental Protection)

(2) Preparation of Steel Surfaces

a) Degreasing

Remove all traces of oils, grease and other contaminants. Scrub the surface, allow to react for 10 minutes, rinse with fresh water to achieve a water break free surface and allow to dry.

b) Abrasive Blasting

Prior to abrasive blasting, all welds shall be free of slag, slag inclusions and pinholes. Adjacent areas shall be free of weld spatter, which shall be removed by grinding or scraping. Abrasive blast cleans all surface to Sa 2.5 of the ISO 8501-1:2007 standard. All dust and abrasive products are to be removed prior to painting.

c) Soluble Salts/Chlorides Test

The soluble chloride content has to be under 75mg/m^2 in accordance with ISO 8502-6:2006 and ISO 8502-9:1998.



Sand Blast Compressor



Sand Blasting

(3) Filling Voids

During steel surface preparation, any existing voids are filled with epoxy putty, especially if the severely corroded surface has lost significant thickness.



(4) Painting

Paint is usually applied on the steel surface using paint brush and paint roller, to ensure smooth and flat surface. It should be strictly executed to keep a continuous, uniform film of specified thickness. Paint consists of one layer of primer and two layers of coat.



Primer



Intermediate and Final Coats

(5) Checking of Paint Thickness

Measure coating film thickness using Paint/Coating Thickness Meter.



(6) Historical Record Marking

It is important to mark on the bridge surface the Painting Historical Record. This shall be marked on web plate, near the bearing, as shown in the adjacent figure.



5-1-4 Required Materials and Tools/Equipment

(1) Required Materials

- Organic Epoxy Zinc Rich Primer
- Epoxy Minacious Oxide Intermediate Coat
- Polyurethane Acrylic Coat
- Thinner

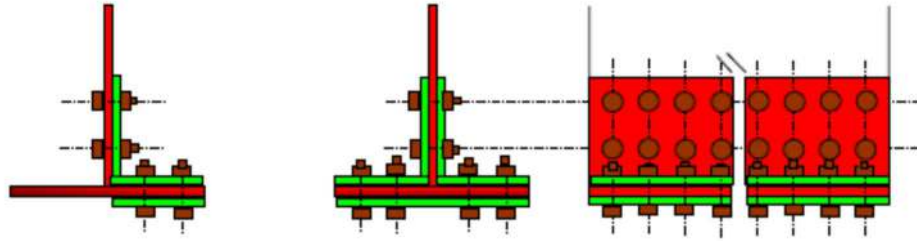
(2) Tools/Equipment

- High-pressure water jet spray
- Water tank
- Generator
- Disc grinder
- Sand blast machine
- Air compressor
- Wire brush and scraper
- Paint roller and Paint brush

5-2 ADDITION OF STEEL PLATE

5-2-1 Description of Repair Method

When severe corrosion had occurred causing significant section loss and defective bolt holes, strength of the lower flange section shall be restored considering the original designed area. This is implemented by adding steel plates or angles connected with high tension bolts (HTB) as shown in Figure 5-1.



(1) One side of lower flange

(2) two sides of lower flange

Figure 5-1 Adding Steel Plate and Angular Plates

Existing bottom flanges with section loss shall be provided with a flat plate at its bottom face, bolted with HTB to angular plates (bent plates) placed at the junction of web and bottom flange. The suggested total thickness of the plates shall be approximately 9 mm.

5-2-2 Application Criteria

In order to restore the lost strength, additional steel plates shall be installed at the portion of existing steel where section loss is more than 20%. This repair method shall be further supplemented by repainting (refer to relevant sections in 5-1 above).

5-2-3 Procedures

(1) Scaffoldings

Scaffoldings for safe and efficient repainting works shall be provided. Chain or wire ropes shall be attached to bottom flanges or stiffeners to tie the supporting timber or steel pipes, which serve as framing for the wooden planks.

(2) Surface Preparation

All surfaces to be provided with additional steel plates shall be thoroughly cleaned of all rust, dirt, oil or grease and other foreign substances. Moreover, surfaces to be painted shall be lightly grinded to increase adhesion of the new paint required. The surface preparation shall conform to subsection 5-1-3 for repainting system or shall be as recommended by the manufacturer.

(3) Surface Treatment

Surfaces of corroded steel plate may have holes and dents. Reduction of original thickness of the steel plate could as well vary. After surface preparation, epoxy sealant is applied to level the surface of the existing steel plate and recover its original thickness and shape.

(4) Holes for HTB

Templates for bolt holes for the additional flat plate or angular plate, which shall be fabricated at the factory, shall be prepared based on the actual positioning required at site. Holes for the HTB are drilled through the plates using portable electric drill or electric coring drill. Suggested diameter of hole is 25 mm to 27 mm, intended for M22 HTB.

(5) Assembling flat plate and angular plate

Additional flat plates and angular plates are placed on the actual bottom flange locations for purposes of installing HTB. After installation, each HTB is first fastened with electric fastener. The details of fastening HTB shall conform to Subsection 5-4-3.

(6) Epoxy Caulking

Small gaps found between the new plate and existing steel plate shall be filled with epoxy caulking.

(7) Tightening High Tension Bolts

After the first fastening as per (5) above, yellow mark is painted on each HTB in order to identify the original orientation. HTB are finally tightened using rotation angle method as means of quality control to maintain design tension stress. The limit of rotation angle for tightening shall be $120^{\circ} \pm 30^{\circ}$ from the marking.

(8) Painting

After installation of the steel plates and HTB are completed, polyurethane acrylic paint is applied.

(9) Historical Record Marking

Historical record for the repair measure performed should be marked on the web plate near the bearing as shown in Sub-section 5-1-3 (6).

5-2-4 Required Materials and Tools/Equipment

(1) Required Materials

- Flat Plate and Angular Plate
- High Tension Bolt (HTB)
- Epoxy Sealant

(2) Required Equipment/Tools

- Electric Drill,
- Fastening Wrench

5-3 CARBON FIBER PLATE BONDING TO STEEL

5-3-1 Description of Repair method

Corrosion of steel girders is accelerated in an environment prone to corrosion and consequently leads to section loss, especially the bottom flange plates near the bearings.

Repair method using carbon fiber plate (CFP) bonding to steel plate provides the same function as the additional steel plates presented in the previous section. Repair method for adding steel plates involve complicated steps such as fabrication of the steel plates in the factory, cutting and drilling of holes for HTB to existing bridge plate in the field and assembling of the additional steel plate. On the other hand, CFP method involves simple application of bonding to steel bridge surface using epoxy resin adhesive. In case of section loss or defective holes, the purpose of bottom flange repair shall be to restore the original strength of the section by installing required area of CFP as shown in the example in Figure 5-2 and Figure 5-3;

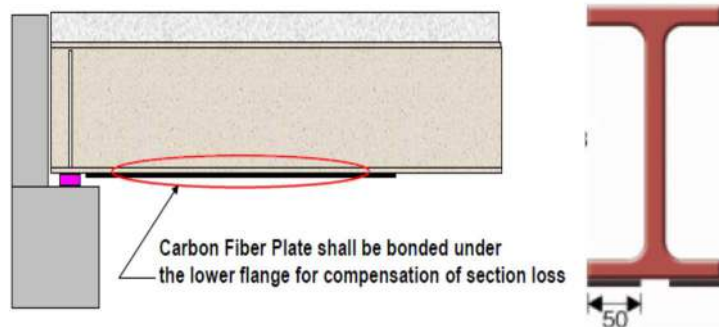


Figure 5-2 CFP Added at Bottom Flange



Figure 5-3 Carbon Fiber Plate Size

5-3-2 Application Criteria

In order to restore the lost strength, CFP shall be installed at the portion of existing steel where section loss is more than 20%. This repair method shall be further supplemented by repainting or by application of anti-corrosion coating (refer to relevant sections in 5-1 above).

5-3-3 Procedures

(1) Scaffoldings

Scaffolding for safe and efficient repair works shall be provided. Chain or wire ropes shall be attached to bottom flanges or stiffeners to tie the supporting timber or steel pipes, which serve as framing for the wooden planks.

(2) Surface Preparation of Steel Plate

All surfaces to be provided with carbon fiber plates shall be thoroughly cleaned of all rust, dirt, oil or grease and other foreign substances. Moreover, surfaces to be painted shall be lightly grinded to increase adhesion of the new paint required. The grade of surface preparation shall conform to subsection 5-1-3 for repainting system or shall be as recommended by the manufacturer.



(3) Adjustment of Unevenness with Sealant

Surfaces of corroded steel plate may have holes and dents. Reduction of original thickness of the steel plate could as well vary. After surface preparation, epoxy sealant is applied to level the surface of the existing steel plate and recover its original thickness and shape.

Epoxy sealant coating shall be applied after steel surface preparation. The surface where the CFP will be placed shall be smoothed using #60 - #100 sandpaper.



(4) Application of Epoxy Resin for Undercoat

Using a roller, epoxy resin shall be applied as adhesive to bond to CFP, thus forming a molded composite through impregnation with the CFP.



(5) Carbon Plate Bonding

An epoxy based adhesive is applied to the CFP with molder to bond. To reduce formation of voids, the adhesive is spread forming a curved profile that measures 3 mm at the center and 1 mm at the edges. CFP should be installed by applying manual uniform pressure along the longitudinal centerline.



(6) Squeezing of Strip to Remove Entrapped Air

For effective impregnation, entrapped air is squeezed out of the strips using roller, before the adhesive sets.



5-3-4 Required Materials and Tools/Equipment

(1) Required Materials

- Epoxy Resin Adhesive
- Epoxy Sealant
- Carbon Fiber Plate

(2) Required Tools/Equipment

- Electric Disc Grinder
- Generator
- Wire Brush, Scraper etc.

5-4 TIGHTENING / RETIGHTENING OF HIGH TENSION BOLT




5-4-1 Description of Repair Method

Missing or loosened high tension bolt (HTB) connection for steel girders are either replaced or retightened in the field during the conduct of maintenance inspection. Before tightening the bolts, surface preparation of steel plate shall be carried out by removing dust, grease and water, and then repainted. Missing bolts or severely corroded bolts found at top flanges shall be replaced as per method presented in Table 5-3. Damaged bolts found to exhibit delayed fatigue fracture (Photo 5-1) shall also be replaced following the method presented.



Photo 5-1 Sample bolt with Delayed Fatigue Fracture

Table 5-3 Replace Method of HTB in Girder Top Flange

Item No.	No.1	No.2	No.3
Method	Replace Bolt only	Chip-off haunch	Break Deck Slab
Outline of method	Remaining Nut still used  Replace Bolt only		
	<ul style="list-style-type: none"> Remove severely corroded HTB from top flange Rotation angle method is applied to fasten HTB as quality control 	<ul style="list-style-type: none"> Chip off concrete from ① or ② shown Replace bolts and nuts Pour non-shrink mortar at chipped off locations 	<ul style="list-style-type: none"> Break deck slab from top surface Replace bolts and nut Pour non-shrink mortar for broken portion of the deck

5-4-2 Application Criteria

This repair method is applied to missing bolts, severely corroded bolts and for loosened fasteners exceeding 10% of the total number of bolt per location.

5-4-3 Procedures

(1) Remove HTB

If the HTB is found to be severely corroded, it shall first be removed from the plate. Removal shall be carried out using electric drill, hammer, wrench, and spanner with long handle. If removal using said devices remains difficult, the bolt shall be cut using acetylene gas.



Photo 5-2 Electric Fastener for HTB

(2) Surface Preparation

After rinsing with water, all adhering rust, scale, dirt, grease or other foreign material shall be removed from the steel plate.

(3) Fastening HTB

After installation of HTB, each shall be initially fastened using electric fastener. Yellow marking is then painted on each HTB in order to distinguish the original orientation.

(4) Quality Control of HTB fastening

HTB are finally fastened using Rotation Angle Method as a means of quality control to meet the required design tensile stress. The fastening rotation angle shall be $120^{\circ} \pm 30^{\circ}$ from the location of the yellow marking.

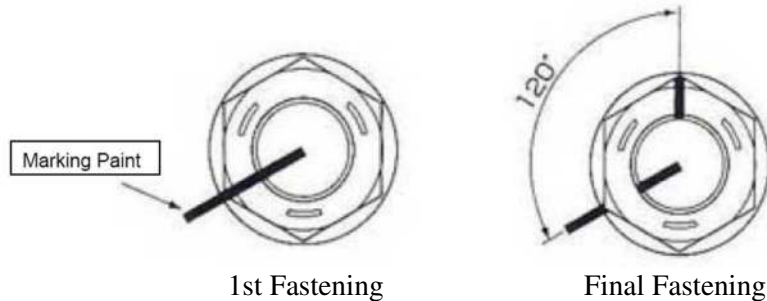


Figure 5-4 Method of HTB Fastening

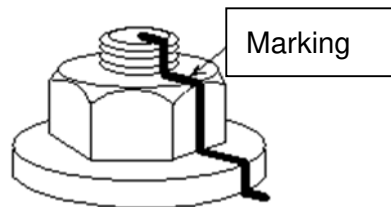


Figure 5-5 Marking

(5) Surface Preparation

After fastening all the HTB, grease or other oil material shall be removed using solvent material. New HTB shall be covered with grease to control rotation friction.

(6) Painting

If repainting of the finally fastened HTB is necessary, refer to Section 5-1 for the required appropriate paint material.

5-4-4 Required Materials and Tools/Equipment

(1) Required Materials

- HTB (22 mm or 7/8 in. diameter)
- Nuts
- Plain Hardened Washers

(2) Required Tools/Equipment

- Torque Wrench
- Electrical Impact Wrench, Special Fastener for HTB

CHAPTER 6 REPAIR OF CONCRETE/STEEL BRIDGE SUBSTRUCTURE

6-1 CAULKING

6-1-1 Description of Repair Method

Active cracks are treated and repaired with flexible sealants as shown in Figure 6-1. The sealant is generally applied in a wide recess cut along the crack. The dimensions of the recess (width and depth) depend on the total crack movement and the cyclic movement capability of the joint sealant used. For selection of sealant material, crack movement should be calculated taking into account the applied loads, shrinkage and temperature variations.

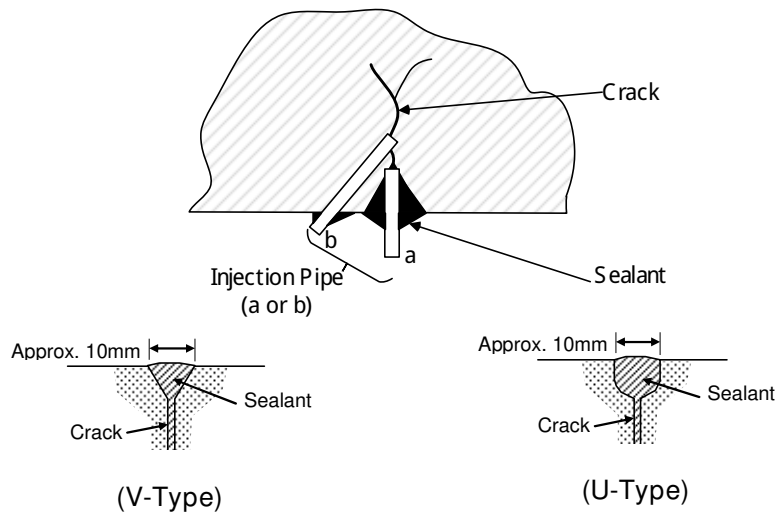


Figure 6-1 Types of Caulking

6-1-2 Application Criteria

Crack widths could be more than 3.0 mm with depth of less than 300 mm. In this case, the top surface edges should be chipped or sawn to form a V-type or U-type groove, in order to provide a caulking for inlet of gravity flow of resin into the crack by injection pump.

Cracks wider than 3.0 mm generally require epoxy based injection material.

6-1-3 Procedures

(1) Clean the cracks

Remove all loose debris such as dirt, concrete fine particles and contaminants (oil, grease, etc.) from the cracks using high-pressure water, or special and effective solvent. Remove the residual water or solvent in the crack with filtered (dust and oil free) compressed air and allow adequate time for drying.



(2) Preparation of Caulking

Using a concrete saw, hand tools or pneumatic tools, a V-groove or U-groove, approximately 10 mm in width and in depth, is prepared at the surface along the crack. The groove shall then be partially sealed with a sealant.



(3) Drilling Holes and Fixing Injection Pipes

Port holes are drilled near the crack, or in the groove. Injection pipes are then fixed at the tip of the groove. Spacing between ports varies between 150 mm to 500 mm, generally depending on the width and depth of the cracks.



The groove is then completely sealed with sealant.

(4) Injecting the Epoxy Resin

Epoxy resin can be injected using injection pumps, or air-activated caulking guns. Duration of injection process shall be in accordance with the supplier instructions.



For horizontal cracks, the injection is carried out from the injection pipe at end of the crack to the other end.

(5) Curing of Injected Material

After the crack is sealed, the projecting injection pipes are cut and the holes are filled with epoxy patching compound. If surface coating or carbon fiber sheet will be applied, the portions with sealant and tip of cut pipe should be grinded to form a smooth surface.



6-1-4 Required Materials and Tools/Equipment

(1) Required Materials

- Epoxy Resin
- Epoxy Sealant
- Injection Pipe

(2) Required Equipment and Tools

- Epoxy Injection Pump
- Power Disc Grinder
- Portable Generator
- Brush

6-2 PATCHING

6-2-1 Description of Repair Method

Patch repair is performed to restore small areas where sound concrete is damaged by spalling, scaling and impact. This method of repair is generally applied using trowel and require none or minimum formworks. The patch thickness is limited to a maximum of 100 mm depth of hollow surface.

Type A Patching is used for defects without exposed rebar while Type B Patching is applied to defect of surfaces with exposed rebar.

Non-shrinkage polymer cement mortar is used for the patch repair.

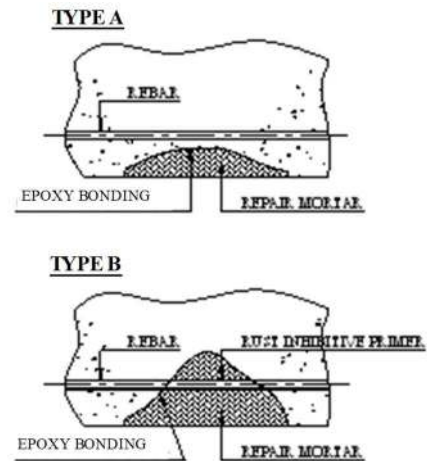


Figure 6-2 Types of Patching

6-2-2 Application Criteria

Patch repair is classified into two types as shown in Figure 6-2, considering defective area and surface. Type-A is applicable to surfaces without exposed rebar having defective widths of up to 300 mm and depths of up to 50 mm. Meanwhile, Type-B is used for surfaces with exposed rebar with defective widths between 300 mm and 600 mm, and up to 100 mm depths.

Non-shrinkage polymer cement mortar is used for Type-A and Type-B patching.

(1) Removal of Defective Concrete

Remove all defective, unsound and contaminated concrete and prepare the edges for the patch area. If local corrosion in reinforcement with section loss is found which would require additional bars, remove only the damaged area of concrete including the length needed to bond the new reinforcement as shown in Figure 6-3.

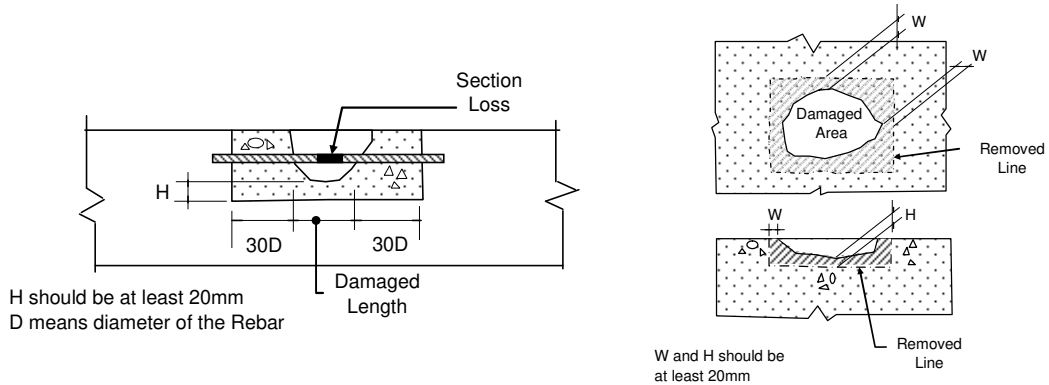


Figure 6-3 Removal of Damaged Concrete

(2) Chipping and Cleaning of Concrete Surface

Concrete within marked out areas shall be removed using light mechanical breakers or hammer and chisel to expose the reinforcement and a sound concrete substrate. The substrate shall be cleaned by brush to remove concrete dust.



(3) Application of Epoxy Bonding Resin

The concrete substrate area is coated with epoxy bonding resin in order to ensure adherence to patching and reinforce the repair. If rebar is exposed, anti-corrosion coating is applied to the bar surface.

As notes, depending on the type of mortar, the bonding coat to the concrete surface may not be needed.



(4) Placing of Cement Mortar

Prepare the mortar mix in a bucket. Use a trowel to spread fresh mortar over the area, covering any nails driven halfway into the old concrete (if nails are provided to further reinforce the repair). Smoothen and level the mortar using the trowel.

It should be noted that polymer cement mortar is suitable for both vertical and horizontal surface applications, with a thin coating of up to 15 mm. As may be required, it can be smoothed using a trowel or broom finished.



(5) Curing

All types of concrete repair need thorough and continuous curing to develop strength and impermeability. Curing also minimizes drying shrinkage while bond strength is developing.



6-2-4 Required Materials and Tools/Equipment

(1) Required Materials

Polymer Cement Mortar (PCM)

- PCM Powder
- Water
- Concrete Nail
- Bonding Agent for Concrete (Epoxy Resin Adhesive)
- Bonding Agent for Rebar (Zinc Rich Primer)

(2) Required Equipment

- Chisel
- Portable Generator
- Wire Brush
- Small Hammer
- Mortar Mix Bucket
- Safety goggles
- Trowel
- Dust mask

6-3 RECASTING CONCRETE/GROUT

6-3-1 Description of Repair Method

Recasting Method which involves casting of the damaged area by placing concrete or grouting mortar on the formwork, is usually most suitable for severely damaged concrete or for largely damaged areas with densely spaced rebars as shown in Photo 6-1. If concrete placing by vibration is a problem, grout and free flowing self-compacting concrete should be developed to minimize the vibration required.



Photo 6-1 Damaged Pier for Repair by Recasting

6-3-2 Application Criteria

Recasting Concrete/Grout is divided into two methods namely: concrete placing and mortar grouting types. The mortar grouting type shall be applied Portland cement grout.

Considering the position and scale of damage, applications of the recasting concrete and grout are classified according to the formwork types, such as the “Envelope Type” and “Mail Box Type,” shown in Figure 4-9 of Section 4-5 RECASTING CONCRETE/GROUT. Envelope type is open at the top for pouring concrete while the mail box type consist of holes or slit at its side for purposes of grouting or pumping mortar. Mail box type formwork is further classified based on concrete volume, applied area and rebar arrangement as also shown in Figure 6-4, with due consideration to cost performance.

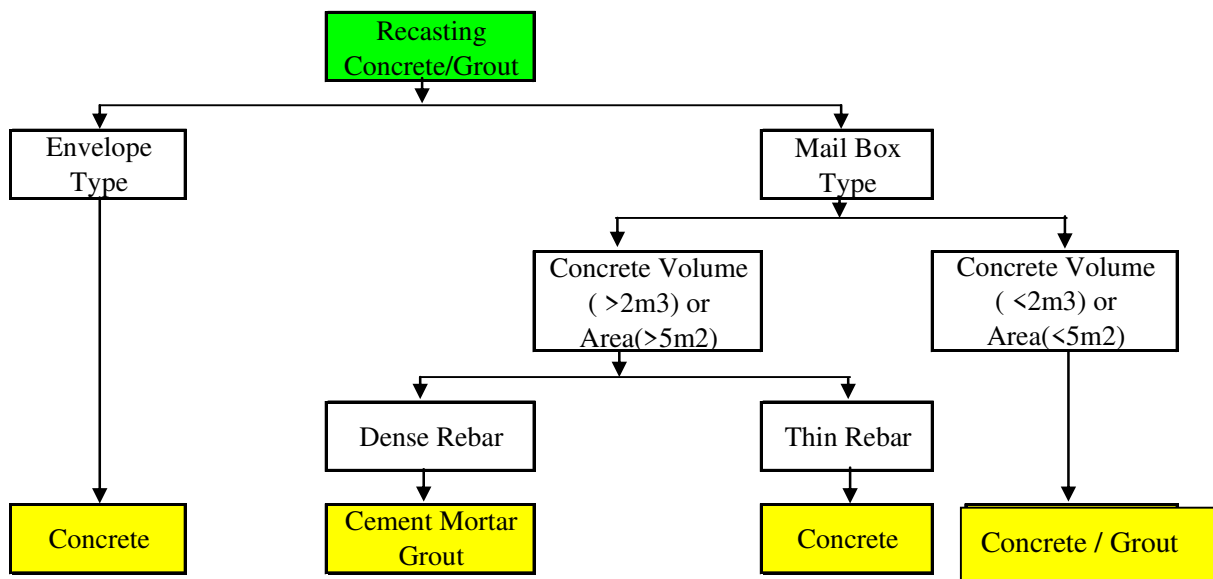


Figure 6-4 Flowchart of Selection Method for Recasting Concrete

6-3-3 Procedures

The procedure of concrete mixing, pouring and curing is in accordance with Section 3-7-3 of “PARTIAL DECK SLAB REPLACEMENT”. The following procedure is only for cement mortar grout and non-shrink grout.

(1) Removal of Damaged Concrete Deck Slab

All deteriorated or damaged concrete are cut using saw to form the vertical edges, and then removed using a breaker and chisel. Rebars are examined for loss of section due to corrosion. If cross sectional area of the reinforcement has reduced by more than 15%, provide extra reinforcements, as necessary.



(2) Preparation of Old Concrete and Rebars

A suitable bonding agent for concrete and reinforcement should be selected taking into consideration its limited working time available for fixing the formworks and placing the new concrete. Concrete should be placed immediately after application of bonding coat to the faces of old concrete and rebars.



(3) Cutting Existing Rebars and Adding New Rebars

Deteriorated old rebars are cut up to the required lap length. New bars to be provided shall be of same or bigger diameter than the existing, considering the current loading condition. The lap length is calculated as 30 times the new rebar diameter. The new rebars shall be tied to the existing bars using tie wires or by welding.



(4) Setting Formworks

Formworks for re-casting the girder have to be very rigid and well-supported to prevent the new concrete from sagging due to its own weight.



(5) Mixing Mortar

Cement mortar grout shall be composed of one part cement, three parts sand and a minimum amount of water necessary for the mixture to flow under its own weight, and then mixed using a grout mixer.



(6) Mortar Placing

The mortar has to be carefully placed to avoid the entrapment of air. Pumping is usually employed for the mail box type formwork which can be used for smaller pours. When pumping is used, the delivery hose should be at a low position while pouring, to allow the air to be displaced.



(7) Curing and Removal of Formworks

Continuous water curing by spraying water is always preferable as membrane cure, which helps slow down drying process.

Formworks for load bearing structural members shall remain in position until at least 80% of the 28 day compressive strength of the new concrete is achieved.

6-3-4 Required Materials and Tools/Equipment

(1) Required Materials

For Concrete

- Portland Cement
- Silica fume
- Aggregate/Sand
- Rebar (Reinforcing bar, Grade 60)
- Bonding Coat for Concrete (Epoxy Resin Adhesive)
- Anti-corrosion Primer for Rebar (Zinc Rich Primer)
- Cotton mat (Curing)

For Mortar

- Portland Cement (Cement Mortar)
- Admixture for consistency

- Reinforcing Bar
- Bonding Coat for Concrete (Epoxy Resin Adhesive)
- Anti-corrosion Primer for Rebar (Zinc Rich Primer)

(2) Required Tools/Equipment

- Sawing Equipment
- High Pressure Water Blasting
- Handy Concrete Breaker or jackhammer
- Handy power Chisel
- Concrete Mixer 30 liters
- Mortar Mixer with Pump (For Mortar)
- Vibrator
- Troweling tools

6-4 JACKETING WITH CONCRETE

6-4-1 Description of Repair Method

Concrete jacket as shown in Figure 6-5 is mainly applied to substructure that has deteriorated concrete due to corrosion of rebar. It should be noted that splash zone portions of bridge concrete piles in marine environment are more exposed to corrosion. Although provision of jackets could delay further chlorides from penetrating the pile, this does not guarantee complete mitigation of corrosion to the rebars.

Steel jacketing remains an effective alternative for strengthening piers or piles against structural failure; however, it is not included in the scope of this guide book.

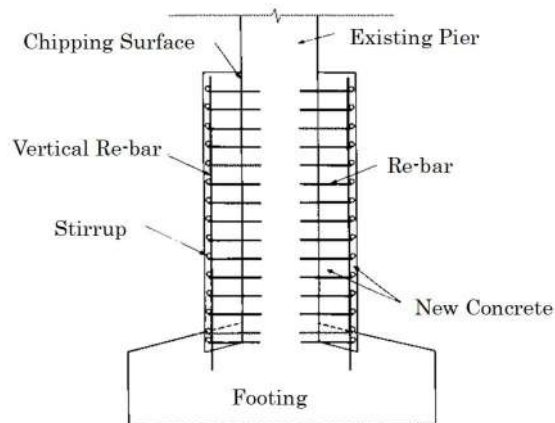


Figure 6-5 Concrete Jacketing

6-4-2 Application Criteria

Two methods of jacketing, namely concrete jacket and steel jacket, are discussed as follows:

Concrete jacket is applied to protect the deteriorated concrete due to corrosion of rebars, damage due to rapid water flow or breakage due to continuous impact from materials flowing in the channel such as drift woods. Concrete jacket should be basically placed above water level as shown in Photo 6.2. If the damaged portion is submerged in water, cofferdam is necessary to achieve a dry condition during jacketing. To minimize cofferdam, related repair works are either carried out while water is at low level in the dry season, or using underwater concrete.



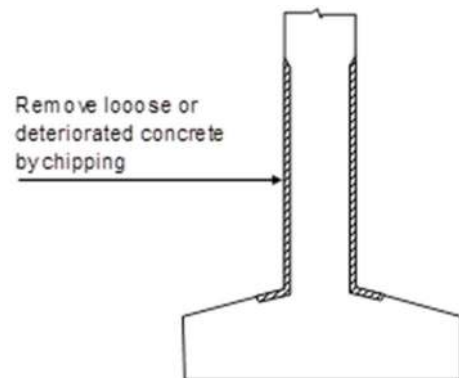
Photo 6-2 Concrete Jacket for Repair Pier

6-4-3 Procedures

(1) Removal of Deteriorated Concrete

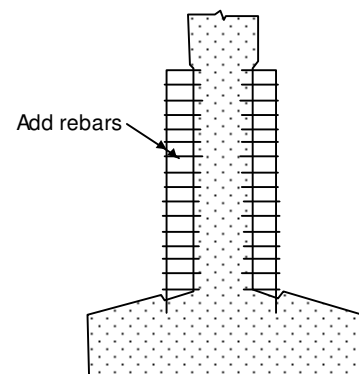
All loose or deteriorated concrete shall be removed. Surface cracks shall also be removed by chipping. Hammer sounding shall be done to locate delaminated areas.

When corroded reinforcing steel is exposed during concrete removal, the corroded bars shall be further exposed by chipping until clean un-corroded steel is exposed.



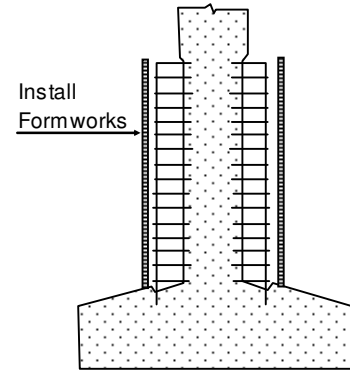
(2) Addition of Rebar

Additional rebars are anchored into drilled holes in the concrete, and placed in conformity with the requirements shown on drawings. Heavily corroded rebars shall also be replaced. Clear concrete cover to rebar, for piers and piles, shall be 40 mm in normal environment, and 55 mm in marine environment



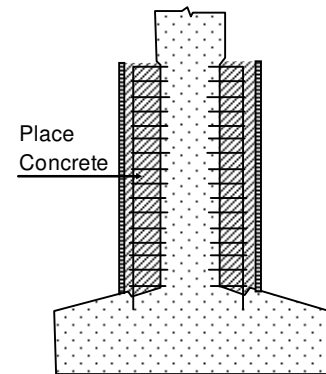
(3) Setting-up of Formworks

Formworks for concrete jacket are usually circular or rectangular in shape. Formworks have to be very rigid and well-supported to maintain the shape and the required covering of the new concrete. It should also be able to withstand pumping forces if concrete is to be pumped and vibrated.



(4) Placing of Concrete

Concrete is placed in the formworks through a suitable method and compacted well using internal or external vibrators. Surfaces shall be finished using broom, wood floating, and steel troweling to match the adjacent existing concrete.



(5) Curing of Concrete

Continuous water curing using wetted cotton mat is preferable to help slow down drying.

Formworks for load bearing structural members shall remain in position until at least 80% of the 28 day compressive strength of the new concrete is achieved.

6-4-4 Required Materials and Tools/Equipment

(1) Required Materials

a. Concrete with Fine Aggregate

A suggested mix design for small scale repairs is given below as reference. These quantities will make about 0.03 cubic meter of concrete and could be fully accommodated in a small mixer.

1) Cement

- Portland cement 13.0 kg
- Silica fume 0.5 kg (If silica fume unavailable, use 13.5kg cement)

2) 10mm Crushed Aggregate 36.0 kg

3) Sand (assumed with 2% water content) 18.5 kg

4) Water (maximum) 5.4 liters

5) Super plasticizer (nominal) 25ml

b. Formworks

- Steel Formwork (Circular)
- Plywood formwork

(2) Required Equipment/Tools

- Drilling Machine to Concrete
- Concrete Vibrator

CHAPTER 7 REPAIR OF BRIDGE EXPANSION JOINT

7-1 ASPHALTIC PLUG JOINT

7-1-1 Description of Repair Method

The quality and maintenance of the expansion joints are vital to the behavior of bridges and their durability. Accordingly, it should be ensured that expansion joints are waterproofed as well as resistant to leakage. In the case of asphalt sealant, the sealant is easily damaged due to traffic load and aging.

The usual gap between concrete edges is around 20 mm. The movement of a 20 m bridge span due to changes in temperature is $12 \times 10^{-6} / ^\circ\text{C} \times 20 \text{ m} \times (\pm 20^\circ\text{C}) = \pm 4.8 \text{ mm}$ and the movement of the same span due to traffic load is approximately less than 5 mm. Total movement of a 20 m span Concrete Girder bridge is below $\pm 10 \text{ mm}$. With these considerations, the most suitable repair measure for damaged asphalt sealant is the installation of asphaltic plug joint.

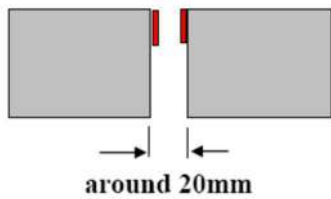


Figure 7-1 Asphalt Joint Sealant

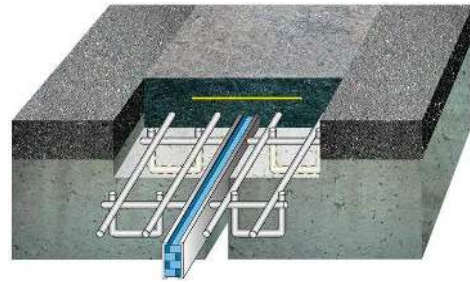


Figure 7-2 Type of Asphaltic Plug Joint



Photo 7-1 Cleaning of the gap



Photo 7-2 Flexible Asphalt pouring

7-1-2 Application Criteria

Asphaltic plug joints are mainly applied on Concrete Girder bridges and steel girder bridges on fixed bearings. This repair method shall be implemented if the following conditions are rated as “Bad” as per suggested condition rating criteria:

- Water leakage: detected area >50%
- Abnormal Space/ Noise: Detected
- Difference in Elevation: >30mm at expansion gap
- Deteriorated Sealant: Pourable joint sealant almost completely lost.

7-1-3 Procedure

(1) Dismantle Existing Damaged Asphalt Joint Sealant

The damaged sealant due to heavy traffic, aging etc. shall be dismantled.



(2) Chipping surface concrete

Chip-off edges of concrete to install steel frame and to insert the form to narrow gap. (Proper gap for seamless joint is less than 25 mm.)



(3) Install steel frame

Steel frame shall be fabricated with box frame and rebars. This frame shall be fixed by welding between concrete anchor and rebars.



(4) Rebar Anchor

Besides intersection of rebar, the concrete anchor shall be inserted for every intersection of rebar.



(5) Pouring Flexible Asphalt

Flexible Asphalt shall be poured to the chipped off edges. The height of pouring is half of the total thickness.



(6) Installation of Expansion Sheet

Expansion Sheet shall be spread on the first layer of flexible asphalt.



(7) Pouring Flexible Asphalt

Flexible asphalt (asphalt- rubber chips) shall be poured as second layer.

The surface of flexible asphalt shall not be compacted or tamped until the temperature has decreased.



Photo 7-3 Application Example in Zambia

7-1-4 Required Materials and Tools/Equipment

(1) Material Requirement

- Steel frame (welded with anchor rebars)
- Concrete anchor with steel bars
- Expansion sheet
- Flexible Asphalt



(asphalt rubber chip, see

Photo 7-4)

Photo 7-4 Sample Asphalt Rubber Chips

(2) Required Tools/Equipment

- Concrete Cutter
- Electric impact hammer/small jackhammer
- Gas burner
- Asphalt mini cooker

-

Surface finisher

7-2 REPLACEMENT OF EXPANSION JOINT

7-2-1 Description of Repair Method

The quality and maintenance of the expansion joints are vital to the behavior of bridges and their durability. Accordingly, it should be ensured that expansion joints are waterproofed as well as resistant to leakage.

When water leakage occurs at expansion joints, dirt, soil, gravel and water are collected on the bearing seat locations. This condition will initiate corrosion of steel members including the steel bearings, bottom flanges at ends of steel girder and steel connection accessories.

This repair method is intended for damaged steel type and rubber type expansion joints, which would be replaced with suitable water-proof type expansion joints.

Concrete cutter shall be used to cut both joint edges of the concrete surface to form a straight cutting line pattern. The defective expansion joint shall then be dismantled after chipping off the concrete with an electric jack hammer. The new expansion joint shall be installed with its top level matching the required finish surface. Concrete/grout shall be finally poured, leveled, and then cured.

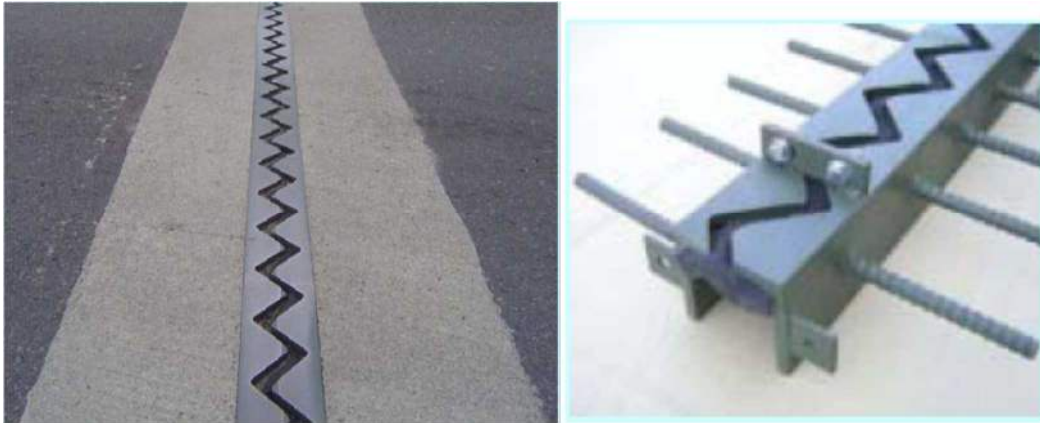


Photo 7-5 Sample of Waterproof Type Expansion Joint

7-2-2 Application Criteria

The replacement of steel expansion joint shall be implemented if the following conditions are rated as “Bad” as per suggested condition rating criteria:

- Water Leakage: Detected area > 50%
- Abnormal space/noise: Detected
- Difference in elevation: Difference in elevation is >30mm at expansion gap
- Displacement: Pourable joint sealant almost completely lost
- Cracking: Cracking on primary members especially in welded parts

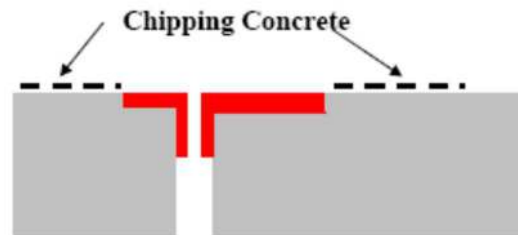
Meanwhile, replacement of rubber expansion joint shall be implemented if the following condition criteria are rated “Bad”:

- Water leakage: detected area >50%
- Abnormal Space/ Noise: Detected
- Difference in Elevation: >30mm at expansion gap
- Rupture: Rubber seal dislodged or peeled-off
- Abnormal Space/ Noise: Detected
- Deteriorated Sealant: Joint sealant almost completely lost.

7-2-3 Procedure

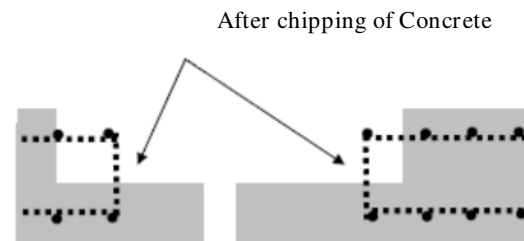
(1) Cut concrete surface

Using concrete sawing device, concrete surface shall be cut in transverse direction.



(2) Chipping off concrete/ Dismantling defective expansion joint

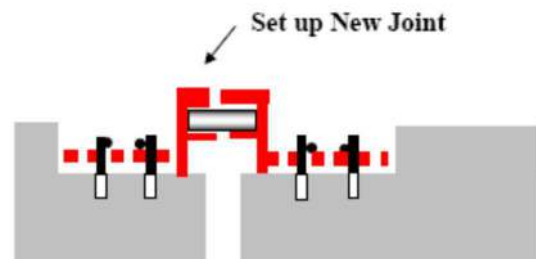
Concrete shall be continuously chipped off to achieve the required positioning for the new expansion joint. Exposed existing rebars shall remain to maintain the strength.



The damaged expansion joint shall then be dismantled after chipping off concrete

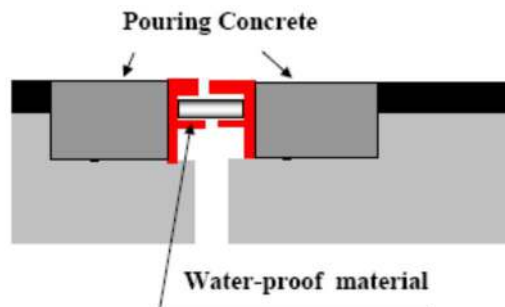
(3) Set up new expansion joint

The new expansion joint with water-proof device shall be installed. Transverse rebars (16 mm dia.) shall be fixed with mechanical anchors.



(4) Pouring Concrete

After verification measurements, concrete shall be poured, and then cured, to complete the works.



7-2-4 Required Materials and Tools/Equipment

(1) Required Materials

- New Expansion Joint with water proof rubber
- Rebar (16 mm dia.)
- Concrete/grout

(2) Required Tool/Equipment

- Concrete Cutter
- Electric impact hammer/small jackhammer
- Electric concrete vibrator
- Trowel

CHAPTER 8 REPAIR OF BRIDGE BEARING

8-1 REPLACEMENT OF BEARING

8-1-1 Description of Repair Method

Effective service life of elastomeric bearings is estimated to be 15 – 25 years. As the material ages during its serviceability period, it exhibits severe bulging or cracking. These are signs that the elastomeric bearings need to be replaced.

Replacement with new bridge bearings should be performed strictly in accordance with the relevant technical requirements and recommendations provided by the bearing manufacturers. Installation should be performed by highly experienced staff subject to close supervision.

Usually, the jack-up girder technique is utilized to allow for replacement of bearings. This is discussed in detail in Section 8-3 of this guidebook (Jack-up Girder). During replacement of the bearings, traffic may remain open but with imposed restriction on passing speed as safety precaution. The girder shall be jacked up from 5 mm to 10 mm, with one jack stroke.



Photo 8-1 Sample of Replaced Bearing

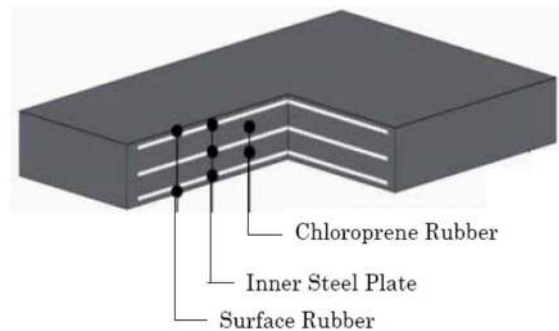


Figure 8-1 Rubber Bearing

8-1-2 Application Criteria

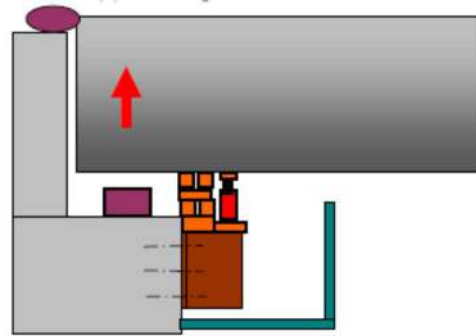
Replacement of bearing shall be implemented if existing rubber bearings already exhibit severe cracks and abnormal bulging. Old steel bearings need to be replaced especially if loose connections are observed. This repair method form part of the jack-up girder method described in Section 8-3.

The capacity of the new bearing should be the same as the old bearing, subject to approval of the Engineer.

8-1-3 Procedure

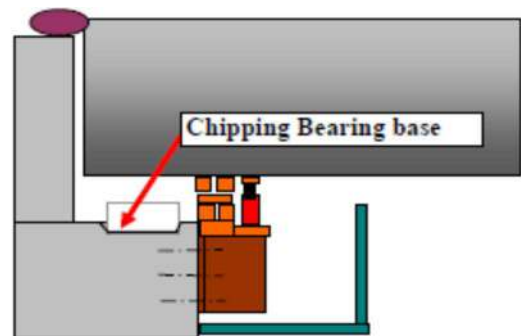
(1) Jack up girder

Jack-up girder process shall be referred to Section 8-3 of this guidebook. The surface of expansion joint shall be secured to provide safety for passing traffic during jacking up process. Moreover, the height difference between surface of abutment and girder shall be kept below 10 mm.



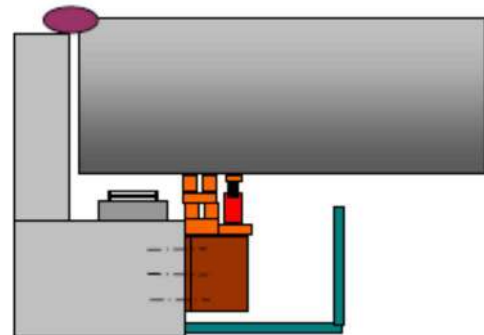
(2) Dismantle existing Bearing and chipping off of bearing base

After jacking-up process, chip-off concrete bearing base to remove existing bearings.



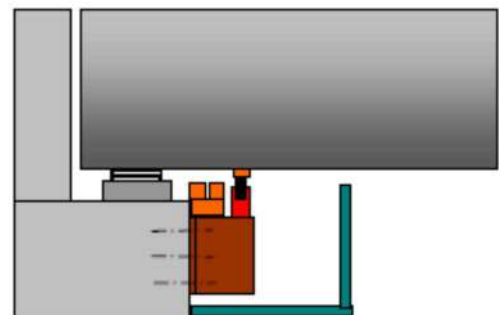
(3) Cast New Bearing Seat and Set up New Bearings

After concrete chipping and the new required bed support replacement with rebar is installed using non-shrink grout, the new bearings shall be set up at appropriate position and level. The level shall consider additional factor such as compressive displacement of elastic rubber bearing.



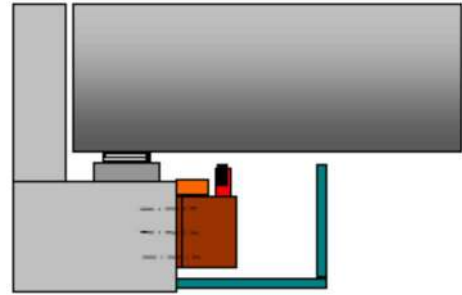
(4) Jack Down Girder after Curing

After curing of the bearing base, it should be inspected to check the level and stability before the girder is jacked down and consequently supported by the new rubber bearing. Final position and height of the new bearing shall be verified, subject to approval of the Engineer.



(5) Dismantle Jacks and Temporary Supports for the Final Work

After replacement of the new rubber bearings are accomplished, jack device and temporary supports shall be dismantled. Steel surfaces shall be painted, if found necessary.



8-1-4 Required Materials and Tools/Equipment

(1) Required Materials

- Elastomeric bearing pads.
- Rebar
- Mortar/concrete

(2) Required Tools/Equipment

- Hydraulic Jack
- Electrical Jackhammer
- Trowel

8-2 EXTENSION OF BEARING SEAT

8-2-1 Description of Repair Method

Normally, the bearings transmit all the loads (dead load, live load, wind pressure and others) from the superstructure to the substructure. Consequently, reaction is concentrated near the bearing seat. This sometimes causes damage to the bearing seat. If such defects are found, damaged concrete shall be removed completely. Anchor bars shall be connected to the existing bearing seat to extend the seat width accordingly. Non-shrink concrete shall finally be poured to the extended bearing seat.

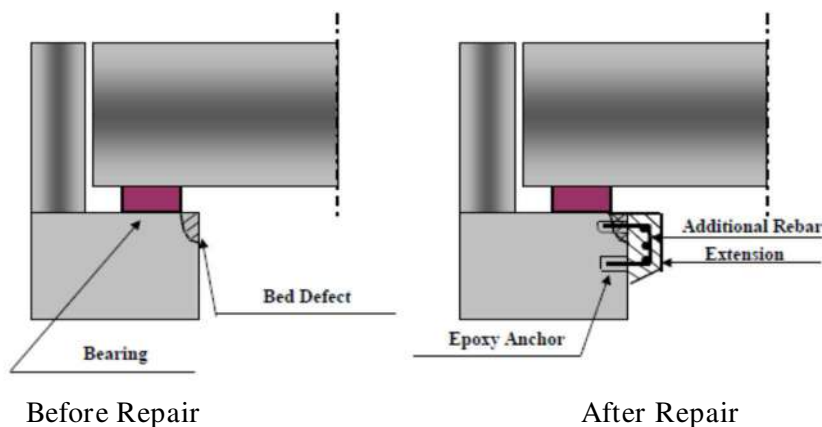


Figure 8-2 Concept of Bearing Seat Extension

8-2-2 Application Criteria

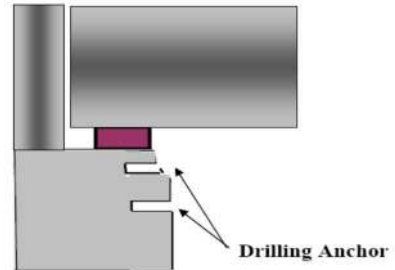
Bearings are sometimes installed close to the edge of the concrete coping. There are cases that these coping edges break off due to support reactions from traffic impact loading. This signifies risk of superstructure collapse as the required bearing seat was reduced. Hence, this repair method is intended to eliminate said risk by extending further the existing bearing seat.

8-2-3 Procedure

(1) Chipping and Drilling of Holes

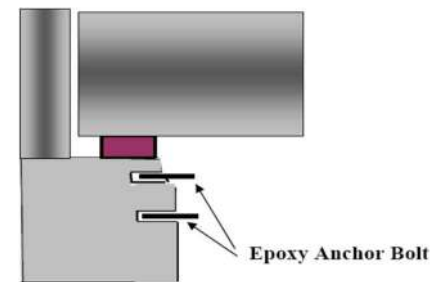
The spalled or delaminated portion shall be removed completely by hammer chipping or electric drilling. Holes for anchor bar shall be drilled using electric drill device.

Drilling of holes shall be performed carefully in order to avoid damaging existing coping reinforcements.



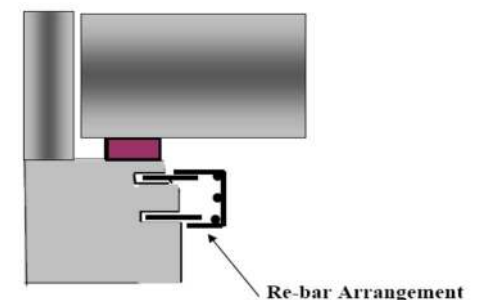
(2) Anchor Bar Fitting

Drilled hole shall be filled with epoxy adhesive before completely placing required anchor bars.



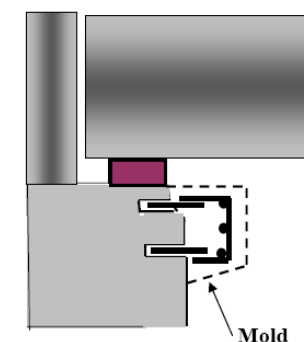
(3) Arrangement of re-bars

After anchor bars are bonded in the drilled holes, new rebars connected to the anchor bars are arranged for the proposed extension of bearing seat.



(4) Formworks

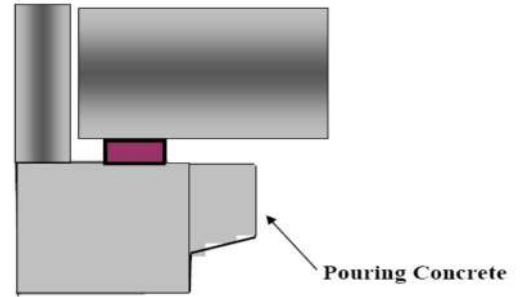
Formworks and required temporary supports are fixed immediately after application of bonding coats to concrete substrate and reinforcement.



(5) Pouring of Concrete

Concrete is then poured to the formed section. After concrete is completely in place, finishing and curing is performed. The rendered surface should match that of the existing structure.

Formworks shall be finally dismantled.



8-2-4 Required Materials and Tools/Equipment

(1) Required Materials

- Primer for Concrete Surface (Epoxy adhesive),
- Anchor bar / Re-bar and concrete

(2) Required Tools/Equipment

- Electric drill,
- Electric concrete vibrator
- Trowel

8-3 JACK-UP GIRDER

8-3-1 Description of Repair Method

Jack up girder method is applied for replacement of bearings and re-arrangement of existing bearing. The computation of jack-up reaction shall be the responsibility of the designated Structural Engineer. Once the required quantity and capacity of hydraulic jacks are determined, this repair method shall then proceed. Required scaffoldings shall also be provided. Jack-up device and temporary supports and jack base bracket shall be fabricated and installed below the concrete or steel girder near bearing locations. For steel girders, jack stiffener shall be welded in proper position before proceeding with raising the girder. During jacking operations, traffic may remain open but shall be under restricted speed and flow to maintain safety. The operation shall be simultaneously performed for all the girders. The height to be raised on a cyclic motion shall be limited to less than 5 mm in order to ensure that constant reactions are transmitted from all the girders. The jack up procedure shall be repeated until the existing bearings are accessible for dismantling. The ideal jack up height could reach between 10 mm to 20 mm.



Photo 8-2 Sample of Replacement Bearing by Jack-up Girder

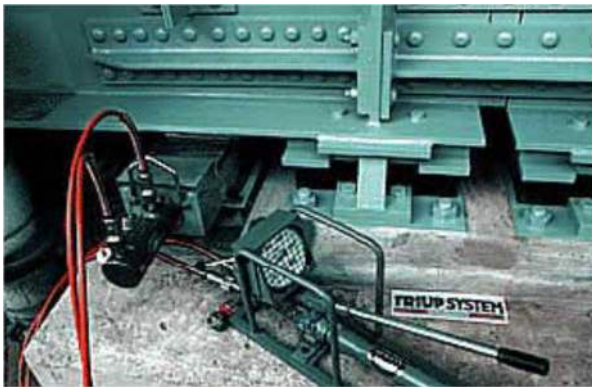


Photo 8-3 Hydraulic jack



Photo 8-4 50-ton hydraulic jack

8-3-2 Application Criteria

In case loose connection of steel bearings or bulging/cracking of rubber bearings are rated as “Bad” as per suggested Condition Rating Criteria, jack-up method will be initiated to perform necessary repairs or replacement of bearings.

In case abnormal displacement of steel and rubber bearing are rated as “Bad”, the jack-up method is also utilized for lifting the girder to reposition the bearing locations.

8-3-3 Procedure

8-3-3-1 Sequence of Jack-up method

The procedure of Jack-up method for replacement of bearings is presented in flowchart below:

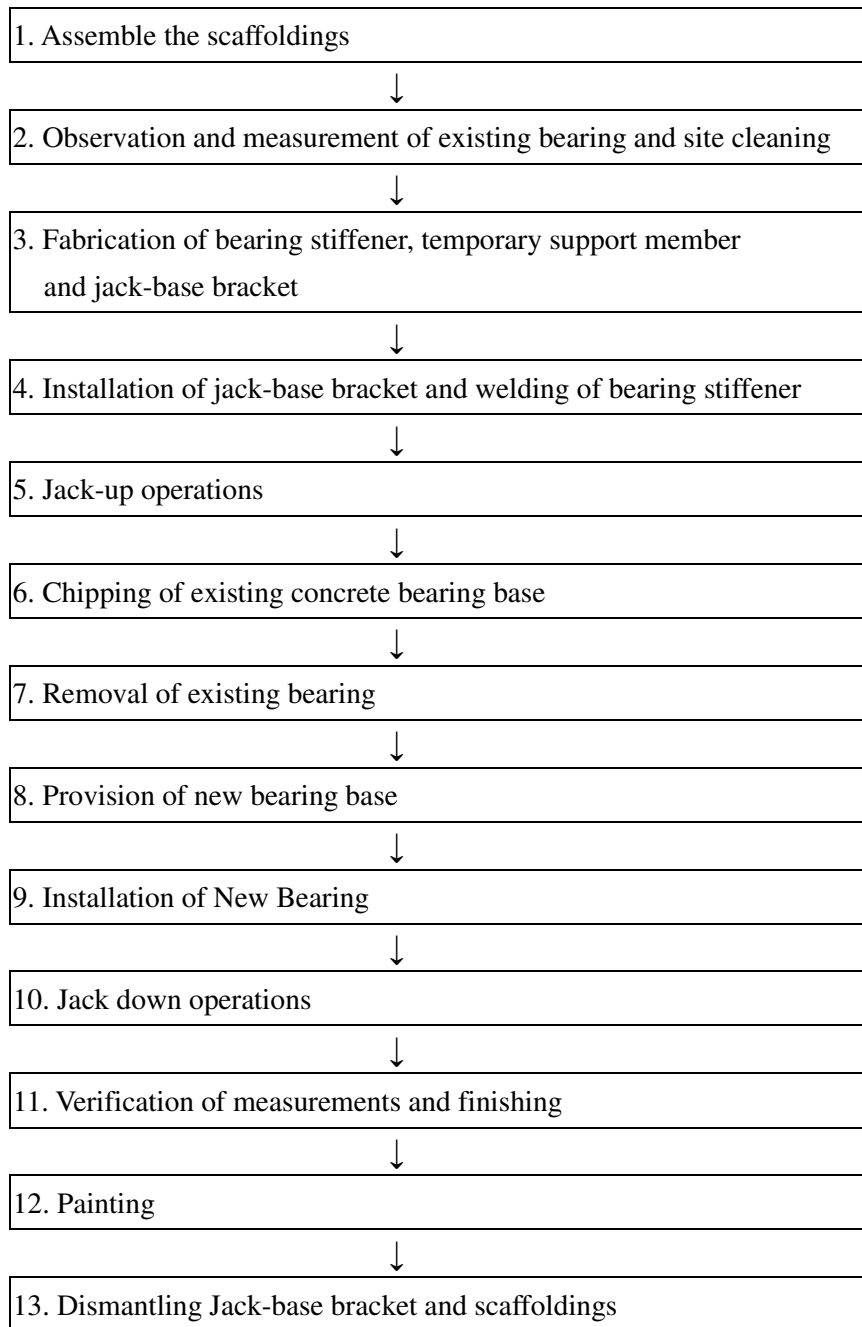
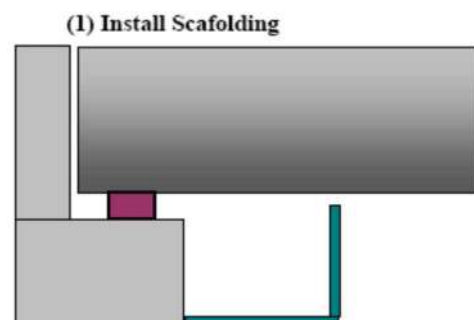


Figure 8-3 Flowchart of Jack-up Method for Replacement of Bearing

8-3-3-2 For Concrete Girder

(1) Preparation of materials, equipment and site cleaning

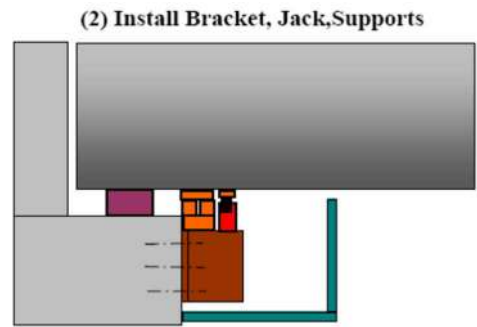
The Scaffolding is installed to prepare jack-up method to proceed. The jack base bracket shall be fabricated in the factory which is approved by the Engineer.



(2) Installation of Jack base frame

The Jack-base bracket is installed using epoxy anchor through drilled holes for anchor bolts.

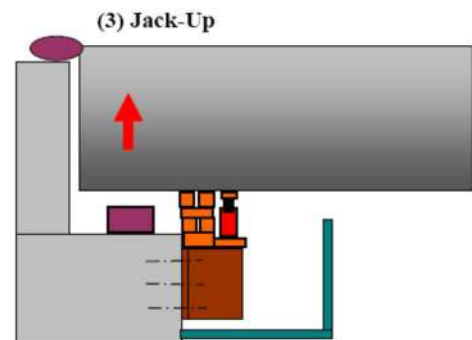
Hydraulic jack with capacity furnished by designated structural engineer is set up on the jack-base bracket. Temporary supporting member shall also be provided.



(3) Jacking up

Jack-up operations shall be simultaneously carried out for all the girders. For this condition, jacking up height is limited to 5 mm for each jack-up motion.

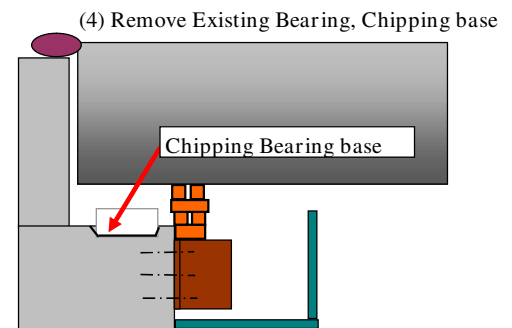
The method is repeated gradually until enough jacking up height is achieved to allow for dismantling of the existing bearing.



(4) Chipping of bearing base and removal of existing Bearing

Concrete bearing base is chipped off to dismantle the existing bearings.

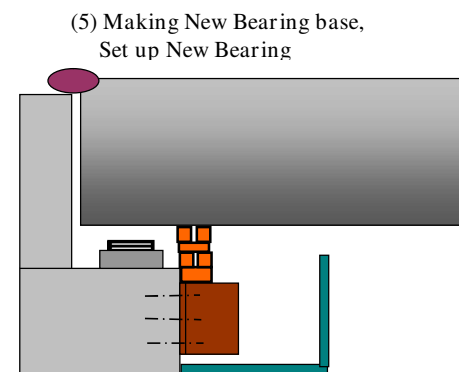
A slope between bridge approach and the expansion joint shall be maintained for passing traffic during jacking-up operations.



(5) Making new bearing base

Additional re-bars for the new bearing base shall be arranged.

After concrete is completely placed, new rubber bearings are installed on the bearing base. During this operation, the girder shall be temporarily supported. The measurement of height, location shall be carefully verified by a designated inspector.



(6) Jack down

If the new bearing installed is determined as satisfactory, jack down operations shall commence. It is important to maintain safety during this operation. Jacking down shall be carried out gradually while carefully removing the temporary supporting members.

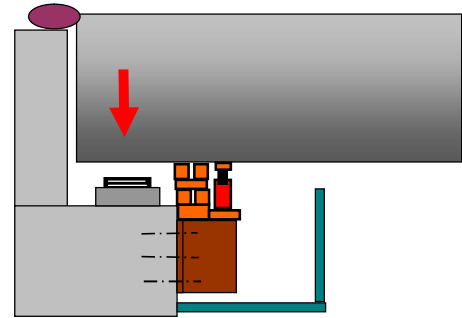
If the temporary support touches the lower surface of the girder during jack down operations, the jack base plate shall be changed with a lesser thickness. Stroke shall be extended to jack down. These steps shall be repeated in cycle. For safety purposes, each stroke should maintain a height of less than 5 mm.

If the temporary support keeps touching the concrete surface, dismantle the jack and remove the jack base plate gradually.

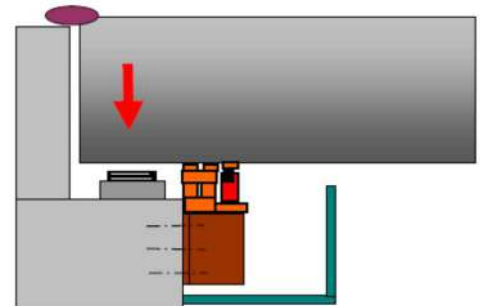
The temporary support shall be taken off from the concrete surface by jacking up slightly. The temporary support shall be dismantled gradually for every 5 mm jack down movement.

Once the concrete girder finally rests completely on the bearings during jacking down motion, the exact location between the girder and bearing shall be measured immediately. If dimensions are acceptable, the jack can be dismantled completely.

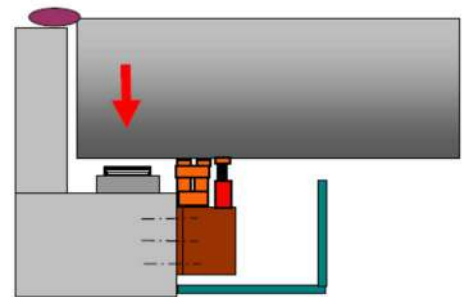
(6-1) Jack down process, dismantle support in cyclic process



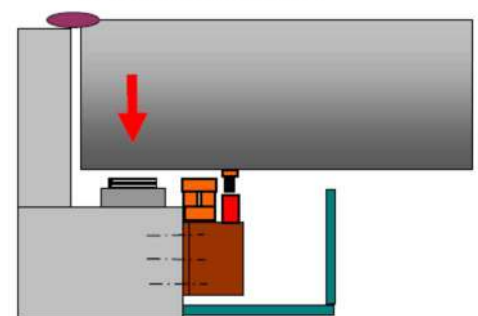
(6-2) Jack down



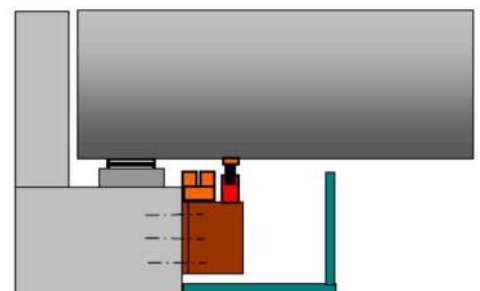
(6-3) Dismantle jack



(6-4) Dismantle Support

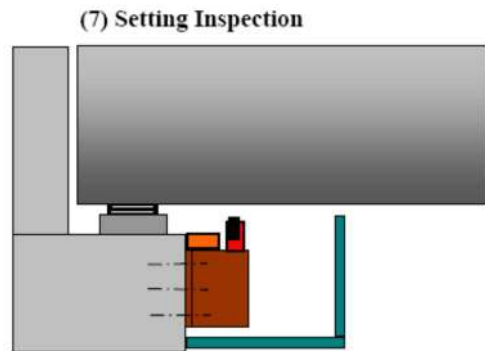


(6-5) Jack down



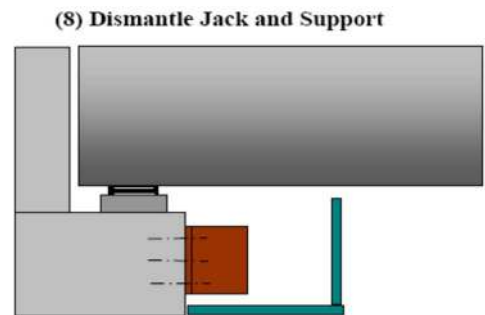
(7) Verification of measurement

Verification measurement shall be conducted to ensure the final height and exact location of all bearing positions. If not satisfactory, re-jack operations shall be done to perform adjustments.



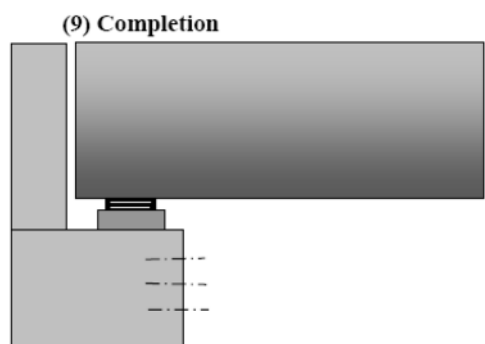
(8) Dismantle Jacks and temporary supports

Jacks and temporary support materials shall be dismantled.



(9) Completion

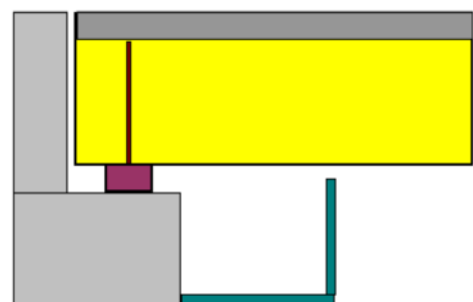
Clean-up site and ensure the measurements are approved by the Engineer.



8-3-3-3 For Steel Girder

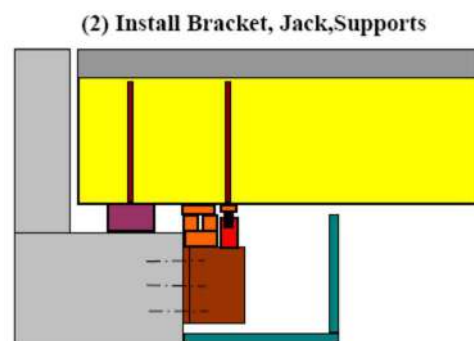
(1) Preparation of materials, equipment and site cleaning

The Scaffolding is installed to prepare jack-up method to proceed. The jack base bracket shall be fabricated in the factory which is approved by the Engineer.



(2) Welding temporary jack stiffeners

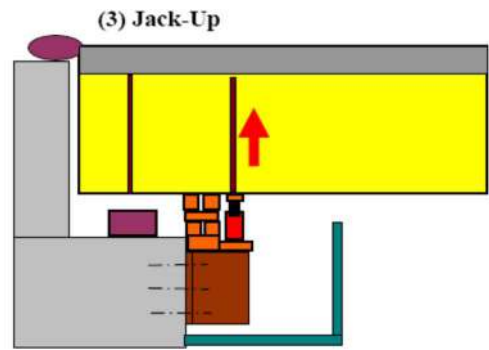
Jack stiffeners shall be welded to both sides of web plate. Jack-base bracket is installed using epoxy anchor installed at drilled holes for anchor bolts.



(3) Jacking up

Jack-up operations shall be simultaneously carried out for all the girders. For this condition, jacking up height is limited to 5 mm for each jack-up motion.

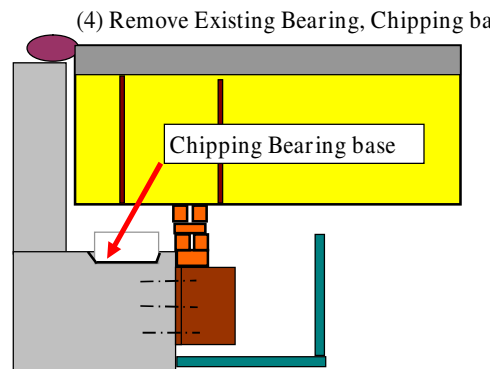
The method is repeated gradually until enough jacking up height is achieved to allow for dismantling of the existing bearing.



(4) Chip-off bearing base and remove existing bearing

Concrete bearing base is chipped off to dismantle the existing bearings.

A slope between bridge approach and the expansion joint shall be maintained for passing traffic during jacking-up operations.

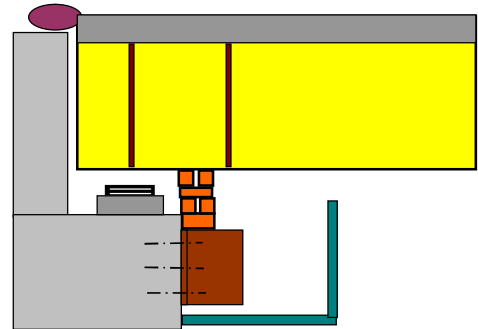


(5) Making new Bearing base

Additional re-bars for the new bearing base shall be arranged.

After concrete is completely placed, new rubber bearings are installed on the bearing base. During this operation, the girder shall be temporarily supported. The measurement of height, location shall be carefully verified by a designated inspector.

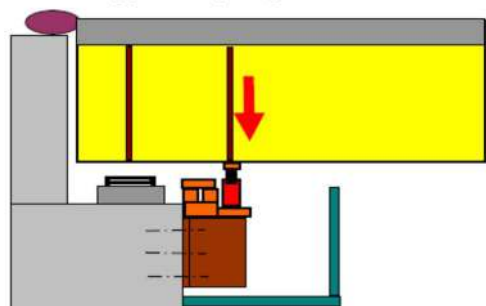
(5) Making New Bearing base, Set up New Bearing



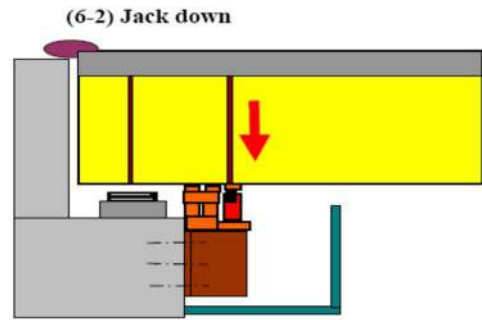
(6) Jack down

If the new bearing installed is determined as satisfactory, jack down operations shall commence. It is important to maintain safety during this operation. Jacking down shall be carried out gradually while carefully removing the temporary supporting members.

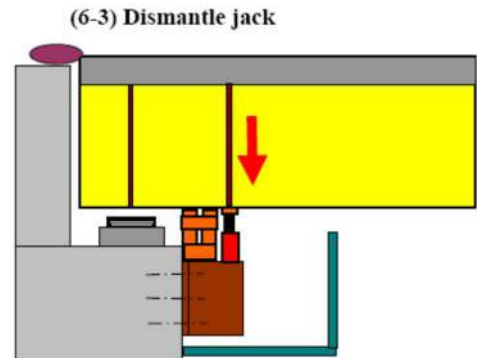
(6-1) Jack down process, dismantle support in cyclic process



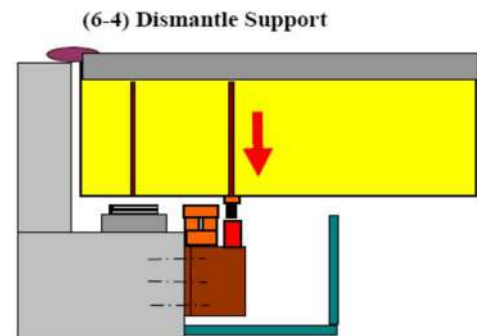
If the temporary support touches the lower surface of the bottom flange during jack down operations, the jack base plate shall be changed with a lesser thickness. Stroke shall be extended to jack down. These steps shall be repeated in cycle. For safety purposes, each stroke should maintain a height of less than 5 mm.



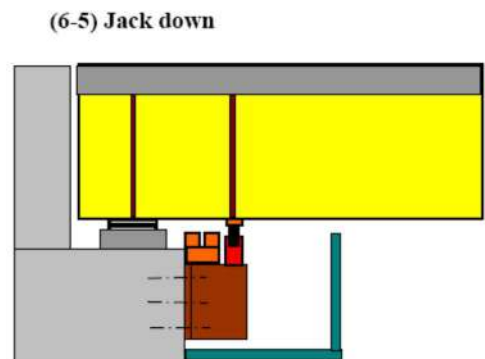
If the temporary support keeps touching the lower flange, dismantle the jack and remove the jack base plate gradually.



The temporary support shall be taken off from the steel girder by jacking up slightly. The temporary support shall be dismantled gradually for every 5 mm jack down movement.

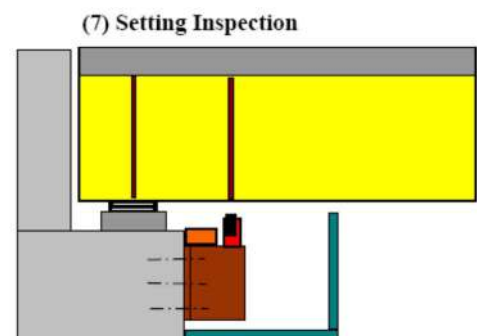


Once the lower flange finally rests completely on the bearings during jacking down motion, the exact location between the girder and bearing shall be measured immediately. If dimensions are acceptable, the jack can be dismantled completely.



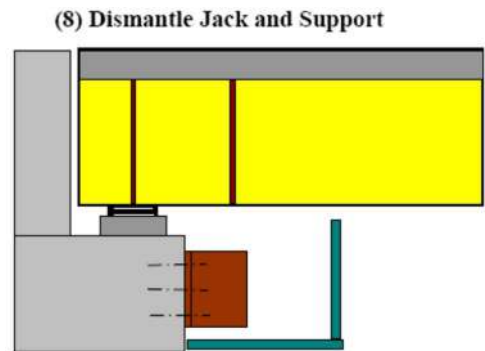
(7) Inspection of measurement

Verification measurement shall be conducted to ensure the final height and exact location of all bearing positions. If not satisfactory, re-jack operations shall be done to perform adjustments.



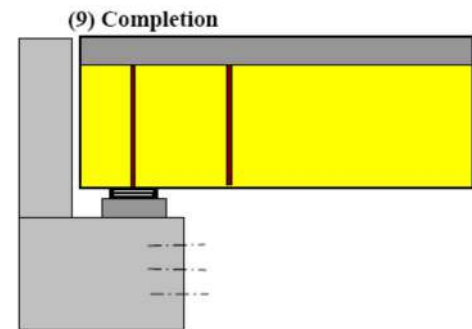
(8) Dismantle Jacks and temporary supports

Jacks and temporary support materials shall be dismantled. Paint steel portion, if found necessary. Dismantle any installed scaffoldings.



(9) Completion

Cleanup site and ensure that the measurements are approved by the Engineer.



8-3-4 Required Materials and Tools/Equipment

(1) Required Materials

- New bearings, (if the purpose is Replacement of Bearing)
- Epoxy anchor bolt for jack base bracket
- Temporary support material for jacking up motion
- Paint (if required)

(2) Required Tools/Equipment

- Hydraulic Jack
- Welding machine
- Hammer
- Electric jackhammer for chipping
- Concrete drilling machine

8-4 REPAINTING OF STEEL BEARING

8-4-1 Description of Repair Method

Steel bearings are provided at bridge abutments and piers. Typically, due to the deterioration of water proofing at expansion joints over the years, steel bearings underneath the superstructure are subjected to corrosion.

Bearings serve as interface between girder and substructure. The gap between girder's bottom surface and top level of bearing seat is usually narrow, making it difficult to perform repainting of bearings. Nevertheless, it is necessary to ensure that condition is dry and satisfactory before carrying out any surface preparation. Repainting of bearings is carried out for Rust Condition 1st and 2nd degree (Affected area is over 30%), in accordance with "Section 5-1 Repainting" of this guidebook.

Repainting consists of Organic Zinc Rich Primer, Epoxy Minacious Oxide Intermediate and Polyurethane Acrylic Coating.

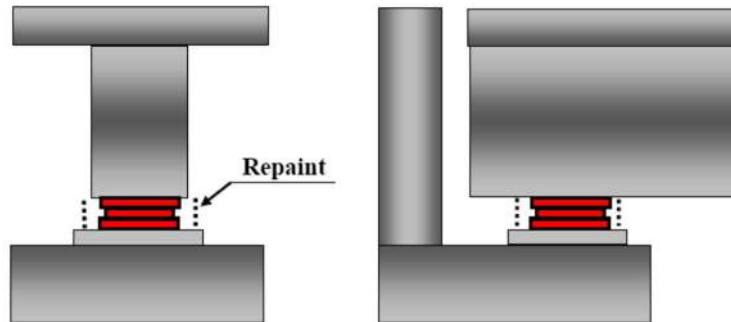


Figure 8-4 Repainting of Steel Bearing

Before repainting, the surface preparation including degreasing, sand blasting and soluble salts/chlorides test is necessary.

8-4-2 Application Criteria

This repair method shall be applied when affected surface area is over 30% (Rust condition: 1st and 2nd Degrees).

The 3rd and 4th degree rust conditions are not recommended for repainting.

For the 3rd and 4th rust degree bridges, the repair is performed by touch-up paint as needed in the routine maintenance.

8-4-3 Procedure

This repair method is basically similar to requirements in Section 5-1 of this guidebook, for Repainting.

(1) Scaffolding

Repainting of bearings on abutments will not require scaffolding. On piers however, scaffoldings need to be installed to access the bearings and for safety purposes.

(2) Surface Preparation for Steel Bearings

The surface preparation for steel bearings includes degreasing, sand blasting and soluble salts/chlorides test, in accordance with “Section 5-1 Repainting” of this guidebook.

(3) Painting

Paint is applied with the use of paint brush and paint roller. These tools are environment friendly and save costs. Quality control of painting should be strictly executed to maintain required coating film thickness. Measurement of coating film thickness after it dries can be easily done using thickness meter gauge.

8-4-4 Required Materials and Tools/Equipment

(1) Required Materials

- Organic Epoxy Zinc Rich Primer
- Epoxy Minacious Oxide Intermediate Coat
- Polyurethane Acrylic Coat
- Thinner

(2) Required Tools/Equipment

- Water jet spray, water tank, water hose, brush and generator for washing Bearing.
- Wire brush, scraper, electric disc grinder, sand blast machine, air compressor and generator for surface preparation
- Paint brush and paint roller

CHAPTER 9 PROTECTION WORKS

9-1 SLOPE PROTECTION WITH FOUNDATION SUPPORTED BY PILES

9-1-1 Description of Repair Method

Slope protection around the abutment is often damaged due to scouring, rapid river flow or improper construction, as shown in Photo 9-1. In most of the defective cases observed, foundation for the slope protection was not provided. Hence, the protection eventually fails due to either sliding or scouring. Repair method for the slope protection involves provision of appropriate foundation at its base.



Photo 9-1 Broken Slope Protection

9-1-2 Application Criteria

Appropriate type will be selected from among slope protection works such as stone masonry, grouted riprap and concrete masonry. The foundation should be a concrete base with wooden pile as shown in Figure 9-1. The wooden pile is normally driven to a minimum depth of 2.0 m. The foundation is usually placed at 1.0 m level below the river bed.

This criterion is only applicable as a standard repair method to damaged protection near small and medium rivers.

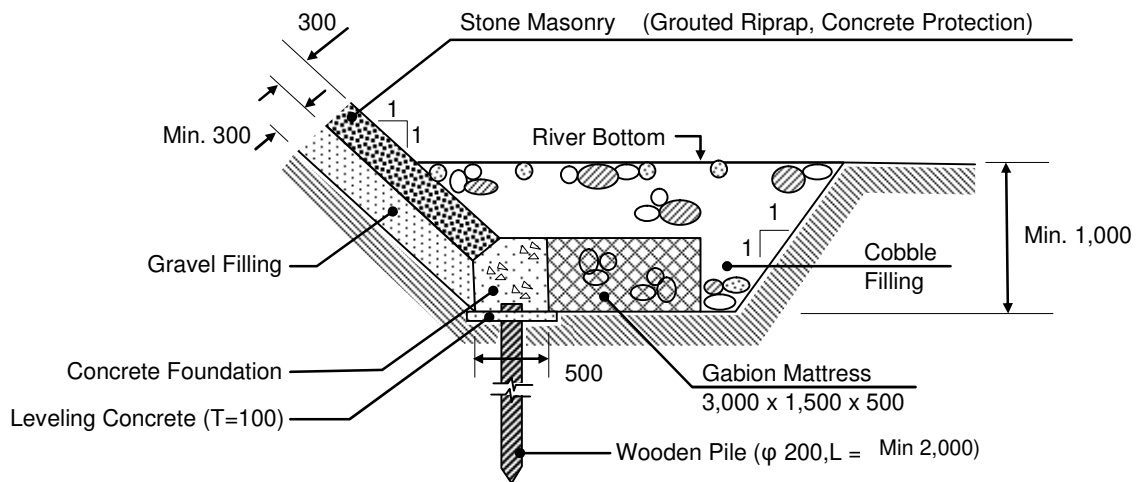
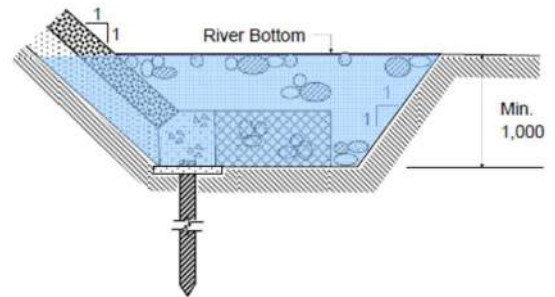


Figure 9-1 Foundation on Pile for Slope Protection Works

9-1-3 Procedure

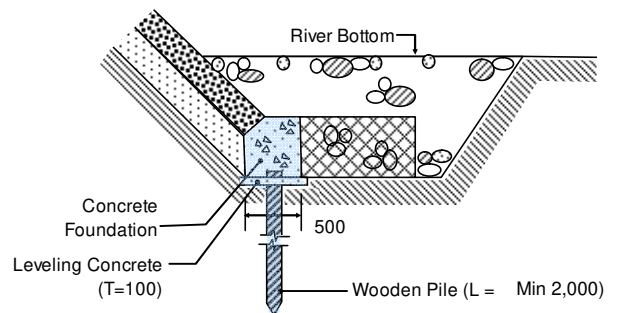
(1) Excavation of Scoured Area

The damaged section of the existing slope protection shall be demolished and the scoured section shall be excavated in accordance with the alignment and depth shown on the drawings. The area to be removed is marked on the existing protection. After excavation, the bed surface is compacted using lightweight mechanical or vibratory compactor.



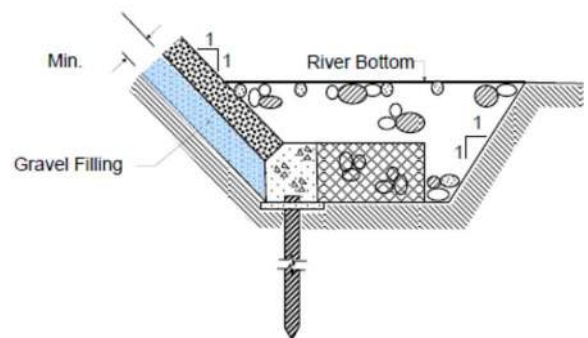
(2) Placing Concrete Foundation

Wooden piles are driven at an interval of 1.5 m. When driven depth is achieved, excess protruding length is cut. Concrete foundation provided with minimum reinforcements is formed and casted above the piles. If river water exists, sand bags acting as cofferdam is provided during foundation works.



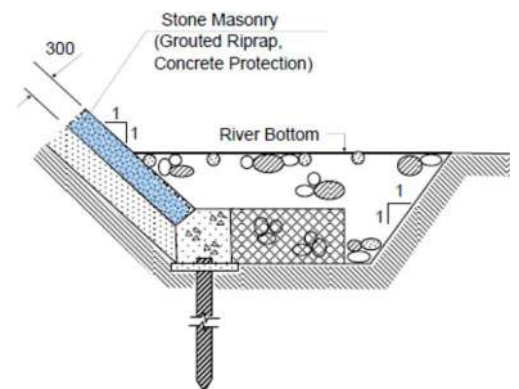
(3) Compaction of Gravel Filling

Natural slope surface shall be properly compacted. Gravel filling for the masonry base is then placed and compacted using lightweight mechanical or vibratory compactor. A thickness of more than 300 mm, placed in 2 layers, is provided at the slope base.



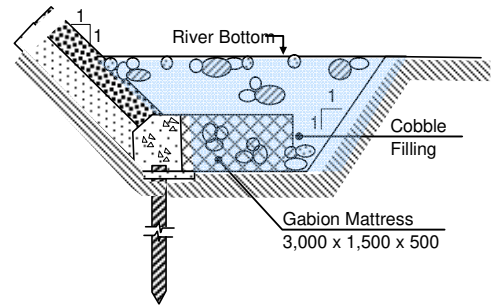
(4) Placing Masonry

Appropriate masonry type will be selected from among variety of slope protection works such as stone masonry, grouted riprap and concrete masonry.



(5) Installation of Gabion Mattress and Backfill

After filter fabric sheet is spread tightly on the bed, gabion mattress is installed in front of the concrete foundation as protection against local scouring and sliding. Finally, the excavated area and voids around the protection structure are backfilled with cobble stones, up to the level of river bed.



9-1-4 Required Materials and Tools/Equipment

(1) Required Materials

- Gabion Mattress
- Rock Fill
- Wooden Pile
- Concrete with minimum steel reinforcements
- Filter Fabric Sheet (under gabion mattress)
- Backfill Materials
- Sand bag as cofferdam, when necessary

(2) Required Equipment

- Vibratory compactor
- Backhoe

9-2 GABION MATTRESS

9-2-1 Description of Repair Method

Local scouring around the pier often occurs due to strong stream flow, weak riverbed materials and type of foundation as shown in Photo 9-2. The worst damage that could occur due to scouring is the settlement of the bridge pier, eventually leading to undermining of the base and failure of the bridge. Thus, protection against local scouring is intended to eliminate or minimize future damage to the bridge substructure.



Photo 9-2 Local Scouring around Pier

9-2-2 Application Criteria

As a simple and effective repair method, gabion mattress is selected as protection for local scouring around bridge piers. The scoured area need to be excavated to a minimum 1.0 m depth for the gabion mattress installation. A filter fabric sheet should be laid under the mattress. From either edge of the pier shaft, the extending width of the upper mattress is ideally twice the estimated scour depth while three times for the lower mattress, as shown in Figure 9-2.

This criterion is only applicable as a standard repair method to damaged protection at small and medium rivers with a maximum discharge of 500 m³/sec.

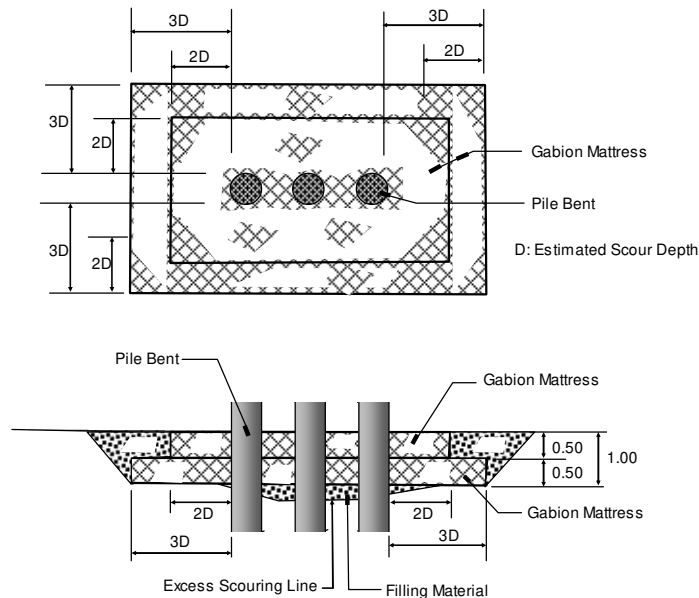
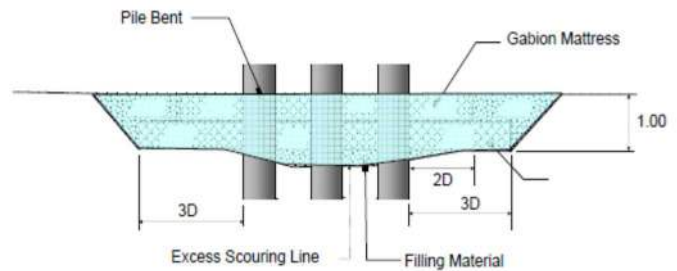


Figure 9-2 Application Requirement for Standard Gabion Mattress

9-2-3 Procedure

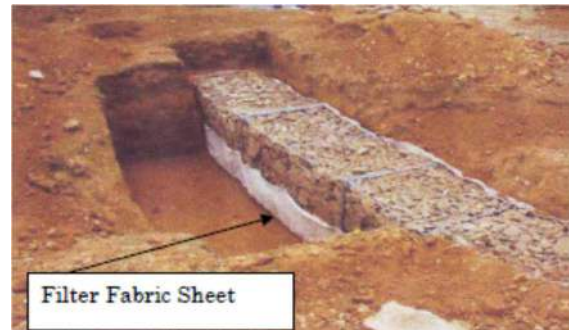
(1) Excavation of Scoured Area

The scoured area around the pier base is excavated in accordance with the alignment and depth indicated in the drawings. The actual excess scour section below the depth shown in the drawings is filled with selected material. After excavation, the bed surface is compacted using vibratory compactor.



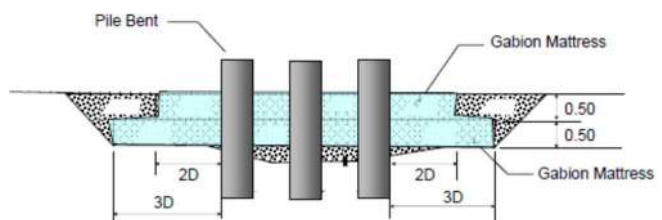
(2) Filter Fabric Sheet Placing

A filter fabric sheet shall be spread tightly and pegged with materials approved by the Engineer. The filter fabric sheet shall be placed with a minimum lapping of 30 cm.



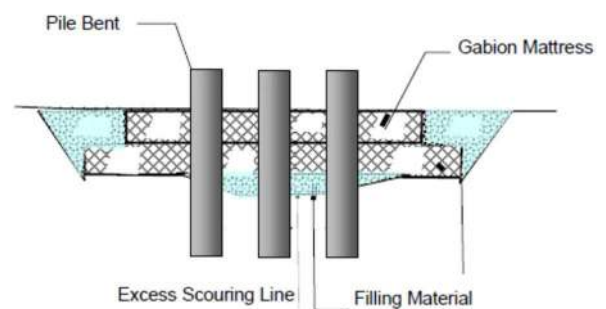
(3) Installation of Gabions

Gabion filling shall be carried out by placing individual stone material into the gabion. When the gabion mattresses are completely filled, the cover panels shall be closed and the edges tied with binding wire as in a typical assembly process. The formed mattress shall be completely tight and square.



(4) Backfilling

The backfill shall be placed evenly on all sides of the formed protection as appropriate. Each backfill layer shall extend to the limits of excavation or to natural ground.



9-2-4 Required Materials and Tools/Equipment

(1) Required Materials

- Gabion Mattress
- Rock Fill
- Filter Fabric Sheet
- Backfill Materials

(2) Required Equipment

- Vibratory compactor

9-3 SLOPE PATCHING

9-3-1 Description of Repair Method

Slope protection around the abutment is often damaged due to inadequate compaction of slope embankment, strong stream flow and insufficient flood drains. Although visible damage to the slope protection may be limited, voids may have formed already under the protection due to the base failure. A large section of the slope protection including the damaged portion, should be removed for purposes of patching repair.



Photo 9-3 Damaged Slope Protection

9-3-2 Application Criteria

Slope patching is an effective method that can be adopted to repair limited damages on the masonry during the early stage of visible defects. The area to be removed shall extend to a minimum of 500 mm around the perimeter of the damaged section. The protection bed should be excavated to a depth of 600 mm from masonry surface, as shown in Figure 9-3. New masonry patched into the excavated portion shall consist of 300 mm gravel filling and 300 mm masonry material as shown in Figure 9-4.

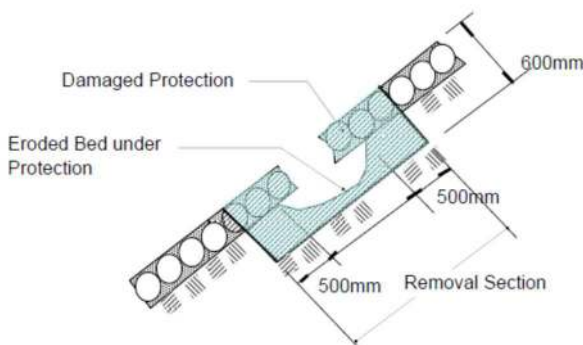


Figure 9-3 Typical Damaged Slope Protection

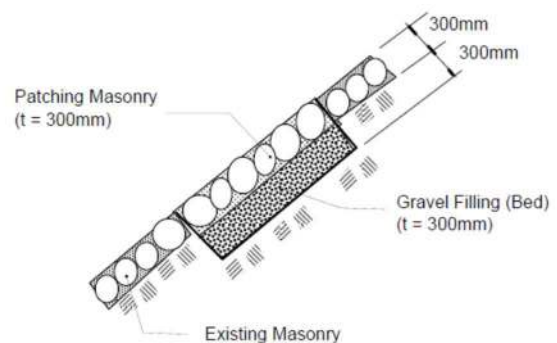
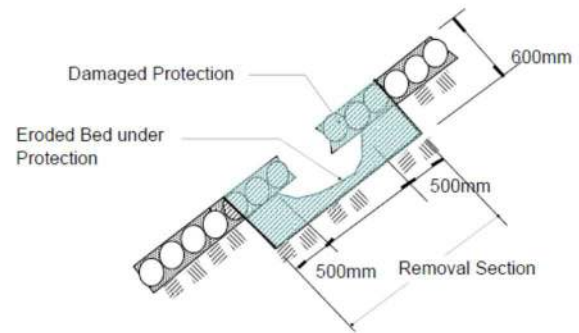


Figure 9-4 Slope Protection After Repair

9-3-3 Procedure

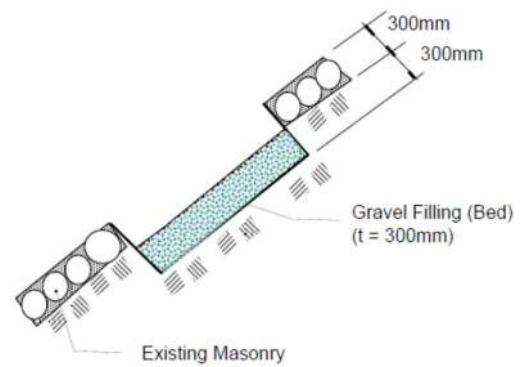
(1) Removal of Damaged Protection

The damaged section of the existing slope protection shall be removed and the scoured section shall be excavated in accordance with the alignment and depth shown on the drawings. The area to be removed is marked on the surface of the existing protection. After excavation, the bed surface is compacted using vibratory compactor.



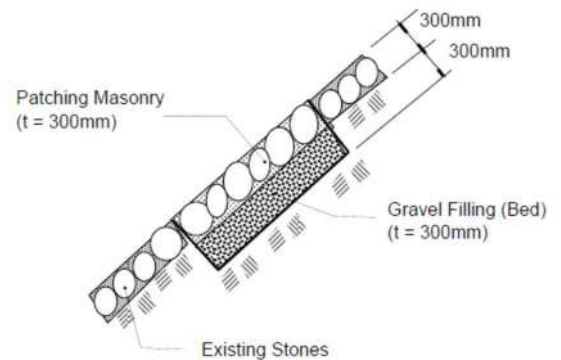
(2) Compaction of Gravel Filling

Natural slope surface shall be properly compacted. Gravel filling for the masonry base is then placed and compacted using vibratory compactor. A thickness of more than 300 mm, placed in 2 layers, is provided at the slope base.



(3) Patching Masonry

Appropriate masonry material will be selected depending on the type of existing masonry (stone masonry, grouted riprap and concrete masonry.)



9-3-4 Required Materials and Tools/Equipment

(1) Required Materials

- Masonry materials
- Crushed Stone

(2) Required Equipment

- Vibratory compactor

9-4 NYLON FIBER GABION

9-4-1 Description of Repair Method

Due to strong river flow, local scouring surrounding bridge piers often occurs. The worst damage that could occur due to scouring is the settlement of the bridge pier, eventually leading to undermining of the base and failure of the bridge. Installation of Gabion Mattress shall be applied as a standard repair method for this kind of defect. . But if river bed shape is irregular, it is very difficult to put Gabion Mattress. In this case, Nylon Fiber Gabion shall be adopted as anti-scouring protection. Thus, protection against local scouring is intended to eliminate or minimize future damage to the bridge substructure.

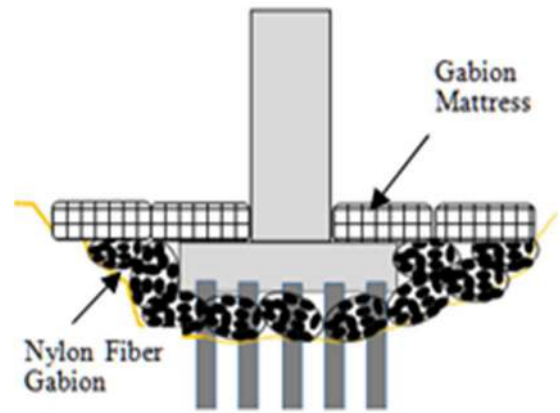


Figure 9-5 Local Scouring around Pier

9-4-2 Application Criteria

Nylon Fiber Gabion is used for prevention of scouring on pier foundation and other underwater structures. It is a bag made of nylon net. The bag is filled with boulders or stones which are also used for conventional box-type zinc-coated wire gabions. The nylon fiber gabion is flexible and conforms to the shape where it is placed. The nylon net allows water passage through the bag ensuring that pressure of the flowing water does not affect the bag and keeps the scour prevention materials (boulders) from being carried or swept away by the water.

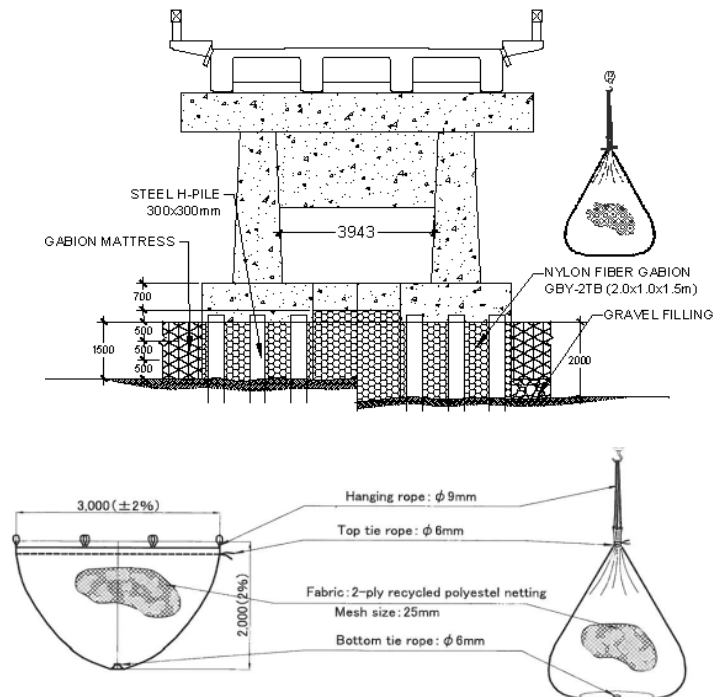


Figure 9-6 Application Requirement for Nylon Fiber Gabion

9-4-3 Procedure

(1) Place Boulders into Nylon Fiber Gabion Bag

Boulders to be used shall conform to Gabions and Mattresses. When filled, Nylon Fiber Gabion weighs 2 tons with equivalent size of 3m x 2m and volume of about 1.24 m³.



(2) Transport to Scoured Area

After filling with boulders, the Nylon Fiber Gabion shall be transported to the scoured area by backhoe.



(3) Place Nylon Fiber Gabion Using Backhoe

Using backhoe, lay gabions in the scoured portion. Continue laying up to the indicated elevation.



9-4-4 Required Materials and Tools/Equipment

(1) Required Materials

- Nylon Fiber Gabion
- Gabion Mattress
- Rock Fill (Boulders)
- Backfill Materials
-

(2) Required Equipment

- Backhoe or Crane

APPENDIX: Specifications

The specifications of the materials which are used for the bridge repair methods described in this guidebook are shown below. The materials shall be approved by the Engineer through mill certificate of the supplier.

3. Repair of Concrete Deck Slab

3-1 Epoxy Coating

(1) Epoxy Sealant

Property	Test Method	Unit	Specification
Viscosity	ASTMD2393/JIS K 6833	mPa-s*	500 below
Bond Strength to Concrete Dry / Wet	ASTM D7234/JIS K5400	N/mm ²	1.5
Slant Shear Bond Strength	ASTM C882/JIS K6852	N/mm ²	15

* mPa-s: milliPascal-second

3-2 Epoxy Injection

(1) Epoxy Resin

Property	Test Method	Unit	Specification
Viscosity	ASTM D2393/JIS K 6833	mPa-s*	≤ 1000
Pot life	-	minute	60
Specific Gravity	ASTM D792/JIS K 7112	-	1.15 ± 0.10
Compressive Strength	ASTM D695/JIS K 7208	N/mm ²	≥ 50
Modulus of Elasticity	ASTM D695M/JIS K 7208	N/mm ²	≥ 1000
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 40
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 10
Bond Strength to Concrete Dry / Wet	ASTM D7234/JIS K5400	N/mm ²	≥ 1.5 CF*

* mPa-s: milliPascal-second, *CF: Concrete Failure

(2) Epoxy Sealant

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K 7112	-	1.50± 0.30
Compressive Strength	ASTM D695M/JIS K 7208	N/mm ²	≥ 50
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 15
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 10
Bond Strength to Concrete (Dry/Wet)	ASTM D 7234/JIS K 5400	N/mm ²	≥ 1.5 CF*

*CF – Concrete Failure

3-3 Calking

(1) Epoxy Resin

Property	Test Method	Unit	Specification
Viscosity	ASTM D2393/JIS K 6833	mPa-s*	≤ 1000
Pot life	-	minute	60
Specific Gravity	ASTM D792/JIS K 7112	-	1.15 ± 0.10
Compressive Strength	ASTM D695/JIS K 7208	N/mm ²	≥ 50
Modulus of Elasticity	ASTM D695M/JIS K 7208	N/mm ²	≥ 1000
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 40
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 10
Bond Strength to Concrete Dry / Wet	ASTM D7234/JIS K5400	N/mm ²	≥ 1.5 CF*

* mPa-s: milliPascal-second, *CF: Concrete Failure

(2) Epoxy Sealant

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K 7112	-	1.50± 0.30
Compressive Strength	ASTM D695M/JIS K 7208	N/mm ²	≥ 50
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 15
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 10
Bond Strength to Concrete (Dry/Wet)	ASTM D 7234/JIS K 5400	N/mm ²	≥ 1.5 CF*

*CF: Concrete Failure

3-4 Patching

(1) Polymer Cement Mortar (PCM)

Polymer cement mortar shall be conform to the following specification and shall meet the requirement of the SABS test method 862-2: 1994 or ASTM C1437-01.

Property	Test Method	Unit	Specification
Compressive Strength	ASTM C39/JSH 416	N/mm ²	At 28 days: ≥ 25
Bonding Strength to Concrete	ASTM D 7234/JHS 416	N/mm ²	≥ 1.5
Bleeding Rate	ASTM C 39/JHS 416	%	0

(2) Epoxy Resin Adhesive

Property	Test Method	Unit	Specifications
Compressive Strength	ASTM D695M/JIS K 7208	N/mm ²	75
Flexural Strength	ASTM D790M/JIS K 6911	N/mm ²	40
Tensile Strength	ASTM D638M/JIS K 7113	N/mm ²	30
Tensile Shear Bond to Steel	ASTM D1002/JIS K 6850	N/mm ²	10
Slant Shear Bond to Mortar	ASTM C882/JIS K6852	N/mm ²	15

(3) Zinc Rich Primer for Rebar

Rebar should have all rust removed by the use of power tools or brushing according to Swedish Standard SIS 05-900 or equivalent standard.

Property	Test Method	Unit	Specifications
Gloss @60° Angle	ASTM D 523	-	Flat
Adhesion	ASTM D 3359	-	Minimum 3A
Salt Spray Resistance	ASTM D 117	-	Excellent
%Zinc by Weight in Dried Film Test	-	%	87.5± 2

3-5 Carbon Fiber Sheet (CFS) Bonding

(1) Carbon Fiber Sheet

Property	Test Method	Unit	Specifications
Carbon fiber weight	JIS K 7071	g/m ²	200
Tensile Strength	ASTM D3039/JIS K 7073	N/mm ²	≥ 3400
Overlap Tensile Strength	ASTM D3039/JIS K 7073	N/mm ²	≥ 3400
Tensile Bond to Concrete (Dry/Wet)	ASTM D7234/JIS K5400	N/mm ²	≥ 1.5 CF*

*CF: Concrete Failure

(2) Epoxy Resin Adhesive

Property	Test Method	Unit	Primer	Epoxy Putty	Penetrating Epoxy Resin
Viscosity	ASTM D2393/ JIS K 6833	mPa-s*	≤ 1000	Paste-like	15,000± 5000
Modulus of Elasticity	ASTM D695M/ JIS K 7208	N/mm ²	≥ 1500	≥ 1500	≥ 1500
Slant Shear Bond to Concrete	ASTM C882	N/mm ²	≥ 15	≥ 15	≥ 15
Bond Strength to Concrete (Dry/ Wet)	ASTM D7234/ JIS K5400	N/mm ²	≥ 1.54	≥ 1.54	≥ 1.54

* mPa-s: milliPascal-second

3-6 Steel Plate Bonding

The steel plate to be used shall be in accordance with ASTM A36.

(1) Epoxy Resin Adhesive for Injection Method

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K 7112	-	1.15± 0.1
Viscosity	ASTM D2393/JIS K 6833	mPa-s*	≤ 1000
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 40
Compressive Strength	ASTM D695/JIS K 7208	N/mm ²	≥ 50
Modulus of Elasticity	ASTM D695M/JIS K 7208	N/mm ²	≥ 1000
Bond Strength to Concrete	ASTM D 7234/JIS K5400	N/mm ²	> 1.5 CF*

(Dry/Wet)			
Tensile Shear Bond to Steel	ASTM D1002/JIS K 6850	N/mm ²	≥ 15

* mPa-s: milliPascal-second, *CF: Concrete Failure

(2) Epoxy Sealant

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K 7112	-	1.50± 0.3
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 15
Compressive Yield Strength	ASTM D695M/JIS K 7208	N/mm ²	≥ 50
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 10
Slant Shear Bond to Concrete	ASTM C882/JIS K6852	N/mm ²	≥ 15

(3) Epoxy Resin Adhesive for Pressure Attaching Method

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K 7112	-	1.16± 0.1
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 40
Compressive strength	ASTM D695M/JIS K 7208	N/mm ²	≥ 70
Tensile Strength	ASTM D638/JIS K 7113	N/mm ²	≥ 40
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 15
Bond Strength to Concrete Dry / Wet	ASTM D7234/JIS K5400	N/mm ²	≥ 3,5

3-7 Partial Deck Slab Replacement

(1) Zinc Rich Primer for Rebar

Rebar should have all rust removed by the use of power tools or brushing according to Swedish Standard SIS 05-900 or equivalent standard.

Property	Test Method	Unit	Specifications
Gloss @60° Angle	ASTM D 523	-	Flat
Adhesion	ASTM D 3359	-	Minimum 3A
Salt Spray Resistance	ASTM D 117	-	Excellent
%Zinc by Weight in Dried Film Test	-	%	87.5± 2

3-8 Waterproofing on Deck Slab

(1) Asphalt Compound Membrane

Property	Test Method	Unit	Specification
Penetration with Conic Needle	ASTM D217/JIS K 5400	mm	2 ~ 5
Melting Temperature	ASTM D3461/JIS K 6839	°C	80
Elongation	ASTM D 638/JIS K 6021	%	3.5
Tensile Strength	ASTM D 638/JIS K 6021	Kgf/cm ²	300

3-9 Fast Setting Mortar

(1) Fast Setting Mortar

Property	Test Method	Unit	Specifications
Compressive Strength (fc)	ASTM C-39 or JHS312	N/mm ² or MPa	1 day: fc ≥ 20 3 days: fc ≥ 30 7 days: fc ≥ 40 28 days: fc ≥ 50
Expansion Rate	ASTM C827	%	0 ~ +1%
Bleeding Rate	ASTM C940/JHS312	%	0
Consistency	JHS312	Sec	6 ~ 10

(2) Fiber Cement Mortar on Surface of Deck Slab (Reference)

1) Physical properties of polypropylene reinforced fiber

Item	Physical properties	Item	Physical properties
Material	Polypropylene	Color	Grey
Density	0.91 g/cm ³	Shape	Rectangular Section
Thickness x Width	0.5 x 0.9 mm	Fiber length	48.0 mm
Cross Section are	0.385 mm ²	Finess	3500 dtex
Tensile Strength	430.3 N/mm ²	Young's Modulus	10,500 N/mm ²
Melting Point	160 ~ 170 °C	Chemical Resistance	Resistant to acids and alkalis

2) Formulation example for concrete with polypropylene reinforced fiber

Maximum Size of Coarse Aggregate (mm)		20	
Slump (cm)	15.0 ± 2.5	Cement (kg/m ³)	340
Air Volume	4.5 ± 1.5	Fine Aggregate (kg/m ³)	947
Water and Cement Ratio (%)	51.5	Coarse Aggregate (kg/m ³)	828
Fine Aggregate Ratio (%)	55	Fiber (kg/m ³)	2.73
Water (kg/m ³)	175	Admixture (kg/m ³)	4.59

4. Repair of Concrete Bridge Superstructure

4-1 Epoxy Coating

(1) Epoxy Sealant

Property	Test Method	Unit	Specification
Viscosity	ASTMD2393/JIS K 6833	mPa-s*	500 below

Bond Strength to Concrete Dry / Wet	ASTM D7234/JIS K5400	N/mm ²	1.5
Slant Shear Bond Strength	ASTM C882/JIS K6852	N/mm ²	15

* mPa-s: milliPascal-second

4-2 Epoxy Injection

(1) Epoxy Resin

Property	Test Method	Unit	Specification
Viscosity	ASTM D2393/JIS K 6833	mPa-s*	≤ 1000
Pot life	-	minute	60
Specific Gravity	ASTM D792/JIS K 7112	-	1.15 ± 0.10
Compressive Strength	ASTM D695/JIS K 7208	N/mm ²	≥ 50
Modulus of Elasticity	ASTM D695M/JIS K 7208	N/mm ²	≥ 1000
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 40
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 10
Bond Strength to Concrete Dry / Wet	ASTM D7234/JIS K5400	N/mm ²	≥ 1.5 CF*

* mPa-s: milliPascal-second, *CF: Concrete Failure

(2) Epoxy Sealant

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K 7112	-	1.50± 0.30
Compressive Strength	ASTM D695M/JIS K 7208	N/mm ²	≥ 50
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 15
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 10
Bond Strength to Concrete (Dry/Wet)	ASTM D 7234/JIS K 5400	N/mm ²	≥ 1.5 CF*

*CF: Concrete Failure

4-3 Calking

(1) Epoxy Resin

Property	Test Method	Unit	Specification
Viscosity	ASTM D2393/JIS K 6833	mPa-s*	≤ 1000
Pot life	-	minute	60
Specific Gravity	ASTM D792/JIS K 7112	-	1.15 ± 0.10
Compressive Strength	ASTM D695/JIS K 7208	N/mm ²	≥ 50
Modulus of Elasticity	ASTM D695M/JIS K 7208	N/mm ²	≥ 1000
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 40
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 10
Bond Strength to Concrete Dry / Wet	ASTM D7234/JIS K5400	N/mm ²	≥ 1.5 CF*

* mPa-s: milliPascal-second, *CF: Concrete Failure

(2) Epoxy Sealant

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K 7112	-	1.50± 0.30
Compressive Strength	ASTM D695M/JIS K 7208	N/mm ²	≥ 50
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 15
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 10
Bond Strength to Concrete (Dry/Wet)	ASTM D 7234/JIS K 5400	N/mm ²	≥ 1.5 CF*

*CF: Concrete Failure

4-4 Patching

(1) Polymer Cement Mortar (PCM)

Polymer cement mortar shall conform to the following specification and shall meet the requirement of the SABS test method 862-2: 1994 or ASTM C1437-01.

Property	Test Method	Unit	Specification
Compressive Strength	ASTM C39/JSH 416	N/mm ²	At 28 days: ≥ 25
Bonding Strength to Concrete	ASTM D 7234/JHS 416	N/mm ²	≥ 1.5
Bleeding Rate	ASTM C 39/JHS 416	%	0

(2) Epoxy Resin Adhesive

Property	Test Method	Unit	Specifications
Compressive Strength	ASTM D695M/JIS K 7208	N/mm ²	75
Flexural Strength	ASTM D790M/JIS K 6911	N/mm ²	40
Tensile Strength	ASTM D638M/JIS K 7113	N/mm ²	30
Tensile Shear Bond to Steel	ASTM D1002/JIS K 6850	N/mm ²	10
Slant Shear Bond to Mortar	ASTM C882/JIS K6852	N/mm ²	15

(3) Zinc Rich Primer for Rebar

Rebar should have all rust removed by the use of power tools or brushing according to Swedish Standard SIS 05-900 or equivalent standard.

Property	Test Method	Unit	Specifications
Gloss @ 60° Angle	ASTM D 523	-	Flat
Adhesion	ASTM D 3359	-	Minimum 3A
Salt Spray Resistance	ASTM D 117	-	Excellent
%Zinc by Weight in Dried Film Test	-	%	87.5± 2

4-5 Recasting Concrete/Grout

(1) Epoxy Resin Adhesive

Property	Test Method	Unit	Specifications
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Compressive Strength	ASTM D695M/JIS K 7208	N/mm ²	70
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	40
Tensile Strength	ASTM D638M/JIS K 7113	N/mm ²	30
Tensile Shear Bond to Steel	ASTM D1002/JIS K 6850	N/mm ²	10
Slant Shear Bond to Mortar	ASTM C882/JIS K6852	N/mm ²	15

(2) Zinc Rich Primer

Rebar should have all rust removed by the use of power tools or brushing according to Swedish Standard SIS 05-900 or equivalent standard.

Property	Test Method	Unit	Specifications
Gloss @60° Angle	ASTM D 523	-	Flat
Adhesion	ASTM D 3359	-	Minimum 3A
Salt Spray Resistance	ASTM D 117	-	Excellent
%Zinc by Weight in Dried Film Test		%	87.5± 2

4-6 Carbon Fiber Sheet/Plate Bonding

(1) Carbon Fiber Sheet (CFS)

Property	Test Method	Unit	Specifications
Carbon fiber sheet weight	JIS K7071	g/m ²	200
Tensile Strength	ASTM D3039/JIS K 7073	N/mm ²	≥ 3400
Overlap Tensile Strength	ASTM D3039/JIS K 7073	N/mm ²	≥ 3400
Tensile Bond Strength to Concrete (Dry/Wet)	ASTM D7234/JIS K5400	N/mm ²	≥ 1.5 CF*

*CF: Concrete Failure

(2) Carbon Fiber Plate (CFP)

Property	Test Method	Unit	Specifications
Carbon fiber plate weight	JIS R 7603	g/m ²	1200
Tensile Strength	ASTM D3039/JIS K 7073	N/mm ²	≥ 2400
Bond Strength to Concrete	ASTM D7234/JIS K5400	N/mm ²	≥ 1.5 CF*

*CF: Concrete Failure

(3) Epoxy Resin Adhesive for CFS Bonding

Property	Test Method	Unit	Primer	Epoxy Putty	Penetrating Epoxy Resin
Viscosity	ASTM D2393/ JIS K 6833	mPa-s*	≤ 1000	Paste-like	15,000± 5000
Tensile Strength	ASTM D638M/ JIS K 7113	N/mm ²	≥ 15	-	≥ 30
Flexural Strength	ASTM D790M/	N/mm ²	≥ 20	≥ 15	≥ 40

	JIS K 7203				
Compressive Strength	ASTM D695M/ JIS K 7208	N/mm ²	≥ 20	≥ 40	≥ 50
Modulus of Elasticity	ASTM D695M/ JIS K 7208	N/mm ²	≥ 1500	≥ 1500	≥ 1500
Slant Shear Bond to Concrete	ASTM C882	N/mm ²	≥ 15	≥ 15	≥ 15
Adhesive Strength (Dry/Wet)	ASTM D7234/ JIS K5400	N/mm ²	≥ 1.5	≥ 1.5	≥ 1.5

* mPa-s: milliPascal-second

(4) Epoxy Resin Adhesive for CFP Bonding

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K7112	-	1.7±0.20
Flexural Strength	ASTM D790M/JIS K7203	N/mm ²	≥ 40
Compressive Strength	ASTM D695M/JIS K7208	N/mm ²	≥ 70
Modulus of Elasticity	ASTM D695M/JIS K7208	N/mm ²	≥ 4000
Tensile Strength	ASTM D638M/JIS K 7113	N/mm ²	≥ 25
Tensile Shear Bond	ASTM D1002/JIS K 6850	N/mm ²	≥ 10
Bond Strength to CFP & Concrete	ASTM D7234/JIS K5400	N/mm ²	≥ 3.5

4-7 Steel Plate Bonding to Concrete

(1) Epoxy Resin Adhesive

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K 7112	-	1.16± 0.1
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	≥ 40
Compressive strength	ASTM D695M/JIS K 7208	N/mm ²	≥ 70
Tensile Strength	ASTM D638/JIS K 7113	N/mm ²	≥ 40
Tensile Shear Bond Strength	ASTM D1002/JIS K 6850	N/mm ²	≥ 15
Bond Strength to Concrete Dry / Wet	ASTM D7234/JIS K5400	N/mm ²	≥ 3.5

5. Repair of Steel Bridge Superstructure

5-1 Repainting

(1) High Build Polyurethane Acrylic Finish over Organic Zinc Rich Epoxy Primer and High Build MIO Intermediate

Coating system		Application Method	Theoretical Spread Rate	DFT / WFT Min & Max	Overcoating time@25°C
1st Coat: Primer	Epoxy Organic Zinc Rich Primer. Minimum 81% Zinc in the dry film	Airless Spray, Agitated Pressure Pot	10.8m ² /ℓ @ 60μm	DFT : 50 to 75μm WFT: 77 to 115μm	Min: 6hrs Max: Indefinite

2nd Coat: Intermediate Coat	Epoxy Minacious Iron Oxide Intermediate coating	Airless Spray, Conventional Pressure Pot	4.9m ² /ℓ @ 125μm	DFT : 100 to 150μm WFT: 163 to 245μm	Min: 5hrs Max: Indefinite
3rd Coat: Top Coat	Recoatable Polyurethane coating	Airless Spray, Conventional Pressure Pot, Brush of Roller	8.8m ² /ℓ @ 125μm	DFT : 40 to 75μm WFT: 75 to 141μm NB: Minimum 60μm	Min: 10hrs Max: Indefinite
Surface Preparation	Degreasing	Remove all traces of oils, grease and other contaminants using a Degreaser containing an emulsifying agent. Scrub the surface, allow to react for 10 minutes, rinse with fresh water to achieve a water break free surface and allow to dry.			
	Abrasive Blasting	Prior to abrasive blasting, all welds shall be free of slag, slag inclusions and pinholes. Adjacent areas shall be free of weld spatter, which shall be removed by grinding or scraping. Abrasive blast clean all surfaces to Sa 2.5 of the ISO 8501- 1: 2007 standard to achieve an angular profile of 50 - 75 μm, to remove the old coating and profile the steel surface. Using Platinum Slag (B60)			
	Dust removal	All dust and abrasion products are to be removed prior to painting. The blast cleaned steel shall not exhibit than 0,3 % dust and debris when tested in accordance with SANS Test Method Number 769.			
	Soluble Salts / Chlorides Test	In accordance with ISO 8502 – 6:2006 and ISO 8502 – 9:1998. The soluble chloride content must be under 75 mg/m ² as measured using an Elcometer 138 Bresle kit.			

All paints and preparations shall be approved by the Engineer through the manufactures recommendations and technical data sheet.

5-2 Steel Plate Adding

Specifications for related materials for this repair method are as follows:

- Flat/Angular plates (JIS G3101, 3106, ASTM A36 or equivalent)
- HTB (JIS B 1186, ASTM A325 or equivalent)

The type of test shall be applied tensile strength test for HTB to be approved by the Engineer.

5-3 Carbon Fiber Plate Bonding to Steel

(1) Carbon Fiber Plate (CFP)

Property	Test Method	Unit	Specification
Carbon fiber plate weight		g/m ²	1200
Carbon fiber plate density		g/cm ³	1.6
CFP Tensile Strength	ASTM D3039/JIS K 7073	N/mm ²	2400
Tensile Bond to Concrete Dry Wet	ASTM C882/ JIS K6852/JHS-411	N/mm ²	≥ 2.0 ≥ 2.0

(2) Epoxy Resin Adhesive for CFP Bonding

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K7112	-	1.7±0.10
Flexural Strength	ASTM D790/JIS K7203	N/mm ²	45
Compressive Strength	ASTM D695/JIS K7208	N/mm ²	70
Modulus of Elasticity	ASTM D695/JIS K7208	N/mm ²	4000

Tensile Strength	ASTM D638/JIS K 7113	N/mm ²	25
Tensile Shear Bond	ASTM D1002/JIS K 6850	N/mm ²	15
Bond Strength to CFP & Steel	ASTM D7234/JIS K5400	N/mm ²	3.5

5-4 Tightening/Retightening of High Tension Bolt

High Tension Bolt (HTB) to be used shall be in accordance with AASHTO M164 (ASTM A325).

6. Repair of Concrete/Steel bridge Substructure

6-1 Caulking

(1) Epoxy Resin

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K 7112	-	1.1± 0.1
Viscosity	ASTM D2393/JIS K 6833	mPa-s*	≤ 2000
Consistency	-	-	Liquid
Pot Life	-	minutes	≥ 30
Elongation	ASTM D638M/JIS K 7113	%	50
Bond Strength Dry Concrete Wet Concrete	ASTM C882/JIS K6852	N/mm ² N/mm ²	3.0 3.0

* mPa-s: milliPascal-second

(2) Epoxy Sealant

Property	Test Method	Unit	Specification
Specific Gravity	ASTM D792/JIS K 7112	-	1.5± 0.3
Consistency	-	-	Paste-like
Pot Life	-	minute	≥ 30
Elongation	ASTM D638M/JIS K 7113	%	50
Bond Strength Dry Concrete Wet Concrete	ASTM C882/JIS K6852	N/mm ² N/mm ²	3.0 3.0

6-2 Patching

(1) Polymer Cement Mortar (PCM)

Polymer cement mortar shall be conform to the following specification and shall meet the requirement of the SABS test method 862-2: 1994 or ASTM C1437-01.

Property	Test Method	Unit	Specification
Compressive Strength	ASTM C39/JSH 416	N/mm ²	At 28 days: ≥ 25
Bonding Strength to Concrete	ASTM D 7234/JHS 416	N/mm ²	≥ 1.5
Bleeding Rate	ASTM C 39/JHS 416	%	0

(2) Epoxy Resin Adhesive

Property	Test Method	Unit	Specifications
Compressive Strength	ASTM D695M/JIS K 7208	N/mm ²	75
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	40
Tensile Strength	ASTM D638M/JIS K 7113	N/mm ²	30
Tensile Shear Bond to Steel	ASTM D1002/JIS K 6850	N/mm ²	10
Slant Shear Bond to Mortar	ASTM C882/JIS K6852	N/mm ²	15

(3) Zinc Rich Primer for Rebar

Rebar should have all rust removed by the use of power tools or brushing according to Swedish Standard SIS 05-900 or equivalent standard.

Property	Test Method	Unit	Specifications
Gloss @ 60° Angle	ASTM D 523	-	Flat
Adhesion	ASTM D 3359	-	Minimum 3A
Salt Spray Resistance	ASTM D 117	-	Excellent
%Zinc by Weight in Dried Film Test		%	87.5± 2

6-3 Recasting Concrete/Grout

(1) Epoxy Resin Adhesive

Property	Test Method	Unit	Specifications
Compressive Strength	ASTM D695M/JIS K 7208	N/mm ²	75
Flexural Strength	ASTM D790M/JIS K 7203	N/mm ²	40
Tensile Strength	ASTM D638M/JIS K 7113	N/mm ²	30
Tensile Shear Bond to Steel	ASTM D1002/JIS K 6850	N/mm ²	10
Slant Shear Bond to Mortar	ASTM C882/JIS K6852	N/mm ²	15

(2) Zinc Rich Primer for Rebar

Rebar should have all rust removed by the use of power tools or brushing according to Swedish Standard SIS 05-900 or equivalent standard.

Property	Test Method	Unit	Specifications
Gloss @ 60° Angle	ASTM D 523	-	Flat
Adhesion	ASTM D 3359	-	Minimum 3A
Salt Spray Resistance	ASTM D 117	-	Excellent
%Zinc by Weight in Dried Film Test		%	87.5± 2

7. Repair of Bridge Expansion Joint

7-1 Asphalt Plug Joint

(1) Flexible Asphalt

Property	Test Method	Unit	Specification
Density	ASTM D1188	g/cm ³	2.26± 0.05
Splitting Strength	ASTM D4123-82	N/mm ²	1.57± 0.29
Deformation (Flow value)	ASTM D1559/JIS K2207	1/100cm	140± 20

7-2 Replacement of Expansion Joint

(1) Expansion Joint Rubber Seal

Property	Test Method	Unit	Specification
Tensile Strength	ASTM D412/JIS K6251	MPa	0.98(Min)
Elongation at break	ASTM D412/JIS K6251	%	100(Min)

8. Repair of Bridge Bearing

8-1 Replacement of Bearing

(1) Bearing Pad

Elastomeric bearing pads shall conform to AASHTO M251.

Property	Test Method	Unit	Specification
Hardness, Durometer A	ASTM D2240	-	60±5

The material test shall be applied for Hardness test to be approved by the Engineer.

9. Protection Works

9-4 Nylon Fiber Gabion

(1) Nylon Fiber Gabion

Property	Test Method	Unit	Specifications
A. Tensile Strength			
1.Netting (25 mm mesh size)	ASTM D4268/JIS A8960	N	≥ 450
2.Hanging Rope (9mm Ø)	ASTM D4268/JIS L2707	kN	≥ 10
3.Top Tie Rope (6mm Ø)	ASTM D4268/JIS L2704	kN	≥ 7
4.Bottom Tie Rope (6mm Ø)	ASTM D4268/JIS L2704	kN	≥ 7
B. Elongation			
1.Netting (25 mm mesh size)	ASTM D4268/JIS A8960	%	≥ 30 to ≤ 50
2.Hanging Rope (9mm Ø)	ASTM D4268/JIS L2707	%	≤ 40
3.Top Tie Rope (6mm Ø)	ASTM D4268/JIS L2704	%	≤ 45

4. Bottom Tie Rope (6mm Ø)	ASTM D4268/JIS L2704	%	≤ 45
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