BRIDGE REPAIR MANUAL

EDITION 1

The Project for Strengthening of Capacity Development on Bridge Management System in the Republic of Kenya

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FOREWORD

The Government of Kenya through the Road Sector Improvement Program has put emphasis on road maintenance works, with the aim of ensuring that the road asset is well maintained to maximize on the value of this investment. The Road Maintenance Levy Fund (RMLF), managed by the Kenya Roads Board, is specifically set aside to fund maintenance works across the road network.

With full implementation of Performance Based Contracting (PBC) and continued funding from RMLF, there has been tremendous improvement in road maintenance in the Country. However, not enough attention has been paid to having a structured program that deals with maintenance of highway structures. Thus, the Bridge Management System (BMS) project was started to address management and repair of structures in Kenya. This is particularly important, as the structures form an integral part of the road network.

This manual gives guidance on how to carry out repair works on highway structures, for both preventive and reactive maintenance works. It is expected that all Road Agencies, Counties and other entities who manage highway structures will make use of this manual to guide their repair works and employment of value for money principles in structures maintenance. With this manual, it is hoped that the culture of preventive maintenance will be strengthened ensuring structures are in good conditions at all times, ensuring safety and uninterrupted connectivity.

This manual was developed by the Bridge Repair Sub-Working Group, constituted under the State Department for Roads with the assistance of the Japanese International Cooperation Agency (JICA), through the BMS project. The membership of the sub-working group was drawn from State Department for Roads, MTRD, KeNHA, KURA, KeRRA, KRB, KWS, NCA and Japanese experts, whose contribution and dedication towards the development of this manual is acknowledged with appreciation.

We are particularly grateful to the JICA team for their continued support to the Roads Sub-sector and in particular, their technical assistance towards the development of this manual.

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Kenya National Highways Authority KeNHA)
Kenya Rural Roads Authority (KeRRA)
Kenya Urban Roads Authority (KURA)
Kenya Wildlife Service (KWS)
Kenya Institute of Highways and Building Technology (KIHBT)
National Construction Authority (NCA)
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JICA Bridge Management System Project Team

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ABBREVIATIONS AND ACRONYMS

AASHTO	The American Association of State Highway and Transportation Officials
AC	Asphaltic Concrete
ASTM	American Society for Testing & Materials
BMS	Bridge Management System
CFP	Carbon Fibre Plate
CFS	Carbon Fibre Sheet
EN	Eurocodes
HGV	Heavy Goods Vehicle
JICA	Japan International Cooperation Agency
KeNHA	Kenya National Highways Authority
KeRRA	Kenya Rural Roads Authority
KIHBT	Kenya Institute of Highways and Building Technology
KURA	Kenya Urban Roads Authority
KRB	Kenya Roads Board
KWS	Kenya Wildlife Service
MoR&T	Ministry of Roads and Transport
MTRD	Materials Testing and Research Division
NCA	National Construction Authority
NDT	Non-Destructive Test
NEMA	National Environment Management Authority
PBC	Performance Based Contracts
PC	Pre-stressed Concrete
PCM	Polymer Cement Mortar
PPE	Personal Protective Equipment
RAs	Road Agencies
RC	Reinforced Concrete
SOP	Standard Operating Procedures

DEFINITION OF TERMS

Abutment	Structural members located at both ends of a bridge that connects the embankment portion of the approach road to the bridge. It supports the load from the superstructure and prevents the earth pressure from the backfill.
Annealing	This refers to a heat treatment process used to modify the properties and structure of steel, particularly to improve its ductility, toughness and reduce internal stresses.
Annual Bridge Maintenance Action Plan	This is a plan addressing/capturing bridge maintenance and repair interventions and budget allocation within a financial year with a network.
Approach slab	It is a concrete slab installed behind the abutment that acts as an intermediate bridge to avoid abrupt changes in elevation or alignment.
Backwall	The vertical wall at the ends of abutments that extends up from the bearing seat and supports the approach slabs, expansion joints and the embankment under the approach slabs.
Bearing	It is a device which transmits the vertical and horizontal actions from the superstructure to the substructure, and allows for movements between the superstructure and the substructure. Bearings allowing both rotation and longitudinal translation are called expansion/ movable bearings, and those, which allow rotation, only are called fixed bearings.
Bridge	A structure, that can be accessed by any traffic, with the function of aiding crossing over a waterway, road or any other obstacle. In the context of this manual, it also includes box culverts, viaducts and tunnels.
Coating	A layer applied to bridge elements to prevent corrosion and negative environmental effects.
Contractor	The entity engaged by the Employer through a due contract for the implementation of a supply, maintenance and/or repair assignment.
Corbel	It is a projecting wall member used as a support for some elements of the superstructure.
Cutback	A mixture of miscible liquids (petroleum and bituminous based liquids) used in construction, repair and maintenance of roads and bridges.
Damage	Defects due to external forces, e.g., flood, vehicle load, vehicle collision, earth pressure, vandalism etc.
Deck slab	A structural member that directly supports vehicles, pedestrians, etc. passing through a bridge and transmits the load to the main girder (main structure).

Design working life	An assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary.
Deterioration	Defects caused by changes in condition with age, e.g., Carbonation, Alkali-Silica Reaction (ASR), salt damage etc.
Diaphragm	It is a bracing that connects main girders at the supports, to resist lateral actions and transfer loads to the supports. It locks the girders in place and also provides support to the deck slab.
Employer	The Employer is the procuring entity responsible for the road network in Kenya and who enters into a road/bridge maintenance contract with a contractor on a certain section of the road.
Emulsion	A mixture of immiscible liquids (water and bituminous based liquids) used in construction, repair and maintenance of roads and bridges.
Engineer	The representative of the Employer with responsibilities and obligations under the maintenance contract.
Environmental Management Plan	A plan developed to ensure that all necessary measures are identified and implemented in order to protect the environment and comply with NEMA environmental regulations.
Epoxy	A type of polymer that when exposed to heat or chemical reactions hardens forming a compound with desirable engineering properties like adhesion, chemical and heat resistance, hardening, waterproofing and electrical insulation.
Expansion gap	A gap provided to allow for expansion and contraction due to temperature changes. It can be installed between a bridge girder and abutment or between girders that are not continuous.
Expansion joint	It is a device installed at the end of a girder or at the gap between girders to ensure smooth expansion and contraction and to allow automobiles and other vehicles to run smoothly on the bridge. It is mainly made of steel or rubber.
Force Account	This is a procurement method that a procuring entity uses its own or hired staff, equipment and purchased material to undertake work or services directly without engaging consultants or contractors.
Foundation	The part of the substructure that is in contact with the ground. Depending on the form, there are different types of foundations such as spread footing, pile foundations, and caisson foundations, etc. It transmits the loading from the substructure to the ground.
Implementers	The actual entity or persons directly involved in the inspections, maintenance/repair of bridges. In maintenance of bridges, the implementers are the road agencies, engineering consultants and contractors engaged in the construction, repair and maintenance of structures/roads.

Initial defects	Anomalies which are caused by design and/or occurred during construction (poor workmanship), e.g., honeycombs, cold joint, etc.
Input	Labour, materials, equipment and other supplies required to carry out the works.
Life Cycle Cost	This is an estimate of the cost that will be undertaken from the selected option of a structure or repair option during its service life. It includes the cost of planning, purchase, installation, operation, maintenance and decommission at the end of the structure service life.
Limit States	States beyond which the structure no longer fulfils the relevant design criteria.
Main girder/ Main structure	The main part of the superstructure, the structural member that supports all the loads acting on the bridge. In general, it is called the main girder in the case of girder structure, and the main structure in the case of truss or arch structure, etc.
Maintenance	The actions taken to keep the condition of a structural element to perform its level of service satisfactorily during its service life.
Mobilization Period	The period required for the contractor to mobilize labour, equipment and materials for the commencement works.
Ninja-tech	The use of straps, ropes and other safety harness to inspect and undertake minor repairs underside of bridge and other hard to reach bridge members.
Obstructions	Accumulation of debris, driftwoods and stumps, rocks, silt, animals or anything that may impede free flow of water through a structure.
Painting	A layer of material applied on bridge elements for protective and/or aesthetic purposes.
Pier	A substructure member which supports the superstructure at intermediate points, and transmits the load to the foundation.
Piles	When the soil under a footing cannot provide adequate support for the substructure, in terms of bearing capacity, overall stability or settlement; support is obtained through the use of piles which extend down from the footing to a stronger soil layer or bedrock.
Policy Formulators	These shall be persons/entities responsible for making policies towards bridge repair and bridge maintenance.
Polymer	This is a long chain molecule made up of many repeating units. Polymer is added to mortar to improve the mortar performance.
Polymer Cement	Binders, compounds and aggregates mixtures that use epoxies, polyesters, vinyl-esters or other polymer resin bonds.
Polyurethane	This is an organic polymer that features many organic units linked via urethane molecules. Polyurethanes, often abbreviated to PU or PUR, are an immensely versatile class of polymers used in insulators, foams, elastomers, synthetic skins, coating and adhesives.

Rating Scale	This is a five stage condition status indicator for bridge elements as inspected. Deterioration rating shall be based on location, severity and element importance. This shall be assigned after detailed inspection.
Repair	This is the reinstatement of a damaged member or structure to its designed or as-built condition.
Safety Officer	Officer responsible for planning, implementing and overseeing health and safety on site.
Scaffolding	Temporary raised platform used to support workers, equipment and materials during construction works when the area being worked on is high/hard to reach from floor level.
Serviceability Limit States	States that correspond to conditions beyond which specified service requirements for a structure or structural member are no longer met.
Stakeholders	Person(s) with interest in the use and maintenance of bridges. They include the road agencies, engineering consultants, contractors, road users and the communities affected by the presence and usage of the bridge.
Stress relief annealing	An after treatment procedure of cast with the aim to reduce inner stress within the castings.
Substructure	Structural members that transfer the load from the superstructure, through the bearings, to the ground. It is a general term for bridge abutments, piers, and foundations.
Superstructure	Supports the weight of objects passing through the bridge and transmits it to the substructure. It consists of main girder, deck slab, cross beam, lateral bracing, diaphragms, etc.
Timber	Processed wood that is suitable for building of structures.
Ultimate Limit State	States associated with collapse or with other forms of structural failure.
Value Management	Value management is the technique concerned with maximisation of limited resources to achieve value for money.
Wingwall	The sidewall to the abutment backwall which is provided for to assist in confining the earth behind the abutment. The wingwalls can be monolithic with the backwall or disjointed.
Works	Combination of materials, skill and manpower and or equipment systematically executed as per the described methodology and in accordance with the Specifications for construction, repair, maintenance, strengthening, reinstatement and decommissioning of bridges.

1 INTRODUCTION

1.1 GENERAL INTRODUCTION

The purpose of this manual is to give guidance to implementers regarding maintenance and repair of bridges using available resources to ensure timeliness, value for money, safety, and uninterrupted connectivity for social economic development within Kenya.

1.2 CONTENTS OF THE MANUAL

This manual starts with a general introduction. It defines the stakeholders involved in bridge maintenance and a rating standard. Chapter two describes the types of bridges, their elements and associated defects. The next chapter highlights various maintenance interventions applicable to various elements deterioration on various structures and outlines the possible repair methods.

1.3 OBJECTIVES

Main objective

To define repair methodologies that result in serviceable, safe and durable structures.

Specific objectives

i. To restore structural integrity and performance – The manual seeks to outline repair methodologies to meet and extend the structures' serviceability.

ii. To limit deterioration – The manual outlines means that can be used to prevent further deterioration that arise out of environmental conditions and usage.

iv. To mitigate usage risk – The manual outlines means of providing various mitigation to selected usage risks that could result to the users and nearby community.

v. To incorporate new technologies – The manual provides for new materials and innovative techniques in repair of defects.

vi. To employ value for money principles in structure maintenance – The manual outlines cost optimization and evidence based decision making in maintenance of structures.

1.4 SCOPE COVERAGE

This Bridge Repair Manual shall cover the bridges within the Republic of Kenya that have been inspected and rated according to the bridge condition rating scale.

1.5 EXPECTED OUTCOMES AND IMPACTS

Outcomes

❖ This manual is a guide for maintenance and it stipulates ways and steps for implementing repairs.

- ❖ Reference document – general perspective for maintenance best practices while undertaking structures maintenance.
- ❖ Process document – it gives step by step procedures for undertaking repairs.

Impacts

- ❖ *Uniformity in implementation* – It is anticipated that this manual shall ensure that all stakeholders implement bridge repairs in a standardized manner.
- ❖ *Standard operating processes* – It is expected that this manual shall inform the SOP development in the various implementing agencies.
- ❖ *Knowledge enhancement document* – This manual shall contribute to knowledge and best practices in bridge repair.
- ❖ *Policy formulation framework* – This manual will inform a basis for development of principles of action to be adopted by stakeholder for bridge maintenance.

1.6 BRIDGE CONDITION RATING

Adoption of bridge condition rating scale

Introduction of condition rating – This manual adopts a five-point condition grading for bridges based on the bridge inspection assessed by these indicators: degree of damage, extent of damage, importance of the structure and urgency required to make or correct the observed deterioration or defect.

Local considerations – The manual outlines a bridge condition index based on inspection, qualitative and element prioritisation.

Rating guidance – The rating guidance as shown in Table 1-1 is adopted.

Table 1-1: Bridge Condition Rating Scale

Condition	Score	Rating	Damage Description	Action/Response Time
Stage 1	80 – 100	Very good	Bridge with minor durability or functional damages	Long-term action
Stage 2	60 – 79	Good	Bridge with moderate durability or functional damages	Mid/long-term action
Stage 3	40 – 59	Fair	Bridges with minor structural damages or extended durability or functional damages	Mid –term action (Requires preventive measures)
Stage 4	20 – 39	Poor	Bridge with moderate structural damages. Serious durability or functional damages	Short-term action (Requires prompt action)
Stage 5	0 – 19	Bad	Collapsed bridge or bridge with high-severity structural damages	Immediate urgent action (Require emergency measures)

Maintenance priority

Stage 1 – Observe or monitor.
Stage 2 – Low priority for repair.
Stage 3 – Repair before next inspection.
Stage 4 – High priority. Reduce inspection frequency time.
Stage 5 – Immediate action / replacement required.

Repair interventions

The repair interventions discussed below refer to initiatives on asset management that focus on planning and strategy management of the network level of the structure network.

1. Routine maintenance:

Maintenance work that is planned and performed on a routine basis to maintain and preserve the condition of the structure or to respond to specific conditions and events that restore the structures to an adequate level of service. This includes minor works that require basic tools and materials.

Routine maintenance should seek to increase the service life of the structure and its overall cost should be low. Below are some typical works for various categories of structures:

For steel superstructure:

- Pressure washing on the beams/girders.
- Touch-up paint to minor defects in the paint system such as scratches and small areas of corrosion.

For concrete superstructure/substructure

- Patching of spalled/scaled areas on the concrete.
- Epoxy coating of cracks with sealant.

For protection works

- Removal of mud, sand and debris on the pier and abutment and cleaning of bridge seat and drainage pipe.
- Removal of drift wood materials.

2. Preventive maintenance:

Preventive maintenance may be condition based or planned (scheduled). It is the planned systematic implementation of cost effective treatments to an existing structure and its appurtenances that preserve the system, retards future deterioration and maintains or improves the functional condition of the road structure without increasing structural capacity.

Examples of preventive maintenance – bridge cleaning, deck sealing, sealing joints, thin deck overlays, removing large debris in channels, spot and zone painting and reconstructing/ closing joints.

3. Restorative Maintenance:

The term "restorative maintenance" as used in this document applies to maintenance activities that are performed as a reaction to deterioration of bridge elements. This work is performed on an as-needed basis rather than on a regular schedule. Restorative maintenance is generally reactive rather than proactive. Restorative maintenance is different from planned preventive maintenance, which is generally performed in order to slow the rate of deterioration of a structure or one of its elements.

Examples of Restorative Maintenance – Painting (Over Coating and Complete Removal and Re-Coating), Hydro Demolition and Rigid Deck Overlays, Reconstructing / Closing Joints, Superstructure Repairs, Substructure Repairs, Fatigue Retroffiting, Scour Repairs, Cathodic Protection, and Electrochemical Chloride Extraction.

4. Rehabilitation:

Rehabilitation involves major work required to restore the structural integrity of a bridge as well as work necessary to correct major safety defects. Rehabilitation projects can include component replacement (deck and or superstructure), repair or some combination thereof. Rehabilitation must be conducted in conjunction with preservation practices that mitigate and slow the causes of the damage being repaired. Examples of Rehabilitation – Superstructure Replacements, Deck Replacements, and Culvert Rehabilitation. Rehabilitation can include significant repairs that to not involve replacement of a bridge component. Examples include but are not limited to hydromilling with concrete overlay, structural beam end repair or strengthening or other significant improvements to bridge components.

5. Replacement:

Bridges that are structurally deficient, and are frequently overtopped are eligible for replacement or rehabilitation. A new structure is constructed and the existing defective structure is removed.

6. Emergency maintenance:

A reactive maintenance resulting from observed an unexpected / unusual occurrence.

1.7 STAKEHOLDERS

Policy formulators - This manual is intended to guide policy development for bridge repair and value for money principles for bridge maintenance.

Implementers - This manual is intended to outline best practices, materials and methods for bridge repair.

Trainers - This manual will be a reference document for human resource development.

Contractors - This manual will be a guide for capacity building and work implementation guide for repair.

1.8 COMPETENCY OF MAINTENANCE PERSONNEL

The Works proposed in this manual should be undertaken by an implementer who possesses necessary and relevant knowledge, qualifications, skills and experience as to handle the repair works for the various bridge structures.

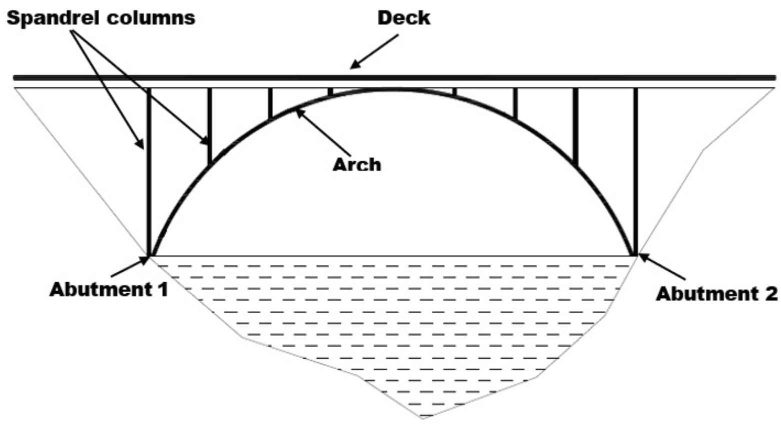
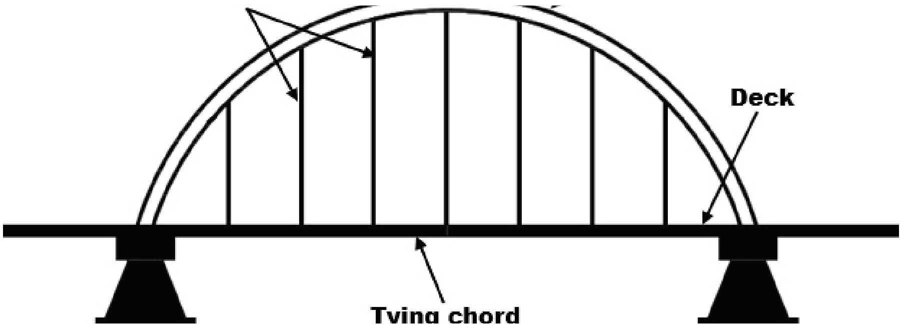
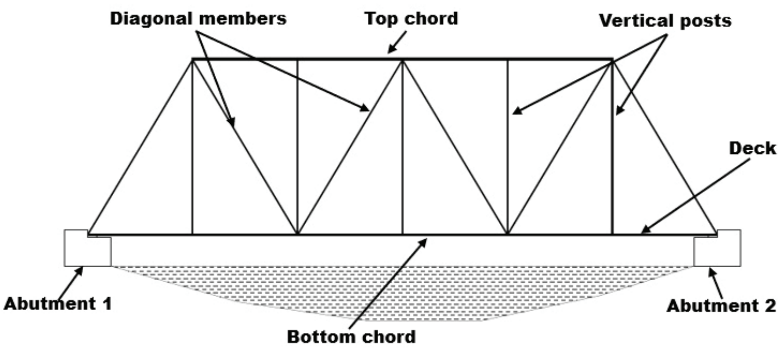
Skilled personnel trained by KIHBT and Registered/accredited by NCA.

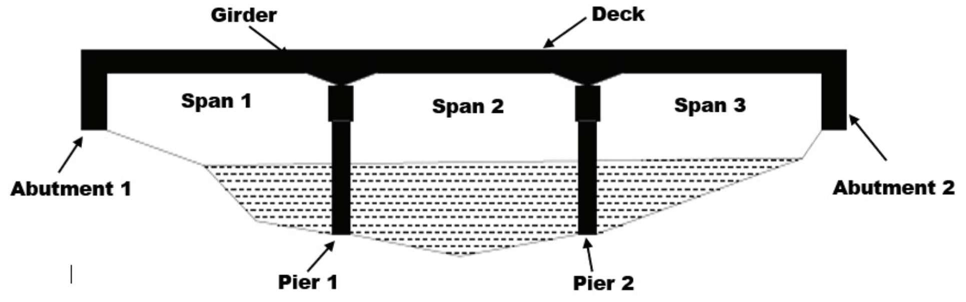
2. TYPES OF BRIDGES AND COMMON DEFECTS

2.1 INTRODUCTION TO BRIDGES

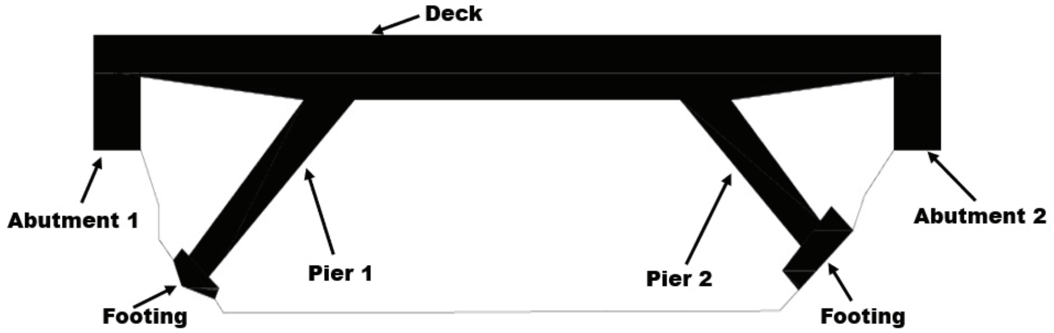
A bridge is a structure that carries a road, path, railway across a water way or any other obstacle. Table 2-1 shows the types of bridges in the world.

Table 2-1: Types of Bridges in the World

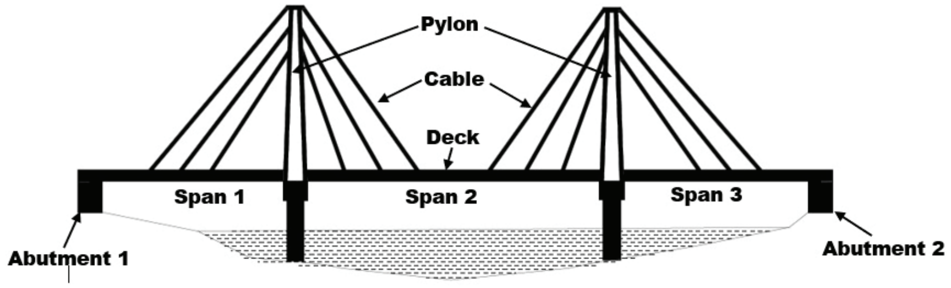
Image / Schematic

Arch bridge

Tied Arch

Truss



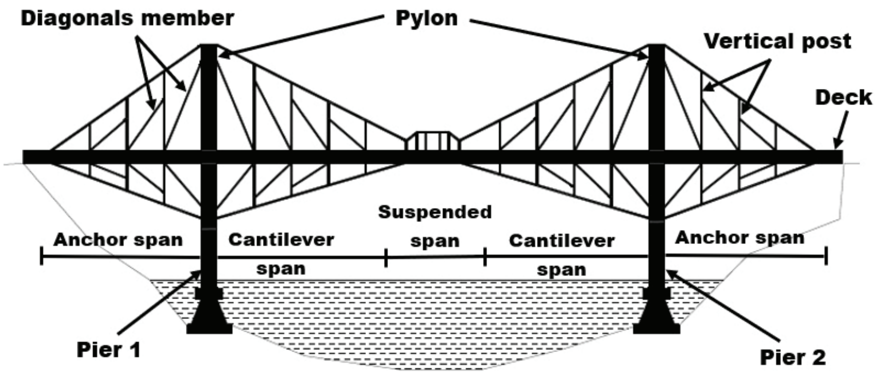
Beam/Girder



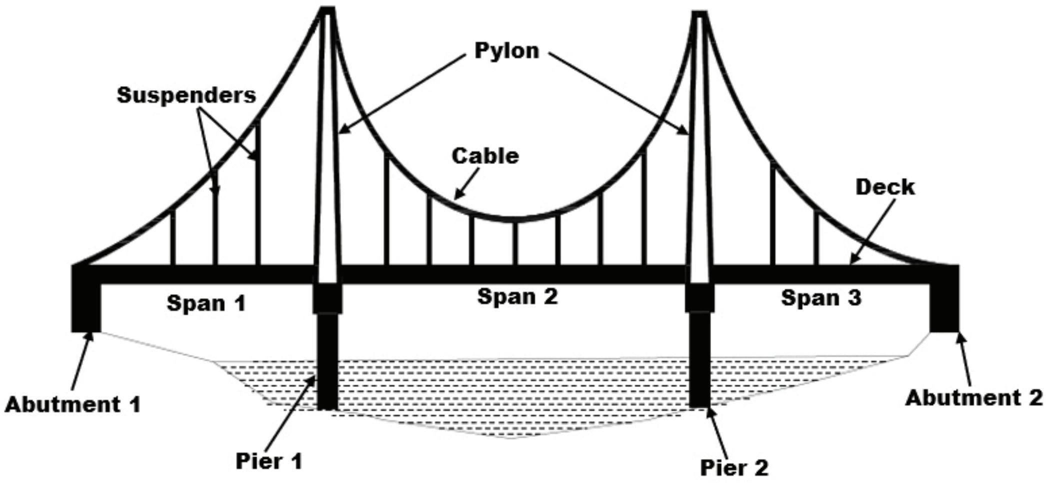
Rigid frame



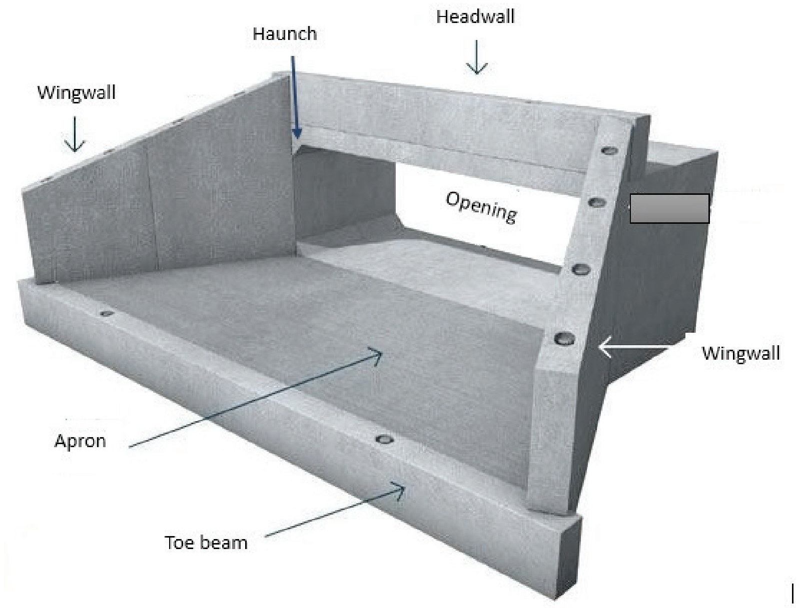
Cable stayed



Cantilever



Suspension



Box culvert

2.2 BRIDGES IN KENYA

In Kenya there are several bridges built for different types of crossings. Most of them are waterway crossings. A number of the structures are crossing the railway lines, road and some provided for the safe crossing of pedestrians and animals. The structures range from pipe culverts, box culverts, footbridges, tunnels and bridges.

Notable structures are as highlighted in Table 2-2.

Table 2-2: Notable Structures in Kenya

No.	Bridge Name	Details	Road Agency
1.	Mteza Bridge	1440 m long, 47 spans, PC girder	KeNHA
2.	Mwache Bridge	660 m long, 21 spans, PC girder	KeNHA
3.	Tsunza Viaduct	690 m long, 46 spans, PC girder	KeNHA
4.	Makupa Bridge	452 m long, PC I-girder	KeNHA
5.	Kilifi Bridge	420 m long, PC box girder	KeNHA
6.	Nyali Bridge	330 m long, PC box girder and RC girder	KeNHA
7.	Mtwapa Bridge	192 m long, PC box girder	KeNHA
8.	Sabaki Bridge	171 m long, PC box girder	KeNHA
9.	Gotu Bridge	160 m long, 8 spans RC girder	KeRRA
10.	Masalani Bridge	134 m long, Suspension bridge	KeRRA
11.	Baricho Bridge	241 m long, 7 spans, Box girder	KeRRA
12.	Galana Bridge	224 m long, 6 spans, Bailey Bridge	KWS
13.	George Adamson Bridge	150 m long, 3 spans, Bailey Bridge	KWS
14.	Viaduct over Mumias and Kangundo Roads	1000 m long, 40 spans, RC girder	KURA

There are several types of bridges depending on the material used in construction as shown in Table 2-3.

The choice of material depends on material availability, length of the bridge, cost and available technology during the design and construction period. Most of the timber and masonry bridges as originally built have now been replaced by concrete and steel bridges.

Table 2-3: Example of Bridges by Material and Superstructure Type

No.	Material	Superstructure Type	Examples
1.	Concrete	Girder	Kilifi Bridge
		Arch	Athi River Interchange
		Rigid Frame	JKIA Overpass

No.	Material	Superstructure Type	Examples
2.	Steel	Girder	Cabanas Interchange
		Composite Girder	Kahiga Bridge Bellevue Footbridge
		Rigid Frame	Pangani Footbridge
		Truss	Embobut Bailey Bridge Galana Bailey Bridge George Adamson Bailey Bridge
		Suspension	Masalani Bridge Thua Suspension Bridge
3.	Masonry	Arch	Muringato Bridge 1 and 2 in Aberdare National Park
4.	Timber	Beam	Kimothon Bridge (Mt. Elgon) Rhodesia Bridge (Tsavo West) Mzima Springs (Tsavo West)

2.3 COMMON BRIDGE DEFECTS

The following are the common bridge defects identified;

2.3.1 Common Defects on Concrete Bridges

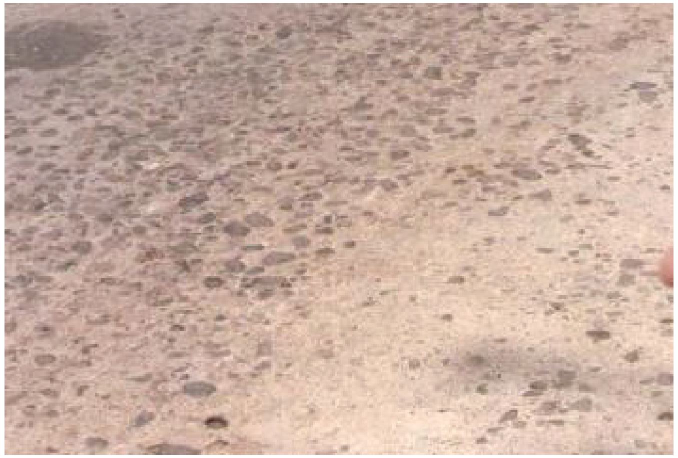
Common defects on concrete bridges, their possible causes and proposed remedial measures are given in Table 2-4. These defects can occur on the superstructure, sub-structure elements.

Table 2-4: Common defects on concrete bridges

Defects	Description	Image	Possible Causes	Remedy
1. Siltation	Accumulation of dirt, debris and unwanted materials. The presence of the unwanted material may cause growth of vegetation.		Blocked/ inadequate drainage. Leaking expansion joints.	Cleaning the affected area. Repair the underlying cause.

Defects	Description	Image	Possible Causes	Remedy
2. Corrosion	It occurs due to chemical reaction leading to formation of iron oxides in the presence of moisture and oxygen. Formation of iron oxides around reinforcement bars leads to increase in volume of steel bars hence causing stresses in concrete. Corrosion can lead to loss of strength in concrete, fatigue and loss of bonding between steel and concrete.		Carbonation. Salt damage. Chemical attack.	Sectional repair with rebar addition. Providing protection coating/mortar.
3. Cracks	It is a linear fracture in concrete that extends partly or completely through the member. Cracks may occur due to overload, structural deficiency, vehicle impact, thermal variation at different concrete layers or unanticipated structural action. Vertically aligned crack patterns in the vicinity of the mid-span of a beam and diagonal cracking at the ends can be indicators that cracking is of a structural nature.		Shrinkage. Stress. Rebar corrosion.	Seal the cracks. Member strengthening.

Defects	Description	Image	Possible Causes	Remedy
4. Spalling with rebar exposure	It is a phenomenon that occurs when a piece of concrete peels off from the main concrete member of a bridge and often leaves the reinforcement bars exposed. It may lead to corrosion of steel bars when exposed to adverse environmental conditions and degradation of structural members of the bridge hence affecting mechanical strength and durability. This can be caused by impact, vibrations and corrosion of rebar.		Impact. Inadequate cover. Exposure to environmental conditions that lead to rebar corrosion.	Sectional repair with rebar addition.
5. Spalling	It is a phenomenon that occurs when a piece of concrete peels off from the main concrete member of a bridge. It may lead to corrosion of steel bars when exposed to adverse environmental conditions and degradation of structural members of the bridge hence affecting mechanical strength and durability. This can be caused by impact, vibrations and corrosion of rebar.		Impact. Inadequate cover. Exposure to environmental conditions that lead to rebar corrosion.	Sectional repair.

Defects	Description	Image	Possible Causes	Remedy
6. Scaling	It is the loss of concrete from the outer surface of concrete members due to weather effects or low quality of concrete grade used on a structural member.		Weather effects.	Application of fast setting mortar overlay.
7. Delamination	It occurs due to expansion in concrete resulting from corrosion in embedded reinforcement bars. Expansion in concrete may result into horizontal cracking or sub surface fracture in concrete at or just above the level of embedded reinforcement.		Exposure to environmental conditions that lead to rebar corrosion	Sectional repair.

Defects	Description	Image	Possible Causes	Remedy
8. Honeycombing	These are voids in concrete or cavities in concrete arising from inadequate compaction of concrete during construction. They normally appear on the face of concrete or inside concrete. It may lead to exposure of aggregates and corrosion of steel reinforcement in harsh environmental conditions.		Inadequate execution during construction.	Section repair by patching or plastering.
9. Efflorescence	It occurs due to migration of salts to the surface of the concrete where they crystallize. It can sometimes be visible as crystallize deposits hanging from the soffit of the deck or beam.		Water penetration from the top. Cracks on the member.	Waterproof surface to prevent infiltration and unclog the drains. Crack sealing/ injection.

Defects	Description	Image	Possible Causes	Remedy
10. Carbonation	It occurs as a result of chemical reaction between Carbon (IV) oxide and Calcium Carbonate due to insufficient cover on structural concrete or porosity/voids in concrete leading to breakage of the protective layer around steel reinforcements. The loss of the protective layer leads to corrosion of the rebar and cracks in concrete appear due to the expansion pressure of the rebar.		Lack of concrete protective layer, exposure to carbon (IV) oxide in the atmosphere.	Sectional repair. Provide surface coating to inhibit carbon dioxide ingress.
11. Chemical attack/ corrosion	It occurs when concrete is exposed to environmental conditions saturated with sulphur dioxide and nitrogen oxides. When precipitation occurs, acid rain is formed which could lead to chemical attack on bridge structures. Chemical attack may occur as a result of the following: - Acids - Salts and alkalis - Sulphate attack		Lack of concrete protective layer. Exposure to acids and sulphates.	Sectional repair. Provide protective coating/mortar.

Defects	Description	Image	Possible Causes	Remedy
12. Alkali Silica Reaction	It is a chemical reaction that occurs between alkali cations and hydroxyl ions in the pore solution of the hydrated cement paste that contain certain reactive silica phases present in the aggregates forming a gel that absorbs water and expands, cracks appear in the concrete. As the ASR progresses, the cracks gradually spread to the surface of the concrete forming alligator cracks.		Concrete aggregates containing alkali reactive minerals.	Sectional repair. Provide protective coating/mortar.
13. Salt attack	Salt attack on concrete occurs when chemicals containing chlorides, including sodium chloride, potassium chloride, or calcium chloride, found in fertilizers, ocean water, marine air presents a danger to the concrete. All are mildly acidic and attack the bonds that hold concrete together.		Lack of concrete protective layer against salt from the sea.	Sectional repair. Provide protective coating/ mortar to inhibit chloride ions ingress.

Defects	Description	Image	Possible Causes	Remedy
14. Abrasion	It occurs when concrete surfaces are unable to resist wear and tear caused by external forces exerted by traffic and hydraulic effects.		Impact of erosive river action. Wear and tear from traffic.	Sectional repair.
15. Leakage	This is the presence of unwanted passage of water on concrete elements due to lack of proper waterproofing material, presence of cracks, poor drainage and failing joints.		Leaking crack.	Repair the concrete fill in part between the girders. Waterproof top of deck slab. Crack injection/ sealing.

Defects	Description	Image	Possible Causes	Remedy
16. Leaching	Seepage of water through cracks and voids in hardened concrete which may dissolve Calcium Hydroxide and other constituent materials in concrete. It can be evident in the form of staining, efflorescence and encrustation at cracks.		Water penetration.	Waterproofing top surface of member/inner surface. Crack injection/ sealing.
17. Excessive deformation /deflection	Excessive deflections occur as a result of creep, over loading, inadequate design, poor construction techniques or failure in material performance.		Fatigue or overloading.	Carry out concrete strengthening works. Limit heavy trucks using the bridge. Reconstruct the bridge.

Defects	Description	Image	Possible Causes	Remedy
18. Discoloration	This occurs when water penetrates through the deck surface down to the columns, beams, abutments and piers, causing a brown discoloration of the members. This is usually caused by poor drainage on the deck surface.		Smoke from illegal human activities. Leaking joints.	Cleaning the affected area. Covering with protective coating/mortar.
19. Buckling	It occurs when a slender column/ beam fails due to excessive compression along its length. The member thus fails when subjected to high compressive stresses, where the actual stresses at failure are smaller than the ultimate compressive stresses that the member can withstand.		Inadequate design and execution.	Concrete strengthening/ replacement of member. Provision of reinforcing members.

2.3.2 Common Defects on Steel Bridges

Common defects on steel bridges, their possible causes and proposed remedial measures are given in Table 2-5. These defects can occur on the superstructure, sub-structure elements.

Table 2-5: Common defects on steel bridges

Defects	Description	Image	Possible Causes	Remedy
1. Siltation	Accumulation of dirt, debris and unwanted materials which may cause growth of vegetation and blocking of drainage structures.		Rising water levels during flood, sediments deposited. Leaking joints. Drainage pipes discharging directly to the steel members.	Clean off the sediments. Clear the river channel of any debris. Check the drainage system provided and repair accordingly.
2. Corrosion	Corrosion of steel members occurs when these members are exposed to environmental conditions such as high salinity and moisture. Corrosion leads to substantial reduction in member capacity and is the primary cause of sectional loss in steel members. It is prevented by applying a protective coating such as paint on the steel member to prevent exposure to environmental conditions.		Worn out/ damaged protective paint.	Clean and apply protective paint.

Defects	Description	Image	Possible Causes	Remedy
3. Paint peel-off /Deterioration of corrosion protection	Painting shields steel from water and oxygen by covering it, thereby preventing corrosion. Paint peel off occurs when paint on a section of the steel member loses it adhesive properties hence leading to the reduction of the protective layer. The paint film deteriorates over time, and if the paint is not reapplied at the appropriate time, the corrosion protection function will deteriorate.		Loss of bond between the protective layers.	Remove the paint, apply primer and protective paint layers.
4. Heat Damage	This is the weakening of steel members as result of exposure to fire or extreme heat. As a result of these exposures, the members undergo serious deformations such as sagging, elongation, buckling and twisting. Rivets and bolts may also fail at connection points.		Fire outbreak.	Reinforce the member or replace. Protect with fire resistant coating.

Defects	Description	Image	Possible Causes	Remedy
5. Sectional Loss	This is the reduction in cross-sectional area of a steel member caused by corrosion or wear and tear on steel structure elements. This sectional loss causes reduction in load carrying capacity of the member.		Corrosion of the member.	Replace member. Clean by blasting, provide additional strengthening plate and reapply protective paint. Member strengthening.
6. Missing Parts	This occurs when some bridge members are lost due to vandalism or failure of bridge members in the case of adverse environmental conditions such as earthquakes and floods.		Vandalism of steel parts. Vibrations on the bridge. Inadequate execution during construction.	Replace the missing parts and weld bolt-ends.

Defects	Description	Image	Possible Causes	Remedy
7. Cracking	Cracking of steel members occurs in a structure resulting from fatigue usually occurring at points of tensile stress concentrations, at welded attachments or at termination points of welds.		Fatigue.	Provide stop-hole at the end of crack to stop the crack from propagating. Strengthen section/ replace.
8. Fracture	Fracture is the breaking of steel due to fatigue or impact.		Fatigue, stress or impact.	Strengthening the fracture member. Replacing with a new member.
9. Excessive vibrations and Noise	Excessive vibration is caused by excessive loading on bridge structure and often indicates occurrence of failure in bridge connections and steel members.		Excessive stress/fatigue.	Reinforce cracked or fractured members. Replace members.

Defects	Description	Image	Possible Causes	Remedy
10. Deformation and deflection	Deformation results from accidental/impact loading on bridge members while deflection is caused by long-term loading on the bridge structure. It results into cracking on other members in case of transfer of excessive stresses.		Overloading. Hit/ Impact.	Reinforce member. Replace the affected member.
11. Buckling	Buckling occurs when a slender structural member is exposed to high compressive stresses likely to result in a sudden sideways deflection. Kinking is the loss of or twist in shape of a bridge member as a result of long term loading. Warping occurs when the twisting of a member results in the cross-sections distorting out-of-plane along the direction of the member's longitudinal axis. Most cold-formed members (i.e. all except closed hollow circular sections) have cross-sections which tend to warp when subject to torsion.		Impact due to accident. Overloading. Inadequate member size.	Reinforcing the member. Replacing the member. Limit the weight of vehicles using the structure.

Defects	Description	Image	Possible Causes	Remedy
12. Loose/ Missing Bolts	This occurs as a result of actions/loading on bridge members connected using structural bolts. Loose bolts may also be as a result of incorrect installation, vandalism, excessive vibrations, corrosion of the connector plates or fasteners, overstressing, cracking or failure of individual fasteners. Factors leading to failure include lack of routine inspection and maintenance on steel bridge structures.		Vibrations. Inadequate execution. Vandalism.	Replace missing bolts. Sensitization against vandalism.
13. Accumulation of water	This is the ponding of water on steel members as a result of depressions on steel deck caused by excessive deflection, failure of vertical members and no drain function.		Inadequate drainage facility. Clogging of drainages.	Provide suitable drainage. Clean the blockages on the drains.

Defects	Description	Image	Possible Causes	Remedy
14. Discoloration	This occurs when water penetrates through the deck surface onto the columns and beams below, causing a brown discoloration of the members. This is usually caused by poor drainage on the deck surface.		Human activities. Leaking joints.	Clean and repaint the steel sections affected. Repair the leaking joints.

2.3.3 Common Defects on Timber Bridges

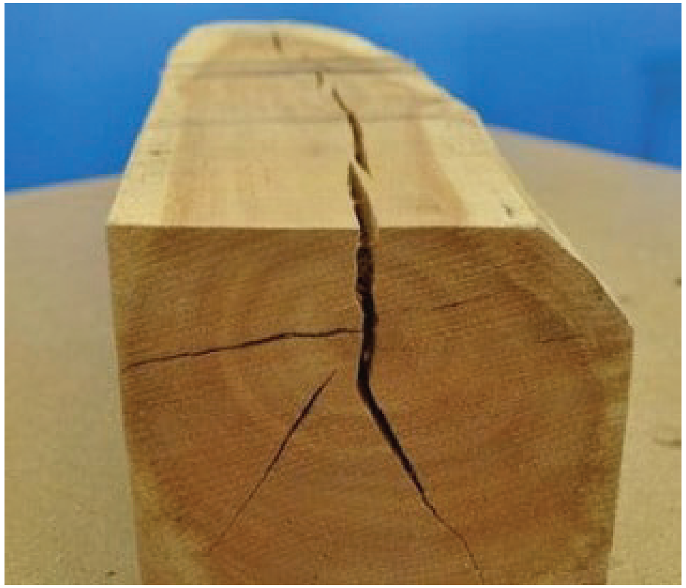
Common defects on timber bridges, their possible causes and proposed remedial measures are given in Table 2-6. These defects can occur on the superstructure, sub-structure elements.

Table 2-6: Common defects on timber bridges

Defects	Description	Image	Possible Causes	Remedy
1. Siltation	This is the build-up of dirt and vegetation on the timber structure. The presence of the siltation encourages wetness hence has an influence on the drying and equilibrium moisture content of the timber and can hasten cracking and deterioration of timber.		Deposition by traffic.	Clean regularly.

Defects	Description	Image	Possible Causes	Remedy
2. Rotting	This is the attack of timber by fungi when the moisture content of the timber is above 20% and there is prescence of air and warmth for the growth of fungi.		Water leakage. Dampness.	Repair/improve the drainage system around the timber elements. Application of fungicide when the timber is drying. Apply chemical preservative to timber. Replace damaged sections.
3. Termite attack	Termites eat the sapwood and heartwood of the timber affecting its quality and strength.		Use of untreated timber. Area with active termites. Fungal rotting.	Inject termite poison into the timber. Installation of pile jackets.
4. Loose connections	This is weakening on timber connections after long term loading and exposure to environmental serviceability and vibrations.		Inadequate execution. Vandalism. Excessive movements under loading. Shrinkage of timber around connections.	Tighten the existing bolts. Replace loose connections.

Defects	Description	Image	Possible Causes	Remedy
5. Cracking	Fractures due to loading, particularly in flexural (bending) members.		Overloading. Inadequate member due to span. Ineffective supports.	Control/limit the traffic using the bridge. Replace timber member with adequate section. Strengthen the timber. member with additional member. Seal the cracks by caulking
6. Excessive deflection	This is abnormal lateral displacement of a timber member when it is loaded laterally. Manifested by a curve along its longitudinal length which may affect its serviceability or functionality.		Overloading. Inadequate member due to span.	Control/limit the traffic using the bridge. Replace timber member with adequate section. Strengthen the timber member with additional member.

Defects	Description	Image	Possible Causes	Remedy
7. Splitting	This is when the crack progresses all through the timber hence separating the timber into two.		Overloading. Inadequate member due to span. Ineffective supports.	Replace member. Strengthen member.
8. Missing member	This occurs when some bridge members are lost due to vandalism or failure of bridge members.		Rotting. Vandalism. Excessive vibrations. Overloading. Traffic impact.	Replace missing member.
9. Discoloration	This is the coating of the original surface of the timber with an unwanted material.		Traffic action. Human activities. Poor drainage/ Leaking areas.	Apply suitable coating if unsightly. Improve drainage.

Defects	Description	Image	Possible Causes	Remedy
10. Abrasion	This is the mechanical wear and loss of section from traffic effects on deck timbers, which sometimes results in an undesirable slipperiness.		Traffic action.	Replace damaged section. Provide measures to prevent or reduce the abrasion of the timber members.

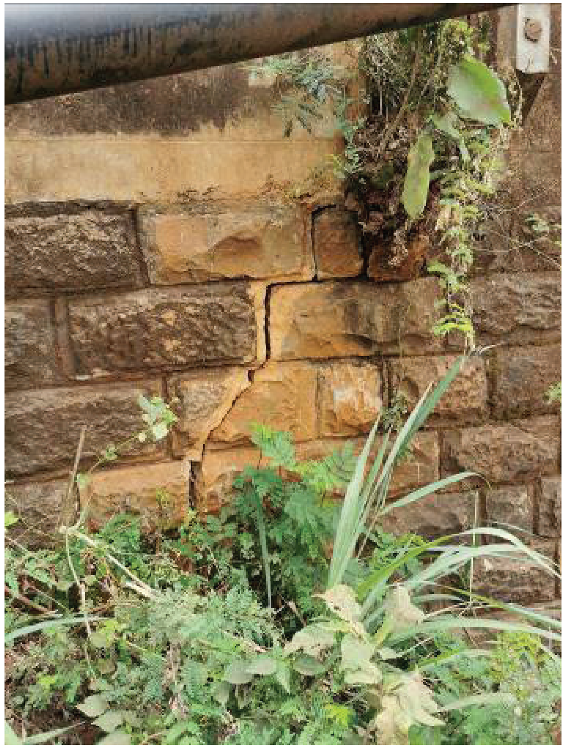
2.3.4 Common Defects on Masonry Bridges

Common defects on masonry bridges, their possible causes and proposed remedial measures are given in Table 2-7. These defects can occur on the superstructure, sub-structure elements.

Table 2-7: Common defects masonry bridges

Defects	Description	Image	Possible Causes	Remedy
1. Siltation	This is the accumulation of dirt or debris on the components of the bridge. Sometimes caused by sedimentation materials.		Deposition by river action. Human/animal action.	Clean regularly. Discourage dumping.
2. Loss of masonry blocks	This is the loss of masonry block(s) on the bridge elements.		Water penetration. Bond failure. Vandalism. River action. Impact during accidents.	Replace the lost bricks/blocks. Coat with protective material the exposed surfaces.

Defects	Description	Image	Possible Causes	Remedy
3. Efflorescence	This occurs when salt laden water typically seeps into the mortar joints first; therefore water stain and efflorescence is most likely to be first visible in the mortar joints.		Water penetration from the back of the masonry wall. Cracks on the mortar/mortar deterioration.	Clean the weepholes provided. Provide suitable weepholes. Repair the cracks.
5. Cracks	These are fissures/openings on the masonry members. The cracks may form on the mortar joint and/or on the masonry itself.		Settlement. Earth pressure. Impact.	Repair the cracks. Replace the cracked section/element.

Defects	Description	Image	Possible Causes	Remedy
6. Vegetation growth	This is the growth of vegetation on/near the masonry elements of the bridge. The growth of vegetation may lead to further damage to the masonry walling.		Presence of cracks. Sediments and moisture.	Clear all the vegetation and the organic sediments regularly. Repair the cracked/ damaged areas.

Defects	Description	Image	Possible Causes	Remedy
7. Discoloration	This is the change in color of the masonry material caused by dampness, chemical attack or even impurities in the environment like smoke from traffic.		Human activities. Dampness. Animal action.	Clean the surface regularly. Coat with protective material the exposed surfaces.
9. Bulging of masonry wall.	This is the movement of masonry unit relative to each other. The movement can cause cracking and loss of mortar.		Earth pressure from moist back fill. Compaction of fill material by traffic loading.	Repair/replace the damaged section. Provide weep holes to drain water from the back fill.
10. Scour	Scour is the erosion of the channel bed. Scour is critical if it occurs adjacent to the footings.		Erosive water action.	Fill and provide suitable protection.

Defects	Description	Image	Possible Causes	Remedy
15. Mortar Deterioration	This is the weathering of the mortar joint leading to cracking, crumbling, chipping away and /or discoloration of the joint mortar.		Water action. Wear and tear.	Replace the deteriorated mortar joint. Protect the masonry surface with suitable coating material.

2.3.5 Common Defects on Ancillary Elements

Common defects on bridge ancillary elements, their possible causes and proposed remedial measures are given in Tables 2-8 to 2-11. These defects can occur on the superstructure, sub-structure elements.

Table 2-8: Common defects on railings and parapets

Defects	Description	Image	Possible Causes	Remedy
Fracture	This is the breaking of steel members of the steel railings.		Impact or hit by the road users. Corrosion. Inadequate execution. Vandalism.	Weld back the fractured member and reinforce. Replace the member with adequate type.

Defects	Description	Image	Possible Causes	Remedy
Corroded railings and parapet walls	Steel railings are susceptible to corrosion when the antirust protective layer is worn out.		Worn out or lack of protective paint.	Prepare steel surface, apply primer and protective paint.
Discoloration	This is the change in colour on surfaces of railings as a result of corrosion, aging on paint coating, defacing of members.		Corrosion. Aging of paint coating. Vandalism.	Clean surface and protect the surface with suitable coating.

Defects	Description	Image	Possible Causes	Remedy
Cracked railings and parapets	Cracks can appear on the steel railings and RC parapet walls.		Shrinkage. Stress. Inadequate execution.	Provide reinforcing member or replace the member for steel members. For steel members, strengthen the section or replace the steel members. Provide the expansion gap for some of the cases. For RC members, repair the crack appropriately.
Missing parts	This is the loss of bolts, sections, rivets and anchorages.		Vandalism. Accidental knocking by traffic and / or forces of nature.	Replace the missing part.

Defects	Description	Image	Possible Causes	Remedy
Loose connections/missing bolts	This is weakening on steel connections after long term loading and exposure to environmental serviceability and vibrations.		Inadequate execution. Vandalism. Accidental knocking. Excessive vibrations.	Tighten the loose bolts and nuts. Replace the missing bolts and weld the bolt ends.
Deformation	This is the change in shape on members or parts of the bridge as a result of accidental knocking by traffic or forces of nature.		Hit/impact by the road users.	Replace the deformed members.
Spalling on the reinforced concrete parapets	This is when a section of concrete peels off from the main member and can leave the reinforcement bars exposed.		Hit/ Impact by the road users. Corrosion of reinforcement.	Section repair the spalled area. If the rebars are corroded apply antirust before repairing with concrete.

Table 2-9: Common defects on drainage

Defects	Description	Image	Possible Causes	Remedy
Broken drain pipes	This is the collapse or splitting of the drainage pipe.		Hit/Impact. Corrosion. Inadequate execution during cleaning.	Replace the broken drain pipes.
Clogging	This is the accumulation of debri on inlet of the drains and/or the drain pipes.		Siltation and sedimentation. Inadequate execution.	Clear all the debris clogging the drains regularly.

Defects	Description	Image	Possible Causes	Remedy
Corrosion	Sections of the drainage pipe that are composed of steel can corrode and lead to functional loss.		Exposure to elements that encourage corrosion.	Replace steel member. Provide measures to protect against corrosion. Replace section with non- corroding material.
Missing drain cover	Absence of drainage covers that were previously provided.		Vandalism. Corrosion. Accidental damage by traffic.	Replace drain cover. Replace drain cover made of non steel materials.

Defects	Description	Image	Possible Causes	Remedy
Root intrusion/ Vegetation growth	This is vegetation growth on the drains and/or intrusion of roots.		Sedimentation and ponding of water on the drainage system. Inadequate slope.	Regurlary clean the drainage system of unwanted material.
Missing drainage facilities	Missing drainage facilities.		Inadequate design.	Provide alternative drainage.

Table 2-10: Common defects on embankment protection

Defects	Description	Image	Possible Causes	Remedy
Surface deterioration	Loss of stones and/or mortar on the provided slope protection works.		Erosive river action. Accident impact. Vandalism.	Repair the deteriorated slope protection. Provide a support toe at the bottom of the slope protection.

Defects	Description	Image	Possible Causes	Remedy
Embankment erosion	Erosion of the embankment soil material leading to the development of trenches.		Surface water run-off. Animal foot action.	Provide suitable slopes of the embankment. Provide suitable slope protection works. Provide scour checks.
Unwanted vegetation	This is growth of unwanted vegetation near the bridge structure which could lead to damage on the bridge abutment and slope protection work.		Uncontrolled growth of vegetation on the embankment.	Regular vegetation control on the embankment.

Defects	Description	Image	Possible Causes	Remedy
Damaged gabion protection	The gabion wire can be torn or the hardcore inside the boxes missing		Vandalism. Erosive river action.	Repair the gabion protection appropriately. Grout the exposed surfaces after repair.

Table 2-11: Common defects on signalling

Defects	Defects	Image	Cause	Remedy
Faulty or missing Lightings	The provided lighting can be missing or not functioning thus not lighting the required areas as required.		Electrical problems. Corrosion. Accident impact. Vandalism.	Repair the electrical issues. Carry out corrosion protection to the areas affected by corrosion. Replace the missing lighting poles complete with fittings.

Missing road signs	Signage should be available to inform the road users about the safe use of the bridge/road.		Vandalism. Impact by vehicles. Wear and tear. Poor quality of materials.	Replace the missing road signs.

2.3.6 Common Defects on Other Structural Components

Common defects on bridge on other bridge structural components, their possible causes and proposed remedial measures are given in Tables 2-12 to 2-19. These defects can occur on the superstructure, sub-structure elements.

Table 2-12: Common defects on pavement/surfacing

Defect	Description	Image	Possible Causes	Remedy
Cracks on the pavement	This refers to cracking on the pavement/surfacing on the deck slab due to excessive loading on the bridge structure.		Stresses caused by overloading.	Spot reconstruction.

Defect	Description	Image	Possible Causes	Remedy
Rutting	It occurs along the wheel path and results from the accumulation of load-induced permanent deformation developed by the pavement layer.		Repeated heavy wheel loading. Pavement depth and material.	Mill and replace with suitable pavement.
Loss of skid resistance	This is loss of sufficient grip/friction needed for traffic movement on the bridge deck. It can be attributed to wear and tear due to traffic whip off and traction forces on tires.		Tear and wear caused by traffic.	Provide a wearing course.

Defect	Description	Image	Possible Causes	Remedy
Siltation	This is the deposition of soil sediments on the pavement where they are undesirable.		Deposition of soil and other solid materials by the road users or surface water. Inadequate drainage system on the bridge.	Regular cleaning of the pavement and drainage.
Potholes	Potholes occur when parts of a road surface gets damaged through cracking or wear forming depressions.		Ingress of water into the pavement. Deterioration of pavement layers. Impact on pavement.	Repair potholes and ruts by patching.

Table 2-13: Common defects on foundations

Defect	Description	Image	Possible Causes	Remedy
Settlement	This is the vertical movement of a foundation. This can be determined by cracks formed on the structure components supported by the foundation.		Inadequate foundation design. Lack of embankment protection.	Provide proper protection of soil around abutments and piers. Underpin the foundation. Replace the foundation.
Lateral movement	This is the horizontal movement of a foundation, this mostly happen when the abutment or pier is constructed on a slope or near river bed.		Inadequate foundation design. Lack of embankment protection.	Provide proper protection of soil around abutments and piers. Underpin the foundation. Replace the foundation.

Defect	Description	Image	Possible Causes	Remedy
Scouring	This occurs when material carried by moving water rub against the foundation material causing tear and wear on the foundation.		River action. Vandalism. Animal action.	Provide suitable slope protection works. Lining the river channel.
Sapping	This is the wearing off of material beneath the foundation of a structure leaving a space between the foundation and the ground.		Scouring by running water.	Provide protective measures e.g. Gabions under the foundation. Lining the river channel. Provision of measures to reduce the erosive action of the river.

Table 2-14: Common defects on bearings

Defect	Description	Image	Possible Causes	Remedy
Breakages	This is the separation of the bearing from its original structure/location.		External forces like overloading and earthquakes.	Partial repair/replacement with a new bearing.
Siltation	This is the accumulation of solid material on the bearings, this may provide conducive environment for corrosion. The debris deposited of the bearings can also hinder the movement of the bearings.		Leaking joints. Sedimentation during flooding. Animal activity.	Regular cleaning of the bearing seat area. Repair the leaking joints.

Defect	Description	Image	Possible Causes	Remedy
Corrosion	This is the slow degradation of the steel bearings where the metal surface is oxidized thus leading to sectional loss.		Exposure to environmental factors that encourage corrosion. Accumulation of silt and/or moisture around the bearing. Deterioration of protective paint.	Prepare surface, apply primer and protective paint. Seal leaking joints. Clean the silt around the bridge seat.
Cracks on the bearing seat mortar.	This are cracks that develop on the mortar provided as the bed for the bearings.		Corrosion. Stress due loading. Tear and wear.	Repair the bearing seat.

Defect	Description	Image	Possible Causes	Remedy
Deformation of elastomeric bearings	Faults include splitting, tearing or cracking of the outer casing and even bulging and distortion.		Deterioration of elastomeric material. Excessive shear force. Separation of composite pad laminations. Uneven compression and twisting of the bearings,	Replace the deformed bearing.
Loose/Missing bolts and nuts	Anchoring bolts may be loose or missing. This may cause excessive movements at the joints.		Vibrations. Vandalism. Inadequate execution.	Tighten loose bolts and nuts. Replace the missing bolts and nuts.

Table 2-15: Common defects on bridge expansion joints

Defect	Description	Image	Possible Causes	Remedy
Fracture	This is the breaking of section(s) of the expansion joint.		Fatigue. Hit or impact by road users. Vandalism. Corrosion of the steel members. Movements of the spans.	Replace the fractured section or whole device. Address the cause of the defect to prevent reoccurrence after repair.
Corrosion	This is the slow degradation of the steel joints where the metal surface is oxidized thus leading to sectional loss.		Worn out protective layer. Exposure to elements in the environment favouring corrosion. Ponding of water near the joint.	Regular cleaning of the joint and pavement. Replacement of joint with similar type or different appropriate type.

Defect	Description	Image	Possible Causes	Remedy
Missing parts	This occurs when some bridge members are lost due to vandalism or failure of bridge members.		Vandalism. Tear and wear. Inadequate execution. Excessive vibrations. Wearing out due to heavy traffic.	Replacement of missing part with similar type or different appropriate type.
Loss of asphaltic joint sealant	This is when the provided joint sealant is lost/damaged.		Inadequate execution. Wearing out due to heavy traffic.	Replacement of the asphaltic joint sealant. Replace the joint with a different type.

Defect	Description	Image	Possible Causes	Remedy
Leaks	This is when water and other unwanted materials leaks through the joint to the elements below.		Wearing of the joint sealant/ drainage membrane. Inadequate execution. Vandalism.	Regular replacement of the joint sealant/ drainage membrane. Replace the joint with a different type that does not allow leakage to the elements below the joint.
Siltation	This is the accumulation of unwanted material on the provided gap that will hinder proper functioning of the joint.		Deposit by traffic/water.	Regular cleaning of the joint using water/air jet.

Table 2-16: Common defects on approach slab

Defect	Description	Image	Possible Causes	Remedy
Cracks	Cracks develop in concrete when stresses in the concrete exceed its strength.		Overloaded traffic loads. Settlement/erosion of materials in the layers below the approach slab. Incorrect design of approach slab.	Replace with a stronger section.
Settlement	This is the evidenced by an uneven transition between the roadway and the bridge deck.		Erosion of materials in the layers below the approach slab. Consolidation of underlying natural foundation soils. Compression of materials directly beneath the approach slab. Settlement of abutment.	Address the cause of the settlement then either replace the approach slab or strengthen it.

Defect	Description	Image	Possible Causes	Remedy
Potholes/ holes	Potholes can occur on approach slabs as voids where pieces of broken concrete dislodge.		Corrosion of rebars. Inadequate cover. Wheel traffic action.	Repair by patching. Provide an approach slab. Replace/strengthen the existing approach slab.

Table 2-17: Common defects on reinforcing members

Defect	Description	Image	Possible Causes	Remedy
Breakages	When subjected to excess loads the reinforcing members break.		Overloading. Inadequate member. Vandalism.	Replace with an adequate member. Strengthen member.
Corrosion	Corrosion leads to substantial reduction in member capacity and is the primary cause of sectional loss in steel members.		Deterioration/lack of protective agent. Water leakages. Siltation.	Prepare surface, apply primer and protective paint. Repair the leaking joints/drainage systems.

Defect	Description	Image	Possible Causes	Remedy
Cracks	Cracks may develop in reinforcing members as a result of shear stresses, flexural moments or fatigue usually occurring at points of high stress concentrations.		Stress. Inadequate member.	Replace with a new member. Strengthen member.
Deformation	Deformation results from accidental/impact loading on reinforcing members.		Overloading.	Replace with a new member.
Missing parts	This occurs when some bridge members are lost.		Inadequate execution. Vandalism. Failure of members. Adverse environmental conditions.	Replace the missing parts.

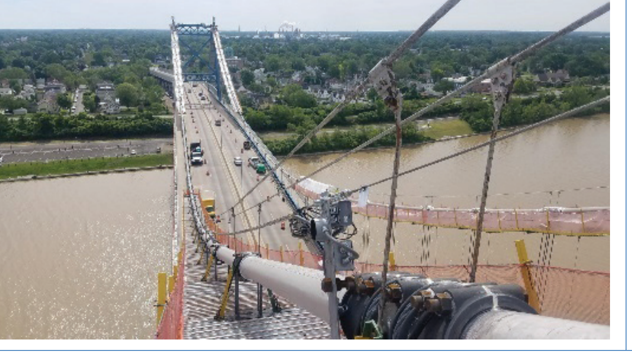
Defect	Description	Image	Possible Causes	Remedy
Delamination	This is the loss of bond between the reinforcing member and the main member.		Inadequate execution. Temperature fluctuations. Differential expansion and contraction of the reinforcing members and the main member.	Repair the bond. Remove and replace/return the reinforcing member.

Table 2-18: Common defects on girder end

Defect	Description	Image	Possible Causes	Remedy
Gap error	The abnormal gap between the girder end and the backwall of an abutment. May be caused by lateral movement of the abutment or inadequate allowance for the movement during construction.		Faulty bearings. Displacement of the abutments or piers. Inadequate execution.	Replace faulty bearings. Underpinning of foundation. Replacement of abutments/piers.

Defect	Description	Image	Possible Causes	Remedy
Accumulation of debris	These are deposits present at the girder end. The accumulated debris limit the movement thus may cause cracking or crushing of the gird-er.		Leaking joints. Poor drainage.	Regular cleaning of the girder ends. Repair the leaking joints/poor drainage.

Table 2-19: Common defects on anchorages

Defect	Description	Image	Possible Causes	Remedy
Breakages	This is the fracture of anchoring material.		Inadequate design/ execution during construction. Overloading. Unplanned natural occurences.	Replace broken anchorage.

Defect	Description	Image	Possible Causes	Remedy
Corrosion	Corrosion leads to substantial reduction in member capacity and is the primary cause of sectional loss in steel members.		Worn out/lack of protective coating.	Prepare surface, apply primer and protective coating.
Missing parts	This is the loss section(s) the anchorages.		Incorrect installation. Vandalism. Excessive vibrations. Corrosion of the connector plates or fasteners, overstressing, cracking or failure of individual fasteners.	Replace the missing parts.

3. BRIDGE MAINTENANCE AND REPAIR

3.1 INTRODUCTION

This section addresses the bridge maintenance and repair approach and methods. It begins with Minor Maintenance followed by Major Maintenance.

The overall aim of bridge maintenance and repair interventions is based on the following principles;

i. Preservation of the investment,

ii. Safety considerations,

iii. Avoidance of catastrophic failure,

iv. Maximization of design life.

3.2 MINOR MAINTENANCE AND REPAIRS

These are activities/interventions undertaken to prolong functionality of the bridge members.

3.2.1 Minor Maintenance and Repairs Method

Minor repair methods carried out on bridges are; cleaning, touch-up painting, epoxy coating on cracks, patching/ plastering, removal and disposal of driftwoods/debris, partial replacement of stone masonry, and partial replacement of gabion wire mesh and stone.

The defects addressed in this section of the manual are listed in Table 3-1.

Table 3-1: Defects addressed in minor maintenance and repairs

Classification	Repair/Strengthening Method	Method	Defects Addressed
Minor Maintenance and Repairs	Maintenance	Cleaning	Siltation Clogging/Obstructions Vegetation Discoloration Accumulation of water
	Maintenance	Removal and Disposal of Driftwoods/Debris	Clogging/Obstructions Vegetation
	Repair	Touch-Up Painting	Paint deterioration Corrosion
	Repair	Epoxy coating on cracks	Cracks

Classification	Repair/Strengthening Method	Method	Defects Addressed
	Repair	Patching/Plastering	Spalling with rebar exposure Spalling Sand streak Honeycombs Delamination Scaling Disintegration
	Repair	Partial Replacement of Stone Masonry	Broken
	Repair	Partial Replacement of Gabion Wire Mesh and Stone	Missing parts Corrosion

3.2.1.1 Cleaning

Definition

This is the removal of debris by hand sweeping, shovel, high-pressure water/air or mechanical devices.

Cleaning of deck, bearings, drains and expansion joint is important before bridge inspection to detect any damage and deterioration of structures. The drainage must be cleaned regularly to prevent clogging of rainwater which may trigger the rusting of structural members.

Cleaning works should be performed on the bridge structure to prevent its deterioration. These works should include the removal of all accumulated foreign materials from the entire bridge such as its deck, sidewalk, kerb, trusses and its web members, lower flanges of beams or girders, expansion joints, bridge seat areas, wind bracing and drains. After cleaning, these areas should be kept free from accumulated sand, gravel, dirt, and other foreign materials.

Cleaning of bridge using water pressure

Cleaning using inspection vehicle

Scope of works

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

i. Surface of Steel Plate

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

ii. Bridge Deck Slab

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

iii. Bridge Substructure

All areas of the under the superstructure should be cleaned, including the bearings, parapet wall, pier caps and concrete diaphragms. This could be executed using high pressure water (blasting) or manual shovelling/sweeping. In case of difficulty in accessing the top of piers, inspection vehicle should be utilized and installed at a higher position.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Water
- Fuel

ii. Required tools/equipment

Cleaning equipment shall consist of hand tools, high pressure water equipment, water bowser, and water pumps with associated delivery hardware necessary to properly flush, clean, and remove all foreign materials from the bridge structure. Other types of cleaning equipment may also be used subject to the approval of the Engineer. Clean water is recommended.

Table 3-2: List of required tools and equipment

No.	Tools	Purpose
1	Hand/Mechanical shovel	Removing debris
2	Ladder/Scaffold/Inspection vehicle	Access to high hard to reach areas
3	Hand/Mechanical Broom	Removing debris
4	Water bowser, generator, water pump, high pressure water equipment	Supply of water for flushing out debris
5	Air blower/compressor	Removing debris
6	Garbage bags	Carting away debris
7	PPE	Protection of workers

Other equipment such as inspection vehicle installed under the bridge, access trucks or movable scaffolding devices may be necessary to access the areas to be cleaned.

iii. Required personnel

Skilled personnel trained by KIHBT and registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Cleaning the surface of steel plate

Steel plate shall be cleaned by washing out chlorides or other chemical deposits known to accelerate corrosion. Washing with high pressure water (blasting) to completely remove all toxic substance is carried out from top to bottom and from end to the center of the steel girder. Steel girders located near the sea are often cleaned especially the bottom surface of lower flanges.

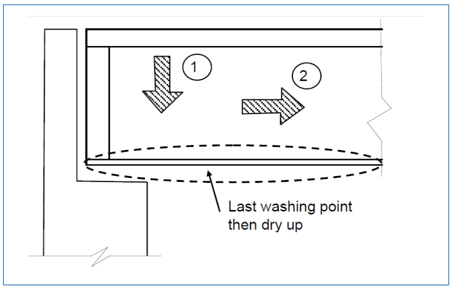


Figure 3-1: Sequence of cleaning girders

ii. Bridge Deck Cleaning

All foreign materials such as dirt, dust, sand, rain water, and moss on concrete surfaces and at the gaps between girders shall also be completely removed manually and then washed using a high-pressure water equipment.

The following areas on the deck should also be carefully cleaned:

- Expansion joints
- Drainage

	
Clogged expansion Joint	*Ponding of water due to poor drainage*

iii. Cleaning of Bridge Substructure

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

Monitoring and Evaluation

- Continuous cleaning,
- Weekly/Daily activity,
- Dust/litter source analysis.

Measurements and Payment

Measurement shall be in square meters of surfaces cleaned and approved.

Payment shall be considered as full compensation for supplying all materials, labour, and equipment and for the performance of all works necessary for the flushing, washing, cleaning, removal and disposal of all foreign materials and debris, in accordance with the contract documents.

3.3.1.2 Touch-Up Painting

Definition

Work under this item shall consist of field touch-up painting on steel at localized areas. This work also includes containment, surface preparation, and collection and storage of all paint debris.

Touch-up painting is done to prevent corrosion. This work only covers painting to small areas where hand and power tool preparation is the only feasible method. Large areas, where sand blast cleaning can be justified, should be painted in accordance with the repainting procedure as described in major maintenance repairs.

Scope of Work

The method of application and the conditions under which paints are applied have a significant effect on the quality and durability of the coating. Standard methods used to apply paints to structural steelwork include application by brush, roller, conventional air spray and airless spray.

Touch-up painting should be partially applied to rusted steel plate as shown below and in Table 3-3.

	
Affected surface area is 10 to 20% in a member	*Affected surface area is 20 to 30% in a member*

Table 3-3: Preparation grades of the surface on corroded steel plate

Grade	Rust Conditions	Working Process	Photograph (After Preparation)
3rd Grade	Corrosion is partially severe on steel surface and coating film is almost visible but partially deteriorated due to corrosion.	Old coating film, rust is removed with scrapper and wire brush, partially revealing the steel texture.	
	Affected surface area is 20 to 30%		
4th Grade	Corrosion is partially visible but not severe. Peeled off coating film is partially visible.	Old coating film, rust is removed with disc grinder, scraper and wire brush.	
	Affected surface area is 10 to 20%		

Note: Affected surface beyond 30% are considered to be under major maintenance covered under section 3.3.2.1 of this manual.

If paint condition is evaluated as 4th Grade "Poor condition," with an affected area of

10 – 20%, aluminum paint shall be applied with similar color shade. If paint condition is evaluated as 3rd Grade or "Poor condition," with an affected area of 20 – 30% and section loss of less than 20%, special anti-corrosion paint shall be applied to prevent further corrosion.

Special anti-corrosion paint systems should be used for galvanised and heavily corroded steel surfaces. Ordinary selected patch paint such as aluminum painting is not suitable for galvanised surfaces.

Required materials, tools/equipment and personnel

i. Required materials

- Aluminium Paint (locally available)
- Thinner
- Anti-corrosion Paint

ii. Required Equipment/Tools

- Power Disk Grinder (Portable type) / Sand Paper
- High Pressure Water Equipment (8.0Mpa, 10.0 liters/min.)
- Portable Generator (3.0 kVA)
- Paint roller (handy type) and Brush
- Scaffolding or Inspection Vehicle

iii. Required personnel

Skilled personnel in paintworks trained by KIHBT and Registered/accredited by NCA.

Preparation Works

- Provide traffic warning signs
- Identify and cordon work area
- Prepare diversion or lane management

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work sequence

i. Scaffolding

Scaffolding should be installed at the side of the structure prior to touch up painting. Movable scaffolding allows movement to any direction, and is commonly used for repainting/touch-up painting for truss-type bridges. Inspection vehicle with scaffolding device can also be utilized at locations where accessibility is difficult, such as for bridges with high elevation or at deep river crossings. Birdcage scaffolding meanwhile is a stationary type built around an abutment and pier or, near a defective area.

Scaffolding can be installed at sites with topographic uneven terrain. Steel pipe scaffolding is popular. Its assembling sequences should comply with manufacture's manual.

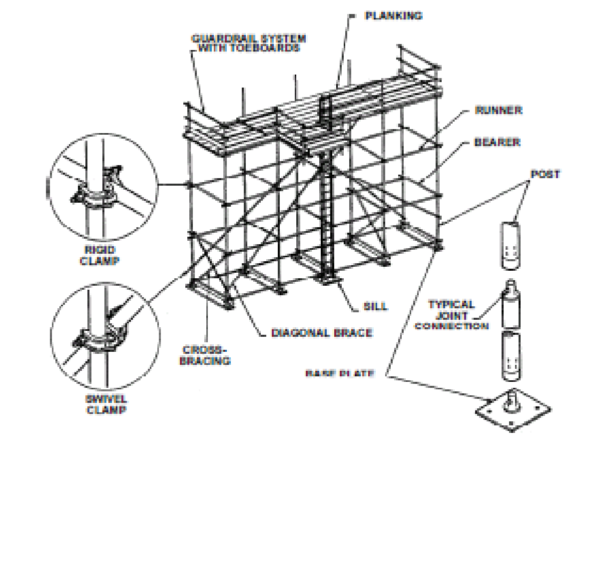


Figure 3-2: Birdcage Scaffolding

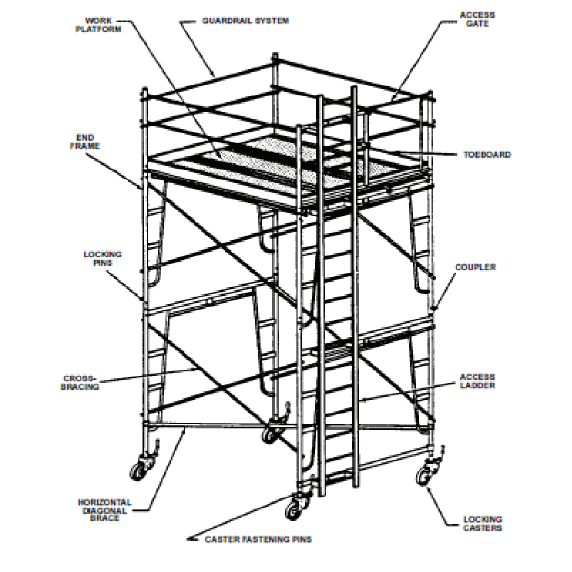


Figure 3-3: Movable Scaffolding

ii. Preparation of the Steel Surface

Depending on the severity of the corrosion on the members, the old coating film rust is removed with disc grinder, scraper or wire brush, partially revealing the steel surface. Sharp ridges and deep narrow grooves or pits shall be removed from the steel surface using power grinder. However, where depth of roughness is less than 0.5 mm adequate and durable paint system can be achieved without multiple coats of surface leveling paint. Each coat shall not be more than the maximum film thickness recommended by the manufacturer.

iii. Touch-up Painting

The paint components shall be mixed properly and applied in accordance with the manufacturer's instructions. The paint shall be applied immediately after surface preparation, preferably within 4 hours on the same day

Paint shall be applied using brush or roller to produce a uniform smooth coat without runs, streaks sags, wrinkles, or other defects.

The minimum total dry film thickness of the system should not be less than 125 micrometers (Aluminum paint) and 500 micrometers (Special anti-corrosion paint).

The total dry film thickness (DFT) of special anti-corrosion paint shall be 500μm (equivalent 1.5kg/m^2) consisting of two layers of coating as follows:

- 1st layer: 250μm
- 2nd layer: 250μm

Monitoring and Evaluation

- Periodic inspection
- Corrosion source analysis

Measurements and Payments

This work will be measured for payment by the actual area in square meters of steel surfaces cleaned, painted and approved.

Payment shall be full compensation for provision of all materials, containers, equipment, tools, labor, services of the technical service advisor, and work incidental for the touch up painting of the structure. There will be no direct payment for the cost of storage or hauling of the paint and other materials to and from the bridge or bridges to be painted, or for the containment, collection, and storage of hazardous or contaminated materials within the work areas. The cost thereof shall be deemed included in the price per square meter.

3.3.1.3 Epoxy Coating on the Crack

Definition

It is protective/preventive measure where epoxy material is applied on concrete structures to seal vertical or overhead (sealing) cracks to prolong the bridge service life.

Scope of Works

This method is generally applied to cracks of widths less than 0.3 mm regardless if crack formation is structural or non-structural, and has no adverse effect on the structure.

In case the slab is leaking, waterproofing should be carried out first on top of the slab before sealing the cracks to avoid ponding of water in the slab.

The repair shall be undertaken as instructed by the Engineer.

Required materials, tools/equipment and personnel

i. Required Materials

- Epoxy Sealant

ii. Required Equipment/Tools

- Brush or Paint Roller

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Preparation of Concrete Surface (cleaning of cracks)

All cracks and surrounding surfaces shall be thoroughly cleaned using clean, oil-free compressed air.

ii. 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.

Monitoring and Evaluation

Monitoring of crack width - The cracks coated with sealant shall be monitored by the Engineer, to determine if the cracks are progressing or not.

Measurements and Payments

Measurement shall be in square meters of the cracks where epoxy coating is applied, as determined and approved by the Engineer.

Payments shall include full compensation for supplying all labor, materials, tools, equipment, and incidental items. This also includes performing all the works involved in preparing the surfaces of existing concrete and application of epoxy coating, as specified on plans and specifications, and as directed by the Engineer.

3.2.1.4 Patching/ Plastering

Definition

This is a method used to repair concrete surfaces that have been damaged by spalling or delamination.

Scope of Works

This repair method requires none or minimum formwork and it is generally applied using a trowel. The repairs are done to deck slab, superstructure and the substructure of the bridge.

Patching thickness is limited to a maximum of 100mm depth of hollow surface but it depends also on the material to be used.

This work involves patching concrete sections that have spalled or delaminated.

There are two types of patching, Type A and Type B.

- Type A is applied to surfaces without exposed rebars and having defective widths of up to 300mm and depth of up to 50mm.

- Type B is applied to surfaces with defective widths between 300mm and 600mm and a depth of up to 100mm.

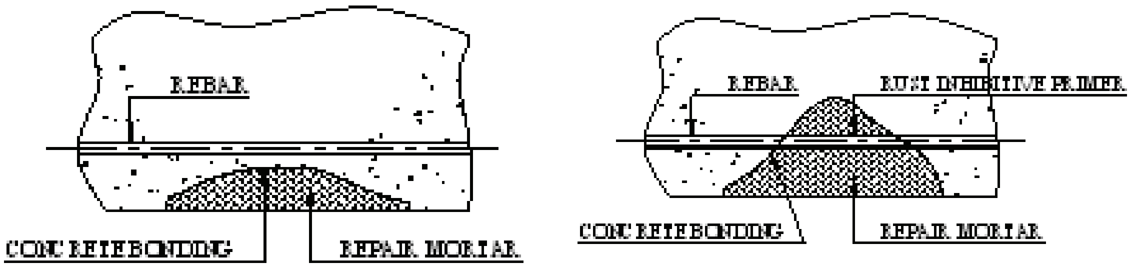


Figure 3-4: Types of patching

Required Materials, Tools/Equipment & Personnel

i. Required Materials

- Portland cement mortar - Pre bagged (pre-packed) materials by supplier, In case of Portland cement, mix design with admixtures (chemicals) shall be shown.
- Ordinary Portland Cement
- Fine aggregate
- Polymer Cement - (PCM Powder, PCM Emulsion)
- Concrete nails
- Bonding agent to concrete (epoxy Bonding)
- Clean water

ii. Required Tools/Equipment

- Chisel
- Portable Generator
- Wire Brush
- Small Hammer
- Mortar Mix Bucket
- Safety Goggles
- Trowel
- Scaffolding or inspection vehicle

iii. Required Personnel

- Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Removal of defective concrete.

All unsound, defective and contaminated concrete should be removed and the edges prepared. If sectional loss (that require additional rebars) caused by corrosion is observed, then the removal of damaged concrete should be extended to the length needed to bond the additional rebars.

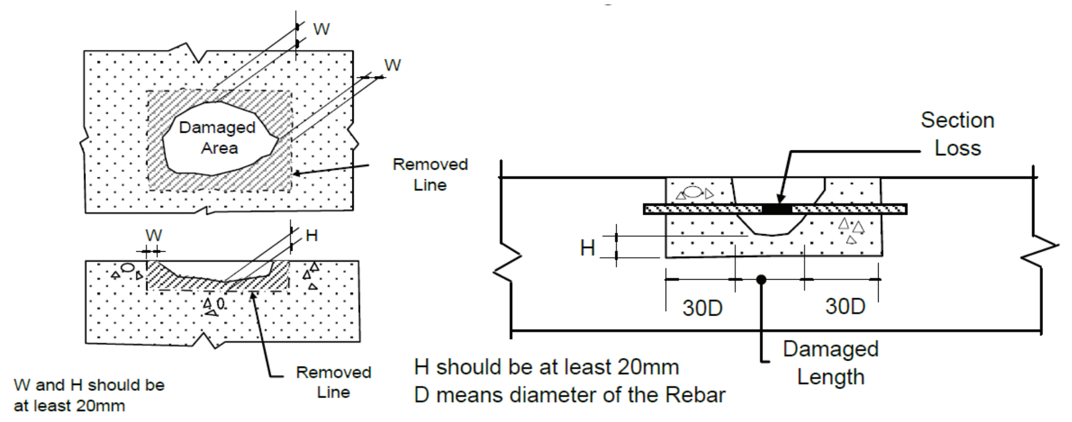


Figure 3-5: Limits of Removal of Damaged Concrete

i. Cleaning of surfaces of concrete and rebar

Loose particles and dust should be removed using high pressure water or vacuum cleaner. The concrete surface to be bonded must be free from dirt, oil, grease or asphalt. Corrosion must be removed before placing the new concrete.

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.

ii. Applying epoxy bonding coats to concrete and rebar

Epoxy bonding coats are applied to clean and dry 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.

iii. 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 compacting 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.

iv. Curing

All types of cement repairs need thorough and continuous curing to gain strength and to minimize drying shrinkage.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be square meter for depth less than 50mm calculated as the area instructed by the Engineer or shall be measured by the cubic meter for depth beyond 50mm calculated as the volume, or as instructed by the Engineer.

Payment shall include full compensation for the removal of deteriorated concrete, surface cleaning and preparation, furnishing and placing of all materials, labour, equipment, tools, as well as construction and removal of formworks and other temporary works necessary to complete the patching works.

3.2.1.5 Removal and Disposal of Driftwoods/Debris

Definition

This work involves the removal of driftwoods/debris around inlets and outlets of structures and disposal to a designated area.

	
Accumulated driftwood around pier	*Driftwoods on the box culvert inlet*

Scope of Works

Driftwoods and debris lodged on the inlets and outlets of structures should be removed at an early stage of routine maintenance otherwise it will become more difficult to dislodge thus increasing the risk of bridge or slope failure. Removal and disposal of driftwoods and debris shall be carried out once a year, or after an occurrence of floods when necessary.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

Fuel

ii. Required Equipment/Tools

Power saw
Scaffoldings/ Inspection vehicle
Axe/Panga
Dump truck
Back hoe
Ropes
Tractor

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

Large driftwoods are cut at the site and properly disposed to a designated disposal area. Burning of driftwoods or debris is permitted within the roads reserve.

Inspection vehicle with scaffolding device can be utilized also for the works.

Monitoring and Evaluation

- Cause analysis.
- Monitor the catchment area.

Measurements and Payment

Measurement shall be lump sum for sites described and approved by the Engineer.

Payment shall include full compensation for cutting, loading, hauling, disposing of driftwoods and cleaning the right of way at each location noted on the plans and for all labour, equipment, tools, and other necessary accessories to complete the work.

3.2.1.6 Partial Replacement of Stone Masonry

Definition

This involves restoration of the missing stones from masonry slope protection.	

Scope of Works

It involves replacement of the damaged/missing masonry slope protection with stone during the early stage of routine maintenance; otherwise, it will become more difficult to repair the damages, increasing the risk of slope failure. The stone patching shall be carried out when necessary.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

Stones
Gravel
Cement

Fine aggregates
Water
Hoop iron
PVC pipes
Damp Proof Course

ii. Required tools/equipment

Trowel
Wheelbarrow
Dump truck
Spades
Mortar mixer
Water bowser

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

The damaged area is replaced by installation of new stone masonry according to alignment and dimensions as shown in the drawings or as directed by the Engineer.

All unsound, imperfect or loose stones and mortar joint, panel, etc. shall be removed. The substrata shall then be compacted as preparation of the base. The slope line shall be carefully prepared at the same level as also shown in the drawings.

Stones shall be laid in full bed of mortar, with joints completely filled with mortar and shoved into place. If necessary to move or shift unit already laid, remove the setting mortar, then clean and apply new fresh mortar for final placement. Coursing and mortar joints must be done as directed by the Engineer. Stone must be laid and anchors must be installed in accordance with the drawings.

Where new stone masonry is placed to the existing masonry wall, joints shall be partially or completely set. Exposed surface of the existing stone masonry shall be cleaned with wire brush and lightly moistened so as to attain best possible bonding with the new work.

Monitoring and Evaluation

- Cause analysis.
- Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be based on square meters.

Payment shall include full compensation for provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.2.1.7 Partial Replacement of Gabion Wire Mesh and Stone

Definition

This is the restoration of damaged section of the gabion wire mesh and/or missing stones.

The gabion mattress protects abutment and pier behind them from the erosive action of water flow. Gabion wire can either be destroyed by strong river flow during rainy season or vandalism.

Scope of Works

Replacement of broken gabion wires should be done at an early stage of routine maintenance otherwise it will be more difficult to repair the damage and the risk of gabion failure will have increased.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

Stones as per the specifications
Wire mesh
Binding wire
Cement
Fine aggregates
Water

ii. Required tools/equipment

Pliers
Hack saw
Wheelbarrow
Dump truck
Spades
Mortar mixer
Water bowser

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

The damaged wire mesh section shall be removed from the gabion boxes. The damaged section of the mesh shall be replaced using similar wire mesh as directed by the Engineer. The gabion box shall be filled with additional stone if required. The stones should have 150mm minimum dimension and 300mm maximum dimension. The sides shall be packed first using large pieces and then the internal using smaller pieces.

The joints in the gabion box shall be stitched together with binder wire. If the Engineer directs, the exposed surfaces of the gabion boxes may be grouted with cement.

Monitoring and Evaluation

- Cause analysis.
- Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be based on square meters for the gabion mesh and cubic metres for the stones.

Payment shall include full compensation for provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.3 MAJOR REPAIRS

These are substantial and extensive interventions aimed at restoring structural integrity, safety and functionality to an existing bridge that has undergone significant damage, deterioration or aging.

3.3.1 Major Repair Methods in Concrete Bridges

Major repair methods in concrete bridges are: epoxy injection, patching/sectional repair, caulking, carbon fibre sheet bonding to deck slab, steel plate bonding, partial deck slab replacement, water proofing on deck slab, fast setting concrete for continued deck slab, protective mortar, protective coating, recasting concrete / grout, carbon fibre sheet/ plate bonding to concrete girder, and jacketing with concrete.

The defects addressed in this section of the manual are listed in Table 3-4.

Table 3-4: Defects addressed in major repair to concrete bridges

Classification	Repair/ Strengthening Method	Method	Defects Addressed
Major Repairs	Repair	Epoxy Injection	Crack Leakage Leaching and staining
	Repair	Patching/ Sectional Repair	Spalling with rebar exposure Spalling Sand streak Honeycombs Delamination Scaling Disintegration Abrasion Cavity
	Repair	Caulking	Crack
	Strengthening	Carbon Fibre Sheet Bonding to Deck Slab	Excessive deformation, deflection/vibrations Fatigue
	Strengthening	Steel Plate Bonding	Excessive deformation, deflection/vibrations Fatigue
	Repair	Partial Deck Slab Replacement	Excessive deformation, deflection/vibrations Fatigue
Major Repairs	Preventive	Water Proofing on Deck Slab	Crack Efflorescence Moisture leaks

Classification	Repair/ Strengthening Method	Method	Defects Addressed
Major Repairs	Repair	Fast Setting Concrete for Continued Deck Slab	Spalling with rebar exposure Spalling Abrasion
	Preventive	Protective Mortar	Chemical attack Carbonation Salt attack Alkali Silica Reaction Surface bubble Sand streak Cold joint Corrosion
	Preventive	Protective Coating	Chemical attack Carbonation Salt attack Alkali Silica Reaction Surface bubble Sand streak Cold joint Corrosion
	Repair	Recasting concrete / Grout	Spalling with rebar exposure Spalling
	Strengthening	Carbon Fibre Sheet/Plate Bonding To Concrete Girder	Excessive deformation, deflection/vibrations Fatigue
	Strengthening	Jacketing With Concrete	Buckling
	Repair	Replacement of member (Section 3.4)	Excessive deformation, deflection/vibrations Buckling

3.3.1.1 Epoxy Injection

Definition

This is an economical method of repairing non-moving cracks in concrete structures and is capable of restoring the concrete to its pre-cracked strength.

Scope of Works

The works include preparation of concrete surface, insertion of pipe fittings, bonding with adhesion, injection of epoxy, curing and conducting performance test.

Required Materials, Tools/Equipment & Personnel

i. Required Materials

- Epoxy Resin
- Sealant
- Injection Port

ii. Required Tools/ Equipment

a. For surface preparation

- Power disc grinder
- Wire brush/Air gun

b. For fixing repair method

- Hand mixer

c. For setting repair material

- Epoxy injection pump/gun

d. Finishing

- Power disc grinder
- Portable generator

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Epoxy may be dangerous when it comes in contact with the skin and if breathed in for a long exposure period.

In Application of the Epoxy, the following precautionary measures should be taken:

1. Wear long sleeved tops and long trousers.
2. Wear shoes and socks since epoxy will drip onto feet.
3. Wear disposable vinyl gloves.
4. Tape over the joint between the gloves and the sleeve if necessary.
5. Take care not to rub the wrist with the dirty fingers of the other hand when removing gloves.

6. Wash any splashes with warm soapy water as soon as possible.
7. Never use solvents.

When sanding, the following precautionary measures should be taken:

1. Never use solvents.
2. Wear long sleeved tops and long trousers and consider wearing coveralls.
3. Wear shoes and socks.
4. Wear a dust mask.
5. Wear a hood or hat and scarf.
6. Wear gloves.
7. Reduce the area of exposed skin to a minimum.
8. Wash dust off skin and hair as soon as convenient.
9. Wash clothing after each exposure.

Maintaining a Clean Work Environment

- Maintain a clean workshop to avoid incidental contact with the epoxy resin. If you have epoxy residue on your gloves, don't touch door handles, light switches, or epoxy containers because you'll probably touch them again when you're not wearing gloves.
- Clean up epoxy spills with a scraper, collecting as much material as possible. Follow up with paper towels.
- Contain large spills with sand, clay, or other inert, absorbent material. DO NOT use sawdust or other fine cellulose materials to absorb hardeners. You may reclaim uncontaminated resin or hardener for use.
- Clean up resin or mix epoxy with acetone, lacquer thinner, or alcohol. Follow all safety warnings on solvent containers.
- DO NOT dispose of hardeners in the trash containing sawdust or other fine cellulose materials—they can spontaneously combust.
- Clean hardener residue with warm, soapy water.
- Pots of curing epoxy can get hot enough to emit hazardous fumes and ignite combustible materials nearby. Place pots of mixed epoxy in a safe and ventilated area, away from works and combustible materials.
- Dispose of the solid epoxy mass only after it has completely cured and cooled.

Work Sequence

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.

i. Cleaning of cracks

All loose debris such as dirt, concrete fine particles and contaminants (oil, grease, etc.) shall be marked out and 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.

ii. Installation of Pipe Fitting

The pipe fittings shall be fixed at intervals along the length of each crack. The spacing of the pipes varies between 150mm to 500 mm, considering the width and depth of crack. The first and last pipe fitting are set at or near the bottom and top, respectively.

iii. Sealing of Cracks at the Surface

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

iv. Fitting of Injector

Connect the terminal of the injector to the pipe fittings.

iv. Injection of Epoxy

Epoxy shall be injected using air-activated epoxy injection guns. 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, epoxy injection is carried out from one end of the crack to the other, in a similar manner.

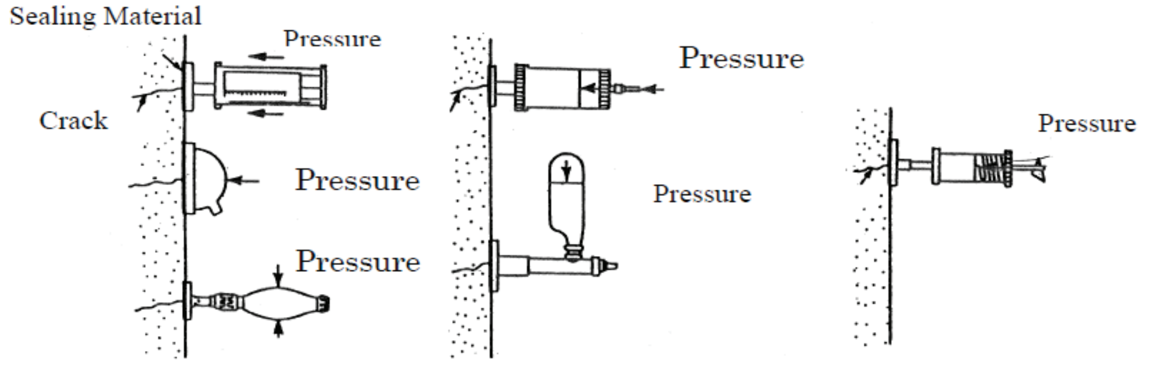


Figure 3-6: Crack Injection Method

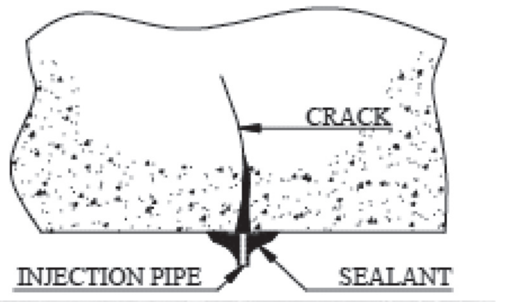


Figure 3-7: Crack Injection Penetration

vi. Curing of Injected Material

After the crack has been sealed, remove the projecting pipe fittings and fill holes with an epoxy patching compound. Surface coating will be applied, if required in the repair process.

vii. Performance test.

Study of the relationship between curing conversion and properties is critical for optimizing the performance of epoxy material. Low Frequency Pulse Velocity Ultrasonic Inspection will determine if the epoxy resin has penetrated the full depth of the crack. If incomplete penetration is revealed by inspection, such conditions shall be reworked

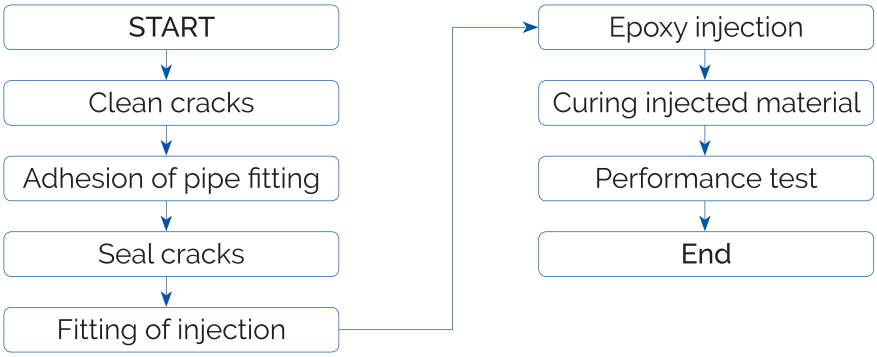


Figure 3-8: Crack injection process

Monitoring & Evaluation

- Performance test.
- Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurement shall be in linear metre (m).

Payment shall include full compensation for the removal of deteriorated concrete, surface cleaning and preparation, furnishing and placing of all materials, labour, equipment, tools, as well as construction and removal of formworks and other temporary works necessary to complete the epoxy injection.

3.3.1.2 Patching/Sectional Repair

Definition

Patch repair is the restoration of small areas where sound concrete is damaged by spalling, scaling, honeycombing or impact.

It is classified into two: Type A and Type B.

Type A is applicable to surfaces without exposed rebars, having defective widths of up to 300 mm and depth up to 50 mm.

Type-B meanwhile is for surfaces with exposed rebars, with defective width between 300 mm and 600 mm, and up to 100 mm depth and shall not to exceed 50% of depth of deck slab.

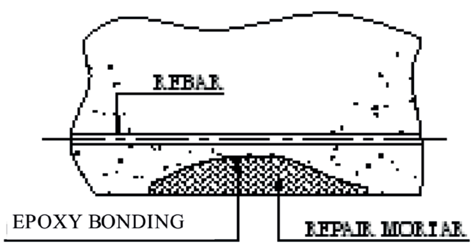


Figure 3-9: Patching Type A

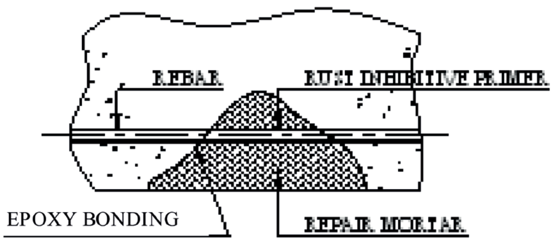


Figure 3-10: Patching Type B

Scope of Works

This method of repair does not require formwork or utilizes minimum formwork. The patch thickness is limited to a maximum depth of 100mm.

Depending on the type of patching, location and extent of damage, the patching repairs may be composed of either Portland cement mortars or polymer cement mortar.

Required materials, tools/equipment and personnel

i. Required Material

Portland Cement Mortar	**Polymer Cement Mortar (PCM)**
– Pre-mixed and pre-bagged Portland cement mortar – Water – Concrete nail – Bonding agent to concrete (Epoxy Bonding)	– PCM powder – PCM Emulsion – Concrete Nail – Bonding Agent to Concrete (Epoxy Bonding)

ii. Required Equipment/Tools

Chisel
Portable generator
Wire brush
Small hammer
Mortar mixer
Mortar mix bucket
Safety goggles
Trowel
Scaffolding or Inspection vehicle

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

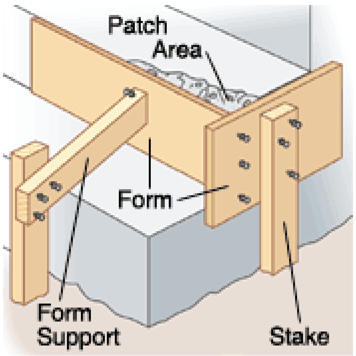
ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

i. Remove loose debris

Using a small sledge hammer and chisel, remove all damaged concrete at corner edges of area to be repaired then use a wire brush to remove the loose debris.	

ii. Furnishing Formwork

If necessary, provide formwork around the damaged concrete to straighten the edges of the damaged section.	

iii. Coating Bonding Agent or Setting Nail

In order for the patch material to adhere, bonding agent is applied to the damaged area. Concrete nails/bids can also be set to reinforce the repair. If the rebar is exposed, anticorrosion agent coating on the bar surface should be applied prior to patching.	

Placing cement mortar

Use a trowel to spread fresh mortar over the area, covering the concrete nails driven halfway in the old concrete. Smoothen and level the mortar with a 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 smoothened using a trowel or broom finished.	Horizontal finish:  Vertical finish: 

iv. 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.

The method and number of curing days is as per the materials specifications.

Monitoring and Evaluation

Monitoring of patched section by the Engineer.

Measurements and Payments

Measurement shall be square meter for depth less than 50mm calculated as the area instructed by the Engineer or shall be measured by the cubic meter for depth beyond 50mm calculated as the volume, or as instructed by the Engineer.

Payment shall include full compensation for the removal of deteriorated concrete, surface cleaning and preparation, furnishing and placing of all materials, labour, equipment, tools, as well as construction and removal of formworks and other temporary works necessary to complete the patching works.

Definition

This method of repair involves the treating of active cracks as movement joint by repairing them with flexible sealants.

3.3.1.3 Caulking

Definition

This method entails repairing of active cracks as movement joint with flexible sealants.

Scope of Work

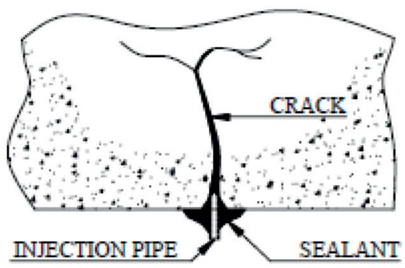
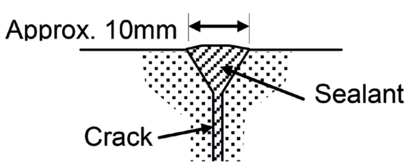
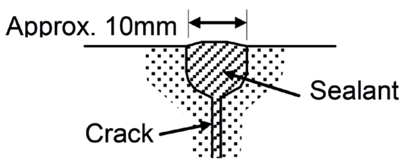
The sealant is generally installed in a wide recess cut along the crack. The dimension of the recess (width and depth) depends on the total crack movement and the cyclic movement capability of the joint sealant used. For selection of sealant material, crack movement should be calculated taking into account the applied loads, shrinkage and temperature variations.	
 **(V-Type)**	 **(U-Type)**

Figure 3-11: Types of Caulking

Required Materials, Tools/Equipment & Personnel

i. Required Materials

- Epoxy grout
- Sealant
- Carbon fibre sheet
- Injection pipe

ii. Required Equipment and Tools

- Grout Injection Pump or Caulking Gun
- Power Disc Grinder/Cutter
- Portable Generator
- Brush
- Set of Injection Tools
- Ladder/hydraulic lift

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Cleaning of cracks.

All loose debris such as dirt, fine concrete particles and contaminants should be removed from the crack using high-pressure water or special and effective solvent. The water and solvent should then be removed with the compressed air and allow adequate time for drying.

ii. Preparation for caulking

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

iii. 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.

iv. Injecting the Epoxy Grout

Epoxy grout 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.

v. 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 fibre sheet will be applied, the portions with sealant and tip of cut pipe should be grinded to form a smooth surface.

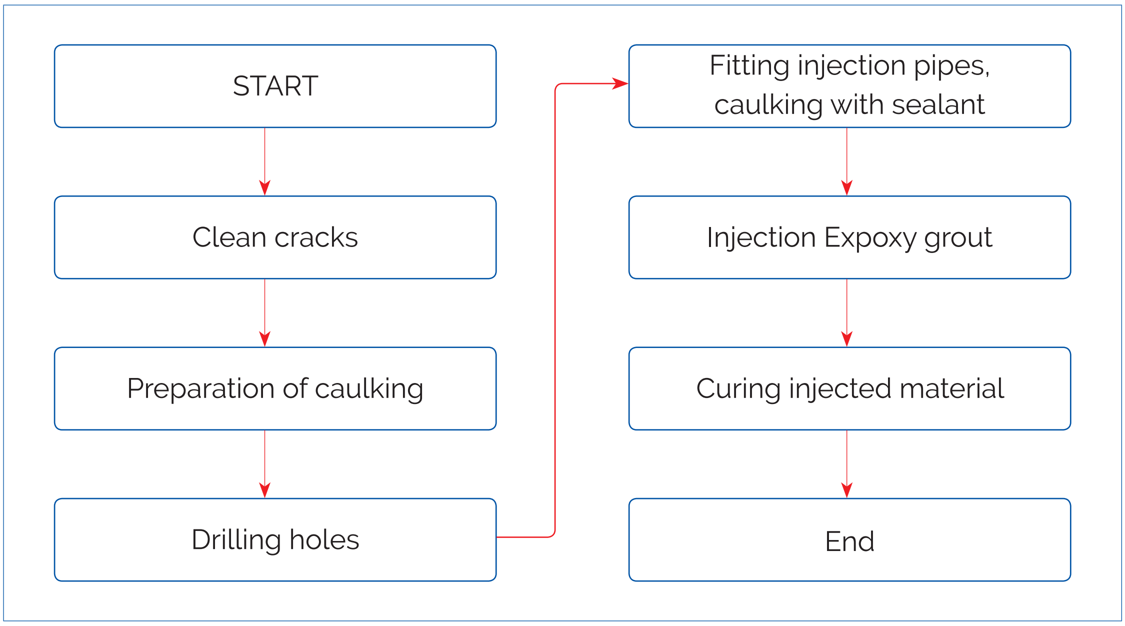


Figure 3-12: Caulking repair process

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be in linear meters (m).
Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for caulking repair as detailed in plans and specifications.

3.3.1.4 Carbon Fibre Sheet Bonding to Deck Slab

Definition

This is a composite where a polymer matrix is reinforced with many relatively thin and long fibres. The carbon fibre sheet is used to enhance the load bearing capacity of the concrete deck slab and extend its service life.

Scope of Works

The works shall consist of furnishing and installing two arrangement types of Carbon Fiber Sheets 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.

In case the slab is leaking, waterproofing should be carried out first on top of the slab before strengthening the deck slab with CFS.

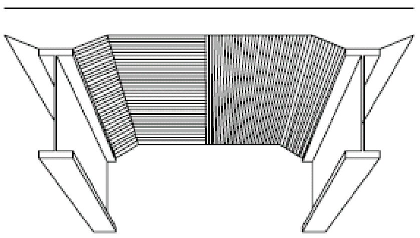
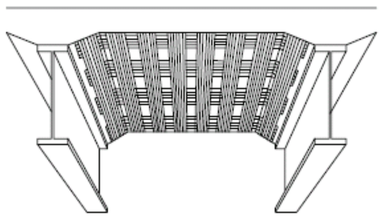
<table>
<tr><td></td><td></td></tr>
<tr><td>Continuous Arrangement</td><td>Grid Arrangement</td></tr>
</table>

Figure 3-13: Arrangement types of carbon fibre sheet

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Carbon Fiber Products
- CFS (Recommended Strap Type)
- Epoxy Materials
- Epoxy primer
- Epoxy putty
- Epoxy resin adhesive

ii. Required Equipment

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

iii. Required personnel

- Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Preparation of concrete	
The concrete surface is cleaned and smoothened using a disc grinder or abrasive sandblasting.	
ii. Application of primer	
The concrete surface is then coated with a primer resin to increase the strength of the surface and improve its bonding with the CFS.	
iii. Adjustment of Unevenness with Putty	
Any concave, pores, gaps on the concrete surface must be smoothened using epoxy putty	

iv. Application of Epoxy Resin for Undercoat

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

v. Installation of Longitudinal Layer CFS

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

Press the carbon fibre sheet by using plastic roller starting from the centre toward the edge.

vi. Installation of Transversal Layer CFS

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

Press the carbon fibre sheet by using plastic roller starting from the centre toward the edge.

vii. Squeezing out of Entrapped Air

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

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

Monitoring and Evaluation

- Performance test.
- Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in square metres.

Payment shall be full compensation for provision for all materials, equipment, supervision, related services necessary for strengthening the concrete as detailed in plans and specifications.

3.3.1.5 Steel Plate Bonding

Definition

The technique of bonding steel plates to concrete deck slab/girder using epoxy adhesives on bridges to enhance their load carrying capacity.

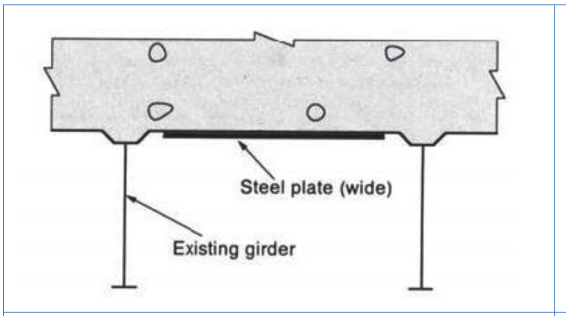
Scope of Works

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. The 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.

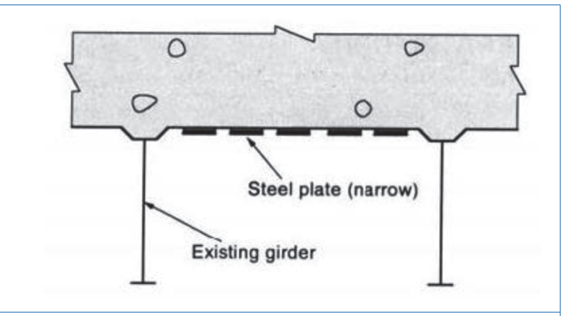
The steel plate bonding for deck slab has two types, namely, wide plate and narrow plate. Wide plates are used for strengthening the slab in both the main reinforcing bar and distribution bar directions. Narrow plates are used for strengthening the slab in one direction only. The bonding of steel for deck slab is achieved using either the ***injection method*** or ***pressure attachment method***.

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

Steel plate bonding for girders 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***.



Wide Plate Type



Narrow Plate Type

Figure 3-14: Types of steel plate bonding

Required Materials, Tools/ Equipment and Personnel

i. Required Materials

Injection Method

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

Pressure Attaching Method

- Steel Plate
- Primer (Epoxy Base)
- Epoxy Resin Adhesive
- Epoxy Sealant
- Anchor Bolts
- Wood and Angle for Fitting

ii. 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

iii. Required personnel

- Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. 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.

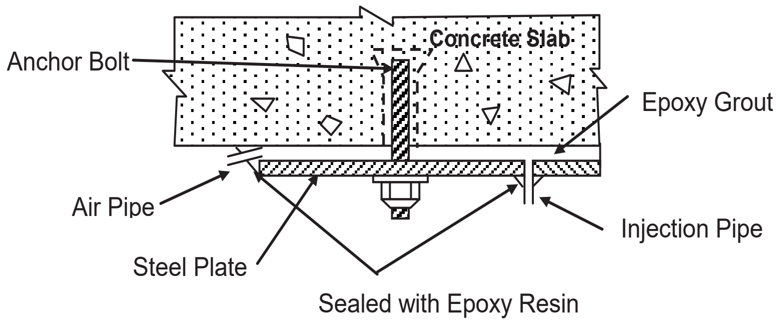
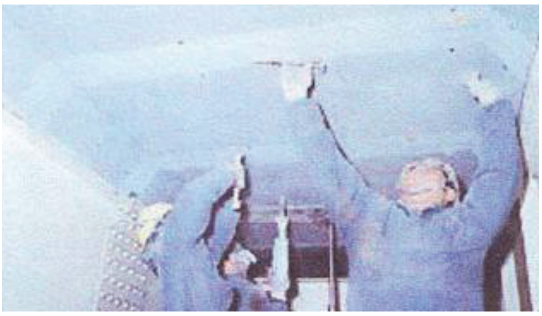


Figure 3-15: Detail of injection method sealing with epoxy adhesive

(1) Surface preparation	
The bottom surface of slab to be bonded with steel plate shall be cleaned the steel surface must also be completely free of any mill scale, rust, grease or other contaminants. Any surface irregularities shall be levelled using a disc grinder.	
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 of 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 putty as well as the area surrounding the injection holes.	
(4) Injection of epoxy resin	
Mixing is continuously done during the injection. Inject the epoxy grout 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.	

ii. 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.

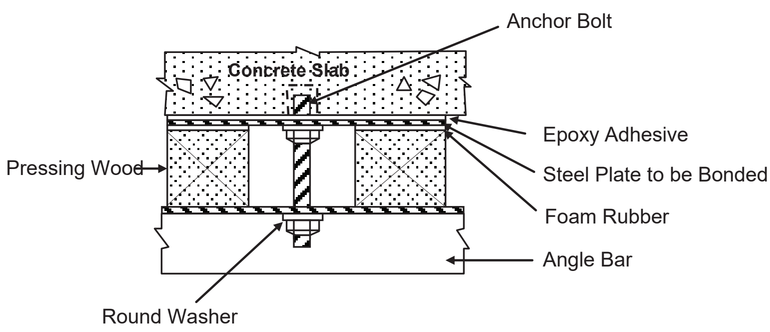


Figure 3-16: Detail of pressure attaching method by anchor bolts

(1) Surface preparation	
The bottom surface of slab/girder to be bonded with steel plate shall be cleaned the steel surface must also be completely free of any mill scale, rust, grease or other contaminants.	
Any surface irregularities shall be levelled using a disc grinder. 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 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/girder, and pressed using the anchor bolts wedging off with the temporary stiff wood and angular.	

(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.	

Monitoring and Evaluation

- Performance test.
- Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in square metres.
Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for strengthening the concrete as detailed in plans and specifications.

3.3.1.6 Partial Deck Slab Replacement

Definition

Partial replacement of slab is carried out to replace a portion of the concrete that has been severely damaged and spalling at either pavement joints or at mid slab locations. If damaged portion is not removed, as shown in Photo 3-1, 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.

Scope of Works

Partial Deck Slab Replacement involves removal of the deteriorated concrete, cleaning up the underlying layer and reinforcement, setting up formwork and placement of new concrete.

Partial Depth is similar to the re-casting method for repair to girder and substructure. In this manual, the first method (Full Depth), which is replacement of concrete by defect section or panel, is recommended for repair of severely damaged deck slab.

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

Photo 3-1: Severely Damaged Deck Slab

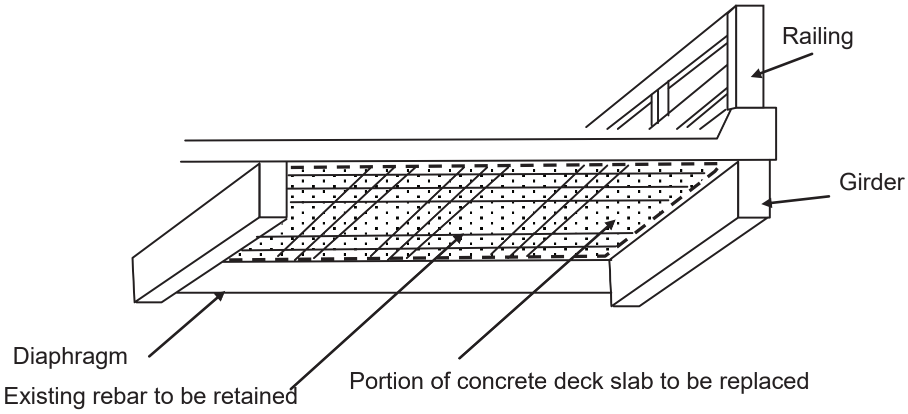


Figure 3-18: Severely Damaged Deck Slab

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Portland cement/Fast setting mortar
- Aggregates
- Water
- Silica fume
- Rebar (Reinforcing bar, use minimum 16mm diameter)
- Epoxy resin (Bonding coat to concrete)
- Anti-corrosion primer (Bonding coat to rebar)

ii. Required Tools/Equipment

- Sawing equipment
- High pressure water equipment
- Handy concrete breaker or Jackhammer
- Handy power chisel
- Concrete mixer
- Vibrator

- Trowelling tools
- Air compressor
- Water bowser
- Scaffolding
- Formwork

iii. Required personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Support of existing Structure

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

ii. Removal of deck slab concrete

All deteriorated or damaged concrete surface are cut by saw, forming vertical edges, and then removed using breaker and chisel. Rebar 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.

iii. 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 formwork and placing the new concrete. Concrete should be placed immediately after application of the bonding coat to the faces of the old concrete and rebar.

iv. Setting of formworks

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

v. Cutting of existing rebar and addition of new rebar

Deteriorated old rebar 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 rebar shall be tied to the existing bars using tie wires or by welding.

vi. 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

vii. 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 days compressive strength of the new concrete is achieved.

Monitoring and Evaluation

- Performance test.
- Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be based on cubic metres (m^3) for replaced concrete on the deck, rebars will be measured in tonnes (Tons) and formwork shall be measured in square metres (m^2).

Payment shall include full compensation for the replaced concrete on the deck, provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.3.1.7 Water Proofing on Deck Slab

Definition

Concrete water proofing is the application of an impervious layer on concrete. This layer prevents water from penetrating such that it remains relatively unaffected by water.

Concrete is naturally alkaline and therefore protects the steel. However, the effect of its contact with water and corrosive materials alters 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 protective measure against this destructive damage is through installation of a waterproofing membrane on the deck slab.

Scope of Works

The bridge deck waterproofing includes the sheet system and liquid (Membrane) system. The liquid system involves a simple procedure similar to painting. In this repair manual, two types of liquid system are introduced, namely, Rubberized Membrane Type and Asphalt compound membrane type.

The rubberized type waterproof membrane mainly consists of chloroprene rubber. Meanwhile, the asphalt compound type consists of asphalt mixed with special rubber, which is melted in a mechanically agitated heating process.

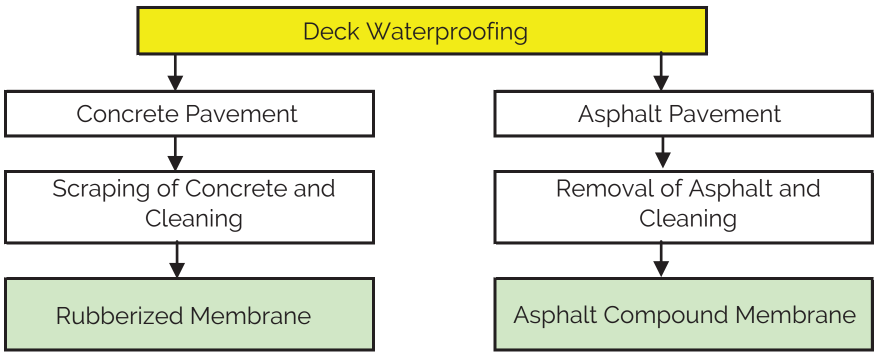


Figure 3-18: Flowchart for selection of waterproofing

Photo 3-2: Rubberized Membrane Type

Photo 3-3: Asphalt Compound

Required Materials, Tools/Equipment & Personnel

i. Required materials

Rubberized Membrane

- Primer (1st layer)
- Rubberized membrane (2nd layer , 3rd layer and 4th layer)
- Tack coat (Finish coat)

Asphalt Compound Membrane

- Primer
- Asphalt compound membrane
- Silica sand No.4

ii. Required Tools/Equipment

Rubberized Membrane

- Paint roller

Asphalt Compound Membrane

- Kettle with heater
- Roller brush or hairbrush
- Rubber brush

iii. Required Personnel

Skilled personnel works trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work sequence

(1) Rubberized Membrane

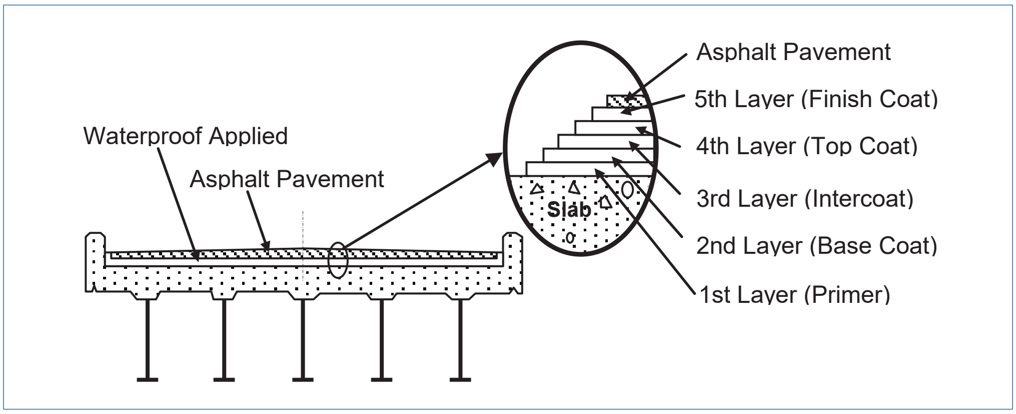


Figure 3-19: Layer composition for rubberized membrane

(i) Preparation of deck surface	**(ii) 1st Layer (Primer)**
	
Deck surface shall be cleaned by 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	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).
(iii) 2nd layer (base coat)	**(iv) 3rd layer (intercoat)**
	
Base coat as 2nd layer is a rubberized membrane which is applied on the primer using a roller brush, to form a uniform film with consistent thickness (Approximately 0.4 kg/m²)	Intercoat, the 3rd layer, is a rubberized membrane which is applied on the base coat using roller brush, to form a uniform film with equal thickness (Approximately 0.4 kg/m²)

(V) 4th Layer (Top Coat)	(VI) 5th layer (Tack coat)
	
Top Coat, the 4th layer, is a rubberized membrane applied on the intercoat using roller brush to form a uniform film with equal thickness (Approximately 0.4 kg/m²)	Tack Coat, 5th layer, is an asphalt base coating which is applied on the top coat using a roller brush, for better bonding to asphalt pavement. (Approximately 0.1 kg/m²)

(VII) Asphalt pavement

For adequate protection of the waterproofing membrane, the application of the asphalt road surface is carried out after tack coat is cured.

(2) Asphalt Compound Membrane

Asphalt Compound membrane is composed of layers as shown in Figure 3-20.

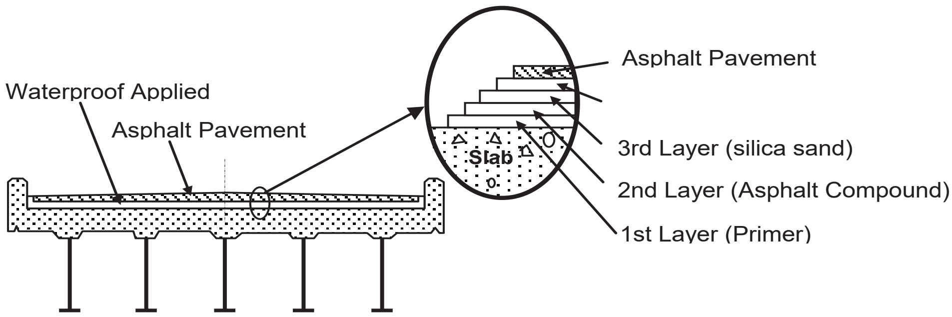


Figure 3-20: Layer composition of asphalt compound membrane

i. Preparation of deck 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.

ii. 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).

iii. 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.

iv. 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 0.7 kg/m^2). The laying operation shall eliminate discontinuities in the membrane.

v. 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 3.0 kg/m². (Refer to the Manufacture's instruction).

vi. Curing/Asphalt Pavement

Curing must 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

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in square meters (m²).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for waterproofing the deck slab as detailed in plans and specifications.

3.3.1.8 Fast Setting Concrete for Continued Deck Slab

Definition

Fast setting concrete is a rapid set concrete that is a blend of ordinary and specialized cements, high quality graded aggregates and a unique combination of polymers and admixtures, and is used in continued deck slab connections where reinforced concrete deck girders (RCDG) bridges are to be constructed.

Continued deck slab is used to connect the deck slabs only.

Scope of Works

Where multiple RCDG bridges are designed as simple span with gaps between the spans, strengthening for stability of the structure will be required. Continued deck slab method is used for connection and to reduce the bridge maintenance work, and to maintain good performance.

The working stress of the main girder is still the same as in original design of simple span girder, because the stiffness of deck slab is very small compared to the stiffness of main girder. It is important to consider that cost of continued deck slab is less than the cost of the continued girders.

Additional rebars of longitudinal direction are required for continued deck slab. Additional rebars are placed at bottom side and upper side of slab.

If the deck slab is required to replace by half-lane at a time, additional rebar of transverse direction should be installed for connection each half-lane. Rebar coupler is very useful in connection of each rebar. The end of the additional transverse rebar should be threaded for connection of coupler. During repair works, traffic control must be maintained.

Threaded rebar and rebar coupler are fabricated in a machine shop. Material of rebar coupler is high carbon steel.

Required Materials, Tools/Equipment & Personnel

i. Required material

- Cement
- Aggregates
- Rapid hardener admixture
- Clean water
- Epoxy Resin (Bonding coat to concrete)
- Special anti-corrosion Primer (Bonding coat to rebar)
- Rebars
- Couplers

ii. Required Tools/ Equipment

- Sawing equipment
- High pressure water equipment
- Handy concrete breaker or jackhammer
- Handy power chisel
- Electric mixer with steel blade
- Water container
- Generator
- Hydraulic pump system
- Brush

iii. Required Personnel

- Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Removal of defective deck slab concrete

Defective 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.

ii. Setting of formworks

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

iii. Addition of longitudinal/Transverse rebar

Longitudinal and transverse rebar to be provided shall be of same or bigger diameter than the existing rebar and should also consider the current loading condition.

Spacing of rebar should be less than 150mm for durability and to avoid occurrence of bending cracks. Length of rebar should be around 1.4m for sufficient connection of each deck slab. For instance, if diameter of additional rebar to be used is 16mm, length of overlapping should be secured 640mm (16mm × 40 times) on each deck slab.

Additional rebar of transverse direction should be connected by rebar coupler. The end of the transverse rebar should be threaded for connection of coupler. The new rebar shall be tied to the existing bars using tie wires or by welding.

iv. Clean up inside formwork

After placement of additional rebars and form work is completed, clean up inside form using vacuum cleaner.	

v. *Apply epoxy resin to existing concrete surface for proper bonding to fast-setting mortar*

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

vi. Wet the formwork

After cleaning inside form, water should be spread to keep wet condition prior to placing mortar.

vii. Mix with water

The material consists of special cement of pre-mixed type and sand for fast setting and non-shrink performance. According to the instruction by the manufacturer, amount of water and method of mixing shall be well organized.

viii. Pour from lower side to upper position

Fast setting mortar is very flowable. Vibrator should not be used for spreading. A Sequence of placing should be started from lower position to upper position in one direction. If a mass of mortar like lump is found during placing the mortar, it should be immediately remixed. It is a sign of insufficient mixing.

ix. Finishing of surface, curing

After placing 1m length of fast-setting mortar, finishing of the surface should be started. Finish of unformed surfaces should be done by broom, wood float, or steel trowel to match the adjacent existing concrete. Ensure continuous curing after 4 hours of placing	

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in cubic meter (m^3).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for provision of fast setting mortar for continued deck slab as detailed in plans and specifications.

3.3.1.9 Protective Mortar

Definition

It is mortar made from polymer cement with lithium nitrate which is effective against chloride ions.

Scope of Works

The work involves application of protective mortar on concrete member susceptible to salt attack. Bridges located less than one (1) km from coastline are prone to deterioration of concrete members by salt attack.

There are two (2) options used in applying protective mortar:

- Apply three (3) coats of protective mortar to surface of concrete member with severely deteriorated areas and/or repaired area.
- Apply one (1) of protective mortar to surface of concrete member for preventive maintenance.

Protective mortar applied on deck slab bottom surface

Protective mortar applied on patching surface

Required Materials, Tools/Equipment & Personnel

i. Required Material

- Polymer cement powder with lithium nitrite
- Emulsion made of lithium nitrite and adhesive

ii. Required Tools/Equipment

- Power disk grinder/cutter
- Portable generator
- Trowel
- Brush/Roller

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

. Surface preparation

Entire surface of coating area should be cleaned by using cup wire brush and/or disc sander

ii. Keep dry condition and avoid sunshine

Always stockpile PCM with Lithium Nitrite powder in dry condition and avoid sun-shine or direct sunlight.

iii. Weigh PCM with Lithium Nitrite

PCM with Lithium consists of Lithium Ni-trite and premix type non-shrink mortar. Measure one (1) kg of powder by digital weigh scale with less than one (1) gram margin of error.

iv. Weighp the emulsion

Emulsion consists of Lithium Nitrite and adhesive. Measurements shall be kept accurate by digital weigh scale with less than one (1) gram margin of error.

v. Mix powder and emulsion

One (1) kg of powder and 180g of emulsion shall be mixed by hand. Use rubber gloves. During mixing, do not add water.	

vi. Application of PCM with Lithium Nitrite

Apply and spread PCM with Lithium Nitrite on surface to be patched using trowel and/or brush.	

vii. Curing of PCM with Lithium Nitrite

Spray water on patched surface for 3 days continuously.	

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be area in square metres (m^2).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for application of protective mortar as detailed in plans and specifications.

3.3.1.10 Protective Coating

Definition

A protective coating is a layer of material applied to the surface of another material with the intent of inhibiting or preventing corrosion. A protective coating may be metallic or non-metallic. Commonly used materials in non-metallic protective coatings include polymers, epoxies and polyurethanes. Materials used for metallic protective coatings include zinc, aluminium and chromium.

Scope of Works

This method is applied to the deck slab, superstructure and the substructure. When bridge members are affected by carbonation, it is recommended that protective coating be applied as preventive maintenance.

Protective coating made from acryl urethane-based coating is effective against Carbon (iv) oxide, weather/UV rays, chemical and oil damage.

After repairing damage due to carbonation, protective coating shall be applied on the concrete member.

Required Materials, Tools/Equipment & Personnel

i. Required material

- Base Resin
- Hardener

ii. Required Tools/Equipment

- Power Disc Grinder/Cutter
- Portable Generator
- Paint Roller and Paint Brush

iii. Required personnel

Skilled personnel trained by KIHBT and registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

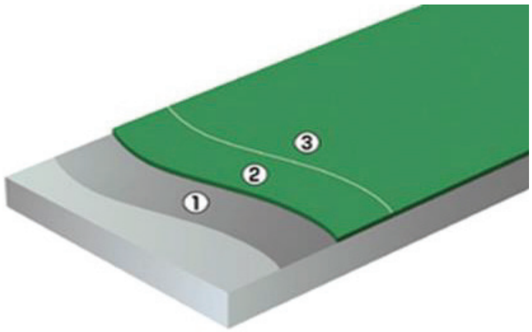
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Surface preparation

Entire surface of coating area should be cleaned by using cup wire brush or disc sander	

ii. Mixing Acryl Urethane protective coating materials

Acryl urethane-based coating is characterized by its resistance to weather/UV, chemicals and oil necessary for the protection of steel and concrete structures. The Base Resin and Hardener are mixed at a ratio by weight of 4:1, respectively.	

iii. Application of protective coating.

Acryl Urethane Protective Coating is applied by roller and/or brush on surface to be coated. Interval time between application of first layer and second layer is minimum 3 hours for next coating. Coating is normally applied for 1 to 3 coats.	

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.p

Measurements and Payments

Measurement shall be in square meters (m^2).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for provision of protective coating as detailed in plans and specifications.

3.3.1.11 Recasting concrete / Grout

Definition

This refers to any replacing, restoring, or renewing of concrete or concrete surfaces after initial placement.

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 admixture added.

Considering the position and scale of damage, the application of the recasting concrete and grout are classified according to the formwork types, such as the "Envelope Type" and "Mail Box Type,"

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 with due consideration to cost performance.

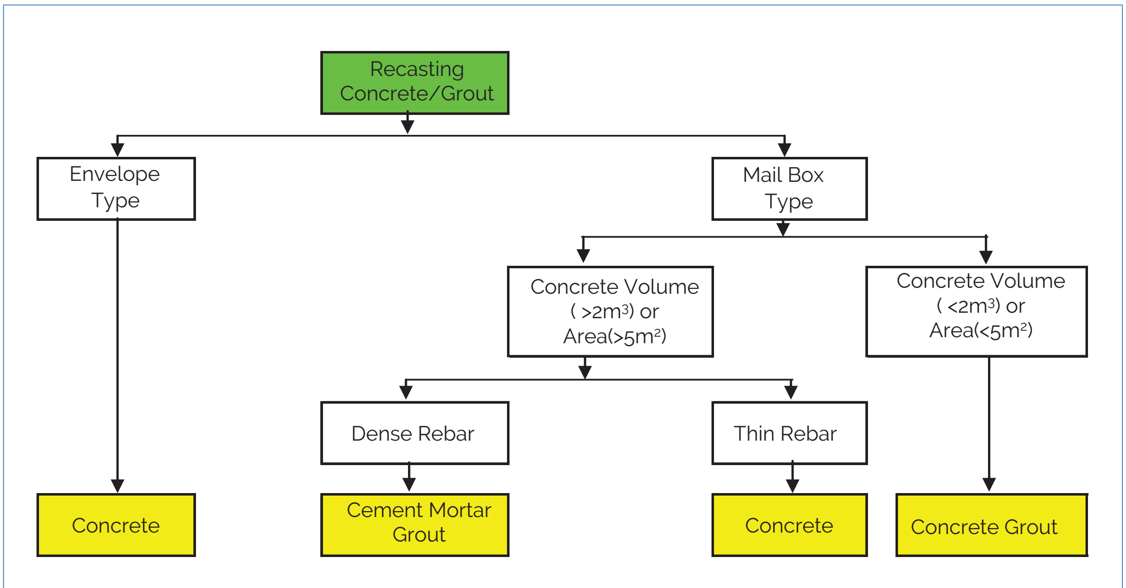
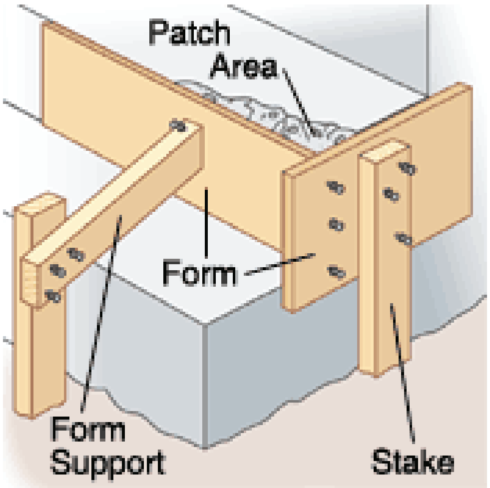
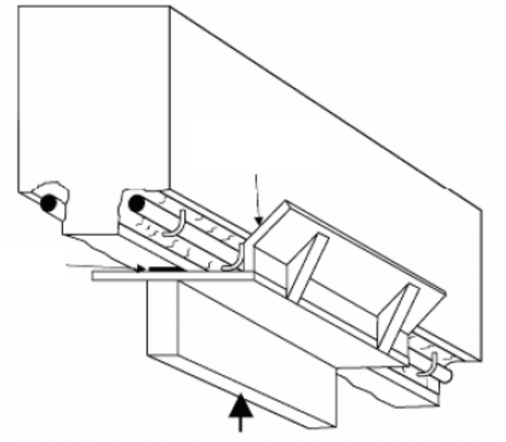


Figure 3-21: Flowchart of selecting material for recasting



Envelope Type



Mail Box Type

Figure 3-22: Types of formwork for recasting

Scope of Works

Recasting 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 rebar. Where concrete placing by vibration is a problem, grout and free flowing self-compacting concrete should be used to minimize the vibration required.

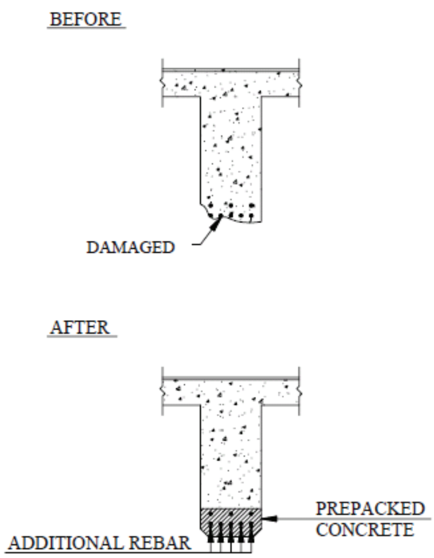


Figure 3-23: Recasting concrete illustration

Required Materials, Tools/Equipment and Personnel

i. Required Material

- Admixtures for consistency
- Reinforcing steel bars

- Bonding coat
- Anti-Corrosion Primer

ii. Required Tools/Equipment

- Formwork – Timber / Medium Density Fibreboard (MDF) and assorted fittings
- Sawing Equipment
- High Pressure Water equipment
- Handy Concrete Breaker or jackhammer
- Handy power Chisel
- Concrete Mixer 30 liters
- Mortar Mixer with Pump (For Mortar)
- Concrete – Cement, Sand and Aggregates
- Concrete Hoisting equipment
- Vibrator
- Trowelling tools

iii. Required personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

The work sequence for cement mortar grout involves concrete mixing, pouring and curing.

i. Removal of girder concrete

All deteriorated or damaged concrete are cut using a saw to form the vertical edges, and then removed using a breaker and chisel. Rebars are examined for any 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.

ii. Cutting of deteriorated rebar and adding new rebar

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, taking into consideration the existing loading condition of the structrue. The lap length is calculated as 30 times the new rebar diameter. The new rebar shall be tied to the existing bars using tie wires or by welding.

iii. Preparation of old concrete and rebar

A suitable bonding agent for concrete and reinforcement should be selected taking into consideration limited working time available for fixing the formwork 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.

iv. Setting formworks.

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

v. Mixing of mortar

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

vi. 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.

vii. 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 days compressive strength of the new concrete is achieved.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurements shall be in tonnes of steel, cubic meters of concrete and square meters of formwork used.

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for recasting concrete as detailed in plans and specifications.

3.3.1.12 Carbon Fibre Sheet/Plate Bonding To Concrete Girder

Definition

Carbon fibre possesses a high tensile strength, higher modulus of elasticity and it is considered an alternative for strengthening bridge girders by increasing its load bearing capacity. It may be used in form of Carbon Fibre Sheet (CFS) or Carbon Fibre Plate (CFP).

Scope of Works

CFS/CFP for reinforced concrete girder repair and strengthening systems are combination of carbon fibre 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. The role of the resin is to serve as an adhesive bond to the concrete surface and facilitate the transfer of stresses to and from the CFS/CFP.

As shown in Figure 3-24, the section of L/4 in span from both ends is applied with CFS as protection against shear cracks (Photo 3-4) while the centre section of L/2 in span is applied with CFP for protection against flexural cracks (Photo 3-5) caused by live load, where L is the effective span length.

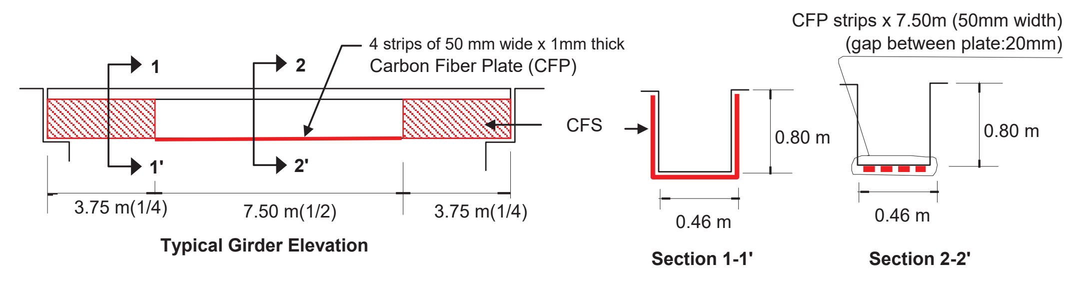
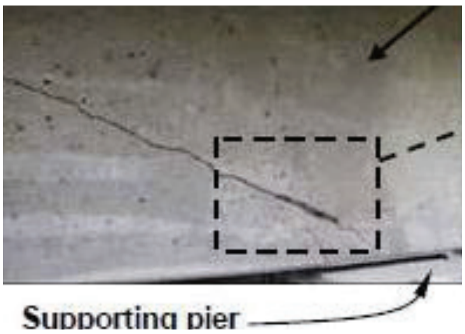


Figure 3-24: Arrangement of Carbon Fibre Sheet/Plate



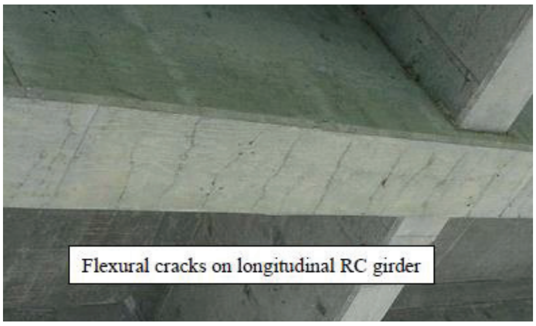


Photo 3-4: Shear cracks at both ends	Photo 3-5: Flexural cracks at the center portion

Required Materials, Tools/Equipment and Personnel

i. Required Material

- Carbon Fiber Products
- Carbon fiber sheet
- Carbon fiber sheet strip
- Carbon fiber plate
- Epoxy Materials
- Epoxy primer
- Epoxy putty
- Epoxy resin

ii. Required Tools/Equipment

- Abrasive sandblaster
- Air compressor
- Disc grinder
- Portable generator

- Paint roller/brush
- Applicator

iii. Required personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

A. For CFS

i. Preparation of concrete surface

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.	

ii. Application of primer

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

iii. Adjustment of unevenness with putty

Any concave, pores, gaps on the concrete surface must be smoothened using epoxy putty. After the putty becomes tack-free, it is to roughen the surface with sandpaper, then cleaned.

iv. Application epoxy resin for undercoat

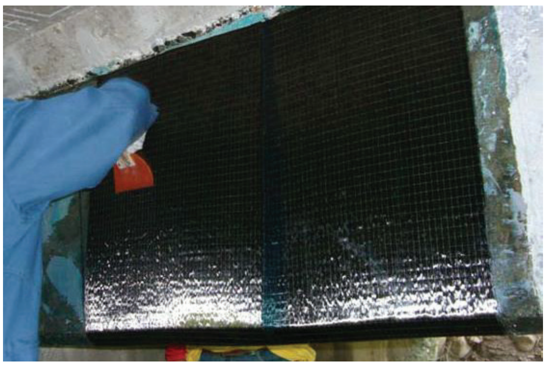
Using roller, epoxy resin is applied to the concrete as adhesive to bond with the CFS. It forms a molded composite by permeating into the CFS.

v. 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.

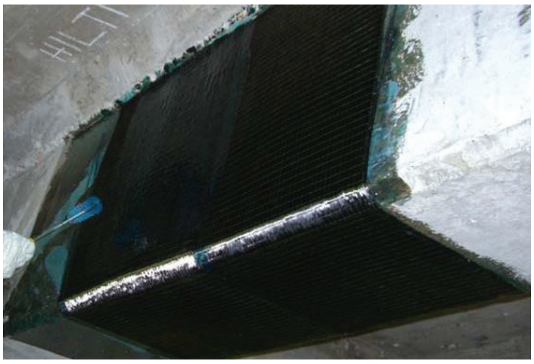
vi. Squeezing out of entrapped air

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



vii. 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.



viii. 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.

ix. Surface protection

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

B. For CFP

i. Preparation of concrete surface

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

ii. Application of primer

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

iii. Adjustment of unevenness with putty

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

iv. Application of epoxy resin on CFP

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

v. Installation of CFP

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

vi. Squeezing out of entrapped air

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

vii. Pressure attachment of CFP

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

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurements shall be in square metres (m^2).

Payment shall include full compensation for provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.3.1.13 Jacketing With Concrete

Definition

Jacketing is a method of structural retrofitting and strengthening. It is used to increase load bearing capacity following a modification of the structural design or to restore structural design integrity due to a failure in the structural member. This technique is used on vertical surfaces such as walls, columns and other combinations such as beam sides and bottoms. It consists of added concrete with longitudinal and transverse reinforcement around the existing column.

Scope of Works

Concrete jacket as shown in Figure 3-25 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 entering 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 manual.

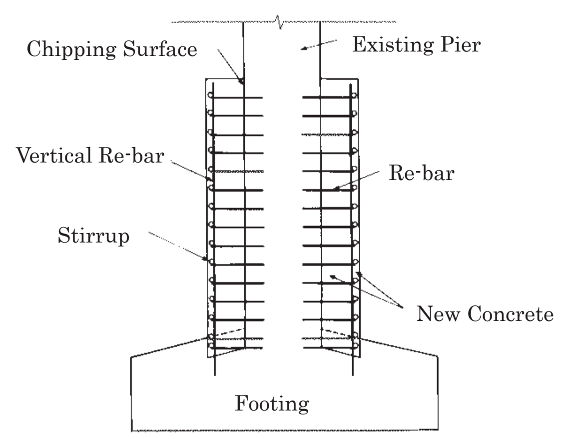


Figure 3-25: Concrete jacketing

The following are the jacketing methods available:

1. Reinforced Concrete jacketing
2. Steel jacketing
3. Fiber reinforced Polymer jacketing
4. Glass Fibre Reinforced Polymer Jacketing
5. Near-Surface Mounted (NSM) Fiber-Reinforced Polymer (FRP) Jacketing
6. Hybrid Jacketing
7. Shape Memory Alloy (SMA) Wire Jacketing

Concrete Jacket for Pier Repair

In this section, two methods of jacketing, namely concrete jacket and steel jacket, are discussed.

Concrete jacket is applied to protect the deteriorated concrete due to corrosion of rebars, damage due to rapid water flow or broken due to continuous impact from materials flowing in the channel such as drift woods. Concrete jacket should be basically placed above water level. If the damaged portion is submerged to 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.

Required Material, Tools/Equipment and Personnel

i. Required Materials

- *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.

  a. Cement
     - Portland cement 13.0 kg
     - Admixture 0.5kg (Silica fume)

  b. 10mm Crushed Aggregate 36.0 kg

  c. Sand (assumed with 2% water content) 18.5 kg

  d. Water (maximum) 5.4 liters

  e. Super plasticizer (nominal) 25ml

- *Formwork*

  a. Steel Formwork (Circular)

  b. Plywood formwork

ii. Required Tools/Equipment

- Drilling machine to concrete
- Concrete vibrator

iii. Required personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

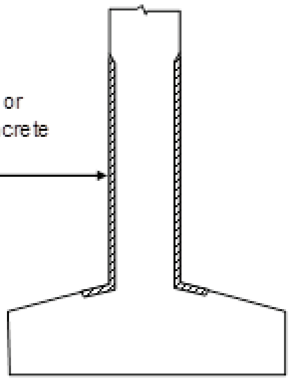
i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

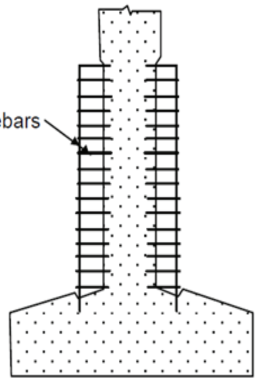
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

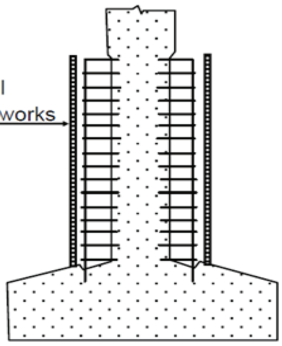
i. Removal of deteriorated concrete

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.	

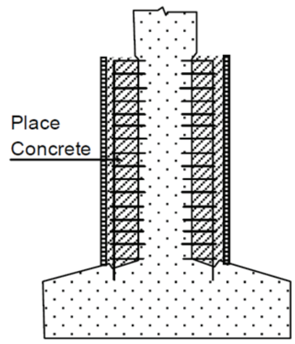
ii. Addition of rebar

Additional rebars are anchored into drilled holes in the concrete, and placed in conformity with the requirements shown on drawings. Heavily corroded rebar 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.	

ii. Setting-up formworks

Formwork for concrete jacket is commonly circular or rectangular in shape. This formwork must 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.	

iii. 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 trowelling to match the adjacent existing concrete.	

iv. 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.

Monitoring And Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurements shall be in tonnes of steel, cubic meters of concrete and square meters of formwork used.
Payment shall include full compensation for provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.3.2 Major Repair Methods in Steel Bridges

Major repair methods in steel bridges are; repainting, steel plate adding, carbon fibre plate bonding, tightening / retightening of high-tension bolt, application of anti-corrosion paint, provision of stop hole and repair to heat damages.

The defects addressed in this section of the manual are listed in Table 3-5.

Table 3-5: Defects addressed in major repairs to steel bridges

Classification	Repair / Strengthening Method	Method	Defects Addressed
Major Repairs	Repair	Repainting	Paint deterioration Corrosion
	Strengthening	Steel Plate Adding	Excessive deformation, deflection/vibrations Fatigue Section loss
Major Repairs	Strengthening	Carbon Fiber Plate Bonding	Excessive deformation, deflection/vibrations Fatigue
	Repair	Tightening / Retightening Of High-Tension Bolt	Missing bolts Loose bolts Unfixed parts
	Repair	Anti-Corrosion Paint	Paint deterioration Corrosion
	Preventive	Stop Hole	Crack
	Repair	Repair of heat damage on steel bridge	Heat damage
	Repair	Replacement of member (Section 3.4)	Missing parts Section loss Fracture Buckling

3.3.2.1 Repainting

Definition

This refers to the application of a new coat of paint to a surface that was initially painted.

Scope of Works

The service life of steel bridges could be expected to exceed 50 years if its surface is kept in good protection using suitable paint coating. However, if corrosion occurs, repainting is the only restoration and effective method for steel structures.

This repair method shall be applied when affected surface area is over 30%.

Table 3-6: Type of paintings

Photography	Rust Condition	Interventions	Type of Paint
	Corrosion is very severe and coating film is not visible. 1st grade surface preparation is necessary.	Repainting	Epoxy Zinc Rich Primer and Polyurethane Aluminum Paint
	Corrosion is severe and coating film is visible but almost deteriorated due to corrosion. 2nd grade surface preparation is necessary.		Modified Epoxy Polyimide Paint and Polyurethane Aluminum Paint

The polyurethane aluminium paint shall be applied as intermediate and top coat for all steel plate surfaces.

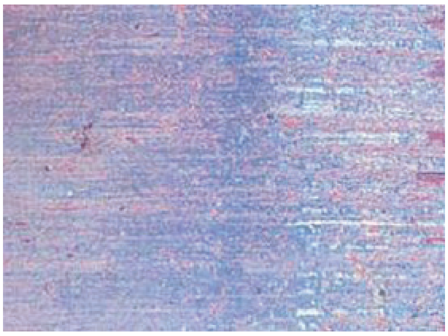
The 1st grade surface preparation shall be applied if the rust is very severe and coating film is not visible.

The 2nd grade surface preparation shall be applied if the rust is severe and coating film is visible but almost deteriorated.

The 3rd and 4th grade surface preparation are not intended for repainting. However, these are carried out for application of special anti-corrosion paint which has strong adhesion to steel surface.

Additional primer coating shall be applied under bottom flanges, which are usually subjected to severe corrosion.

Table 3-7: Preparation grades of the surface of corroded steel plate

Grade	Rust Conditions	Working Process	Photography (After Preparation)
1st Grade	Corrosion is very severe on steel surface and coating film is not visible due to corrosion. Affected surface area is over 30%	Old coating film, red rust and black rust are completely removed and revealed steel color with sand blasting or shot blasting.	
2nd Grade	Corrosion is severe on steel surface and coating film is visible but almost deteriorated due to corrosion. Affected surface area is over 30%	Old coating film, rust is completely removed and revealed steel color with disk grinder.	
3rd Grade	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%	Old coating film, rust is removed and partially revealed steel color with scraper and wire brush.	
4th Grade	Corrosion is partially visible but not severe. Peel-off of coating film is partially visible. Affected surface area is 10 to 20%	Old coating film, rust is removed with disk grinder, scraper and wire brush.	

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Epoxy zinc-rich primer
- Modified epoxy polyimide paint
- Polyurethane Paint – Thinner

ii. Tools/Equipment

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

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. 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. If sand blasting is required, steel girder shall be covered with plastic sheet to avoid pollution impact to surrounding soil and water.

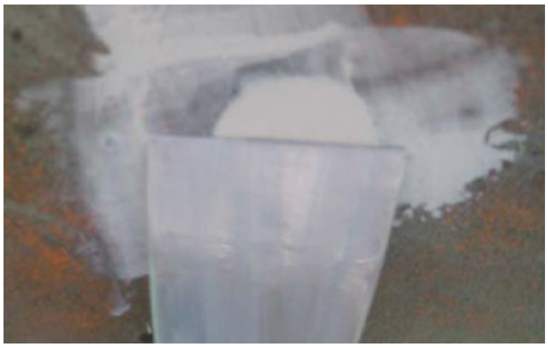
	
Scaffolding	*Environment Protection*

ii. Preparation of steel surfaces

As first step, the steel bridge shall be washed with fresh water. All adhering rust, scale, dirt, grease or other foreign material shall be removed using a disc grinder or steel wire brush, depending on required surface preparation.

iii. Filling voids

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



iv. 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 polyurethane aluminium paint.

Primer

Paint (2nd Layer)

v. *Checking of paint thickness*

Measure coating film thickness using Paint/Coating thickness meter.

vi. *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 Figure 3-26.

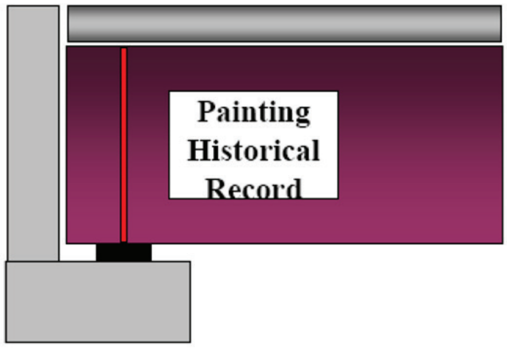


Figure 3-26: Paint Historical Record

Monitoring and Evaluation

Monitoring of repainted section by the Engineer.

Measurement and Payment

Measurement shall be in square metres (m^2).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for repainting as detailed in plans and specifications.

3.3.2.2 Steel Plate Adding

Definition

This refers to strengthening of the lower flange section to restore the original designed section area. It is mainly applied to steel girders that are prone to corrosion which could accelerate consequently leading to section loss, especially of the bottom flange plates and sections near bearings.

Scope of Works

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

In order to restore the lost strength, additional steel/angular plates shall be installed to the portion of existing steel, where section loss is more than 20%. This repair method shall be further supplemented by repainting or special anti-corrosion coating.

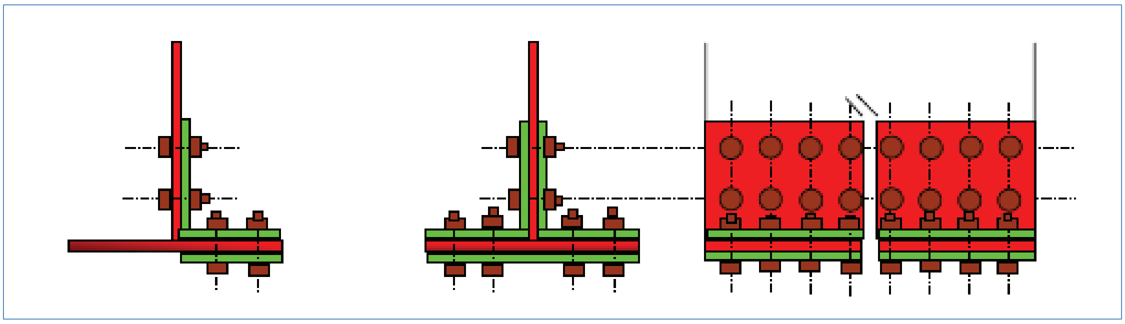


Figure 3-27: Steel plate adding

Required Materials, Tools/Equipment and Personnel

i. Required Material

- Flat plate and angular plate
- High tension bolt (HTB)
- Anchor bolts
- Epoxy putty
- Paint

ii. Required Tools/Equipment

- Welding machine
- Electric drill
- Epoxy injection pump with accessories
- Disc Grinder
- Portable Generator
- Paint Roller/Brush

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Scaffoldings

Scaffolding 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.

ii. 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 grade of surface preparation shall conform to section on repainting system or shall be as recommended by the manufacturer.

iii. 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 putty is applied to level the surface of the existing steel plate and recover its original thickness and shape.

iv. 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.

v. 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.

vi. Epoxy caulking

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

vii. Tightening high tension bolts.

After the first fastening as per (v) 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.

viii. Painting

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

Portions of steel plate where section loss or severe corrosion are found shall be painted with special anti-corrosion paint as protection against further rusting.

ix. Historical record marking

Historical record for the repair measure performed should be marked on the web plate near the bearing.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurement shall be in tonnes.

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for strengthening the steel plate adding as detailed in plans and specifications.

3.3.2.3 Carbon Fiber Plate Bonding

Definition

It is the application of carbon fibre plates to steel bridge member surfaces using epoxy resin adhesives.

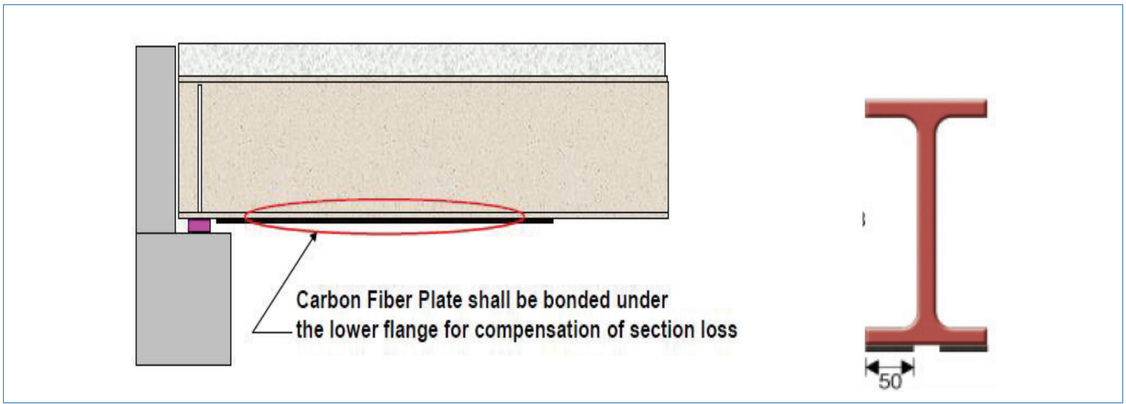


Figure 3-28: CFP Added at Bottom Flange

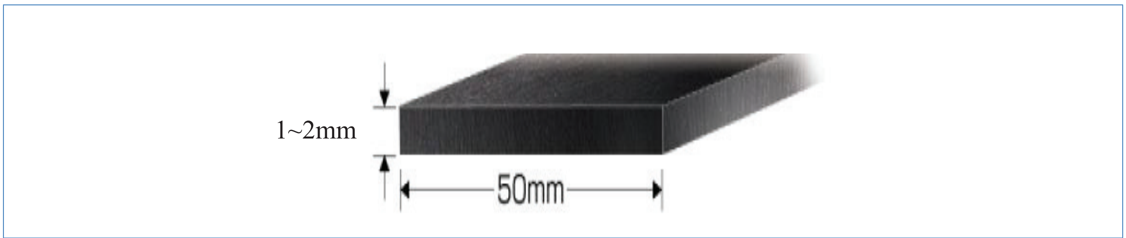


Figure 3-29: Carbon Fiber Plate Size

CFP shall be installed at the portion of existing steel members where section loss is more than 20% in order to restore the lost strength. This repair method shall be further supplemented by repainting or by application of anti-corrosion coating.

Required Material, Tools/Equipment and Personnel

i. Required materials
- Epoxy putty
- Carbon fiber plate

ii. Required Tools/Equipment
- Electric disc grinder
- Generator
- Wire brush, scraper etc.,

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

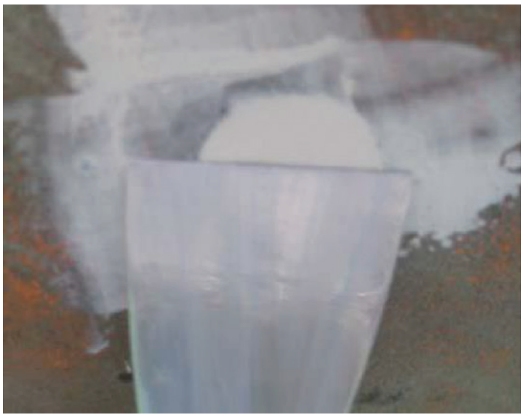
i. Surface preparation of steel plate

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 on for repainting system or shall be as recommended by the manufacturer.

ii. Adjustment of unevenness with putty

Surfaces of corroded steel plate may have holes and dents. Epoxy putty is applied to level the surface of the existing steel plate and recover its original thickness and shape.

The surface where the epoxy putty has been applied shall be smoothened using 60 - 100 sandpaper.



iii. 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 into the CFP.

iv. Carbon plate bonding

An epoxy-based adhesive is applied to the CFP using an applicator to bond. To reduce formation of voids, the adhesive is spread to form a curved profile that measures 3 mm at the center and 1 mm at the edges. CFP should be installed manually by applying uniform pressure along the longitudinal centreline.

v. Removal of entrapped air

For effective impregnation, entrapped air is squeezed out of the strips using roller, before the adhesive sets. This is intended to expel excess adhesive and produce even edges.

vi. Clamping of CFP

Clamp the bonded CFP to the member being strengthened for at least 24 hours to allow the initial resin saturate to dry.	

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurement shall be in linear meters (m).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for the works as detailed in plans and specifications.

3.3.2.4 Tightening / Retightening Of High-Tension Bolt

Definition

This is refers to replacement of missing or retightening of loose high-tension bolt (HTB) connection for steel elements of a bridge during maintenance.

Scope of Works

This repair method is applied to missing bolts, severely corroded bolts and for loosened fasteners exceeding 10% of the total number of bolts per location on a steel element. Damaged bolts found to exhibit delayed fatigue fracture need to also be replaced.

Figure 3-30: Sample bolt with delayed fatigue fracture

Required Material, Tools/Equipment & Personnel

i. Required Material

- HTB
- Grease
- Anti-rust spray
- Yellow paint

ii. Required Tools/Equipment

- Torque wrench (calibrated)/Electrical Impact wrench/Special fastener for HTB.
- Paint brush
- Hammer
- Spanner
- Electric drill
- Acetylene gas cutter

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

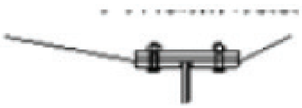
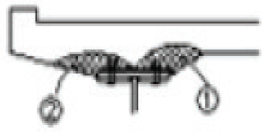
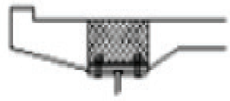
i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

Table 3-8: Replacement method of HTB

Item No. / Method	No.1	No.2	No.3
	Replace Bolt only	**Chip-off haunch**	**Break Deck Slab**
Outline of method	**Remaining Nut still used**  **Replace Bolt only**		
	·Remove severely corroded HTB from top flange ·Rotation angle method is applied to fasten HTB as quality control	·Chip of concrete from ① or ② shown ·Replace bolts and nuts ·Pour non-shrink mortar at chipped off locations	·Break deck slab from top surface ·Replace bolts and nut ·Pour non-shrink mortar for broken portion of the deck

i. Remove high tension bolt

If the HTB is found 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.

Electric Fastener for HTB

ii. Surface preparation

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

iii. 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.

iv. 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°±30° from the location of the yellow marking.

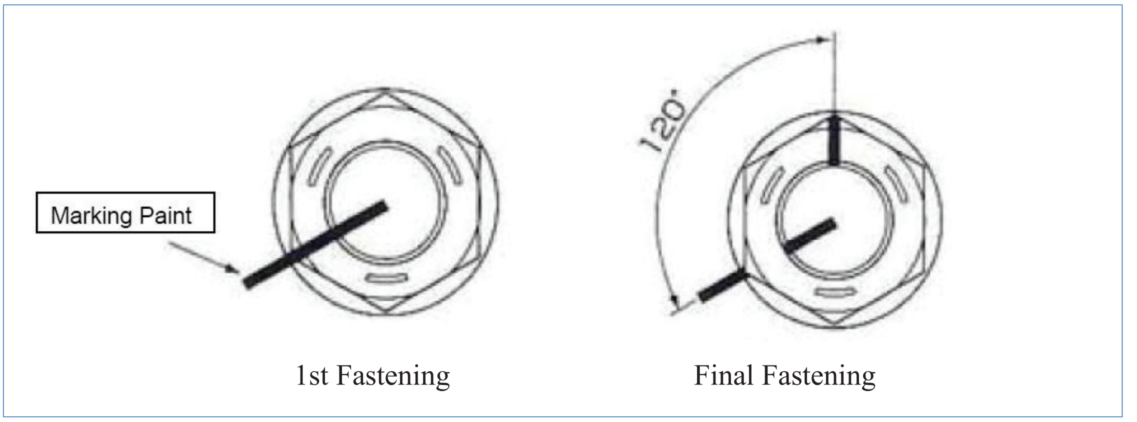


Figure 3-31: Method of HTB fastening

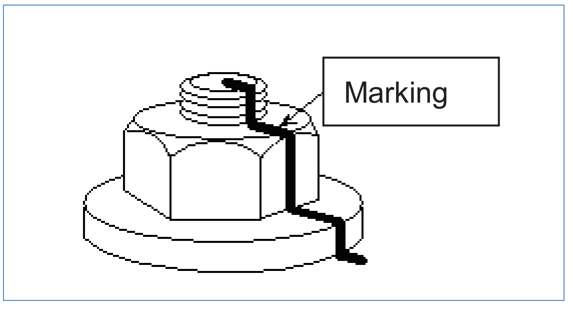


Figure 3-32: HTB marking

v. Finishing 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.

vi. Painting

If repainting of the finally fastened HTB is necessary to refer to the section on repainting, for Polyurethane Aluminium Paint (Repainting) and Anti-corrosion Paint, respectively, for the required appropriate paint material.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurements shall be in number of bolts.

Payments shall include full compensation for supplying all labour, materials, tools, equipment, and incidental items. This also includes furnishing, preparing, fabricating, transporting, placing, fastening and greasing of the HTB.

3.3.2.5 Anti-Corrosion Paint

Definition

Anti-corrosion paint is ideally applied to protect solid metal surfaces and, in some occasions, various non-metals.

Environmental exposure has a great impact on the effectiveness and suitability of an anti-corrosion paint.

Anti-corrosion paint is applied to maintain good surface condition of bridges situated in severely active environment, subjected to wind-borne sea water spray.

It was observed that progressive rust was arrested after application of high alkaline atmosphere special anti-corrosion paint. As a minimum coating requirement, the total special anti-corrosion paint weight should exceed 1.0kg/m^2 for two coats.

Photo 3-6: Lunga Lunga Bridge along the Kenyan Coast

Scope of Works

Anti-corrosion paint shall be applied to the portion of steel plate that has section loss of more than 10% but less than 20%. This repair method is also applied in combination with repainting repair method.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Emulsion
- Compound

ii. Required Tools/Equipment

- Hand mixer
- Paint roller and paint brush
- Wire brush
- Electric grinder
- Portable generator

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Scaffolding

Scaffolding shall be provided below the bridge or at bridge sides, to facilitate painting works.

ii. Preparation of steel surface

After rinsing with water, all adhering rust, scale, dirt, grease or other foreign material shall be removed to clean the identified surfaces.

The 3rd Grade surface preparation is commonly adopted for the steel surface, using wire brush and electric disc grinder.

Existing undamaged coating film may be maintained. It is also not necessary to completely remove rust using the disc grinder, as this will be arrested after application of the special anti-corrosion paint.

The surface preparation shall be accepted by the Engineer before applying special anti-corrosion paint.

	
Before surface preparation	By hand scraper
	
By electric scraper	After completed surface preparation

iii. Mixing paint

Proper mixing of compound and emulsion is vital to attain expected quality of this special paint. Usually, a mixing ratio of 1:2.3 is required between emulsion and compound. Hence, using a hand mixer device, a 7 kg emulsion shall be mixed with 16 kg compound.

During the mixing process, no water shall be added to the mixture. If the mixed powder becomes dry while being stored, emulsion shall be added to maintain consistency. Water shall never be added to the mixture. The mixing of the paint materials shall be followed as per the manufacturer's instructions.

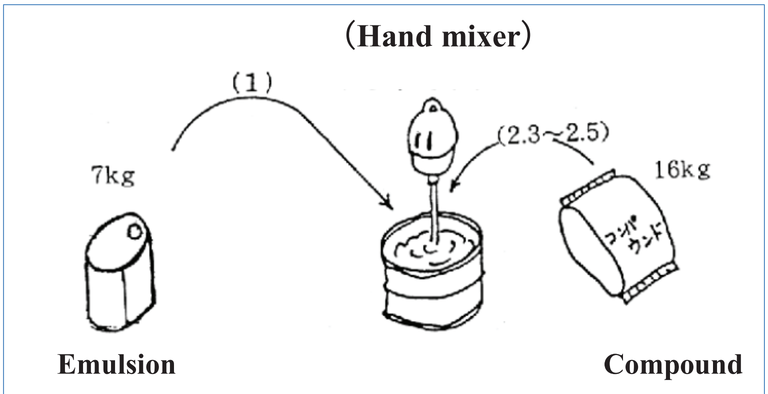


Figure 3-33: Mixing materials for anti-corrosion paint

iv. Painting

To avoid negative impacts to environment at the site as well as appreciate savings on materials, the paint to be applied using either paint brush or roller.

Hand painting with brushes as a traditional method, does not require artificial supply of energy. It should however be carefully executed and strictly controlled to maintain the required quality of coating film thickness.

To ensure consistency, the coating film thickness shall be measured under dry condition, using a thickness gauge.

If the applied paint is damaged by electric grinder while removing some dust particles, over coating of the special anti-corrosion paint shall be provided.

1st layer painting by spray gun

After completed 2nd layer painting

Shaded finish (blue color as example in the above photo) can be applied as top coating for aesthetics purpose only, if required.

v. Curing

The coating film should completely dry within a day, under a temperature of 30°C. During rainy season, drying time is more 2 days. Nevertheless, once the coating dries, water is not expected to affect the surface.

vi. Inspection

The paint film thickness shall be measured using thickness gauge to verify consistency of thickness. The minimum thickness allowed shall be 70% of the required value, similar to the quality control adopted for ordinary painting system.

vii. Historical record making

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 Figure 3-27.

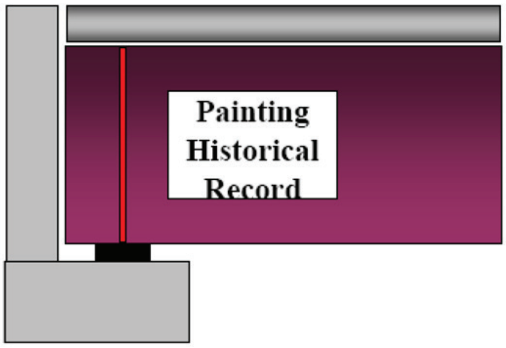


Figure 3-27: Paint Historical Record

Monitoring and Evaluation

Monitoring of painted section by the Engineer.

Measurement and Payment

Measurement shall be by square meters.

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for painting the structure as detailed in plans and specifications.

3.3.2.6 Stop Hole

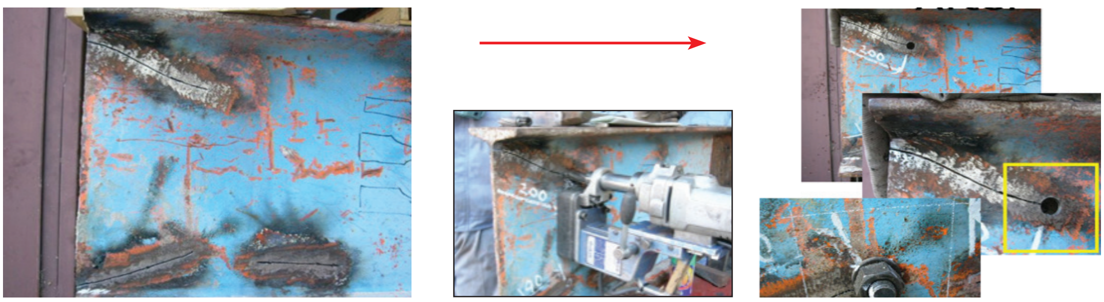
Definition

This method is one of useful countermeasures against fatigue cracks originated in steel members. It involves drilling a hole at the edge of fatigue crack for reduction of stress concentration. It should be combined with another method like supplementing steel plate bonding method.

Scope of Works

The stop hole method involves drilling a hole at the end of a crack to stop propagation. A bolt is then placed in the drilled hole to compensate for the lost section.

This method is applied as an emergency measure before applying a permanent solution.



Before *After*

Required Materials, Tools/Equipment and Personnel

Required Materials

- Drill bit
- Bolts, washers and nuts
- Fuel

Required Materials/Equipment

- Electric drill
- Generator
- Torque wrench

Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

- Investigate the end of the crack,
- Drilling hole at the edge of the crack,
- Removing the burrs and surface treatment around the hole,
- Fix and tighten the suitable sized bolt and nut with washers using the torque wrench.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in the Numbers (No.) of Holes drilled as instructed by the Engineer.

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for crack repair of fatigue cracks as detailed in plans and specifications.

3.3.2.7 Repair of heat damage on steel bridge

Definition

Heat damage on a steel bridge refers to adverse changes in the properties and structural integrity of the steel components caused by exposure to high temperatures. These elevated temperatures can result from various sources such as fire, hot work, prolonged exposure to high ambient temperatures, or other heat-related incidents. Heat damage can adversely affect the steel's mechanical properties, structural stability, and overall performance, posing a significant threat to the safety and functionality of the bridge.

Heat damage on a steel bridge can manifest in several ways, including: softening and weakening, distortion and warping, brittleness and cracking, color changes, microstructure alteration, loss of ductility.

Repairing heat damage on a steel bridge involves addressing any structural or cosmetic damage caused by high temperatures, such as fire or excessive heat. The severity and extent of the damage will determine the specific repair procedures needed.

Scope of Works

- Remove the damaged section,
- Reinstate/replace the damaged section,
- Finish to match the initial design.

Required Materials, Tools/Equipment & Personnel

i. Required Materials

- Steel section and accessories
- Paint

ii. Required Tools/Equipment

- Grinder
- Generator
- Welding machine
- Oxy-acetylene torches
- Scaffolding
- Support planks

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Cleaning and surface preparation

Clean the damaged areas of the steel bridge to remove any contaminants, debris, or loose material. Use appropriate cleaning methods such as power washing or abrasive blasting to prepare the surface for repairs.

ii. Removal of damaged material

Remove severely damaged or weakened sections of the steel that cannot be repaired effectively. This may involve cutting out the damaged parts using cutting tools such as plasma cutters, oxy-acetylene torches, or other appropriate equipment.

iii. Welding and structural repairs

Weld new steel sections or plates to replace the removed or damaged portions. Ensure that the welding process is performed by skilled welders, following proper welding procedures and adhering to welding standards for structural integrity.

iv. Stress relief and annealing

If needed, subject the repaired sections to stress relief annealing, a heat treatment process, to relieve internal stresses and improve the material's structural properties.

v. Surface finishing and protection

Finish the repaired areas to match the existing structure's surface finish. Apply appropriate coatings, paints, or protective layers to prevent corrosion and enhance the steel's durability.

vi. Quality inspection and testing

Conduct non-destructive testing (NDT) or other relevant tests to ensure the repairs meet the required quality and safety standards. Common NDT methods for steel include ultrasonic testing, magnetic particle testing, and dye penetrant testing.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be as instructed by the Engineer.

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for the repair of heat damaged steel element as detailed in plans and specifications.

3.3.3 Major Repair Methods in Timber Bridges

Major repair methods in timber bridges are: repair of splitting of timber sections by split banding, repair of severely split timber by anti-split bolt, repairing splitting timber stringer, repairing split and rotten corbels, replacing severely split spiking planks, replacing timber crosshead/cap wales/half caps, repairing timber deck, repairing timber kerbs, replacing timber corbels and installation of flashing.

The defects addressed in this section of the manual are listed in Table 3-9.

Table 3-9: Defects addressed in major repairs to timber bridges

Classification	**Repair / Strengthening Method**	**Method**	**Defects Addressed**
Major Repairs	Repair	Repair of Splitting of Timber Sections by Split Banding	Split
	Repair	Repair of Severely Split Timber by anti-split bolt	Split
	Repair	Repairing Splitting Timber Stringer	Split
	Repair	Repairing Split and Rotten Corbels	Rot Split
	Repair	Replacing Severely Split Spiking Planks	Split
	Repair	Replacing Timber Crosshead/Cap Wales/Half Caps	Rot Split
	Repair	Replacing Timber Crosshead/Cap Wales/Half Caps	Crack Rotting Split
	Repair	Repairing Timber Deck	Crack Rotting Split
	Repair	Replacing Timber Corbels	Crack Rotting Split
	Preventive	Installation of Flashing	Rotting
	Repair	Replacement of member (Section 3.4)	Crack Rotting Rattling of member Abnormal deflection Inclination Abnormal alignment

3.3.3.1 Repair of Splitting of Timber Sections by Split Banding

Definition

This is a minor repair method to arrest splits by clamping a timber section using steel bands to prevent further development of the splits by drawing the section together.

Scope of works

The repair involves the installation and tightening of steel bands around a timber member to arrest cracks, splits, or delamination.

Required materials, tools, and personnel

Required material

- Steel band
- Bolt
- Nuts

Required tool

a. For Surface Preparation
   - Wire brush

b. For Strapping
   - Strapping machine,

c. For tightening
   - Wrench

Required personnel

- Skilled personnel trained by KIHBT and registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

1. Remove loose material in the vicinity of the split using a wire brush.
2. Using a suitable strapping machine, tension the recommended steel band into position.
3. Fasten the bolts and nuts on both ends of the steel band using a wrench to the recommended tension.

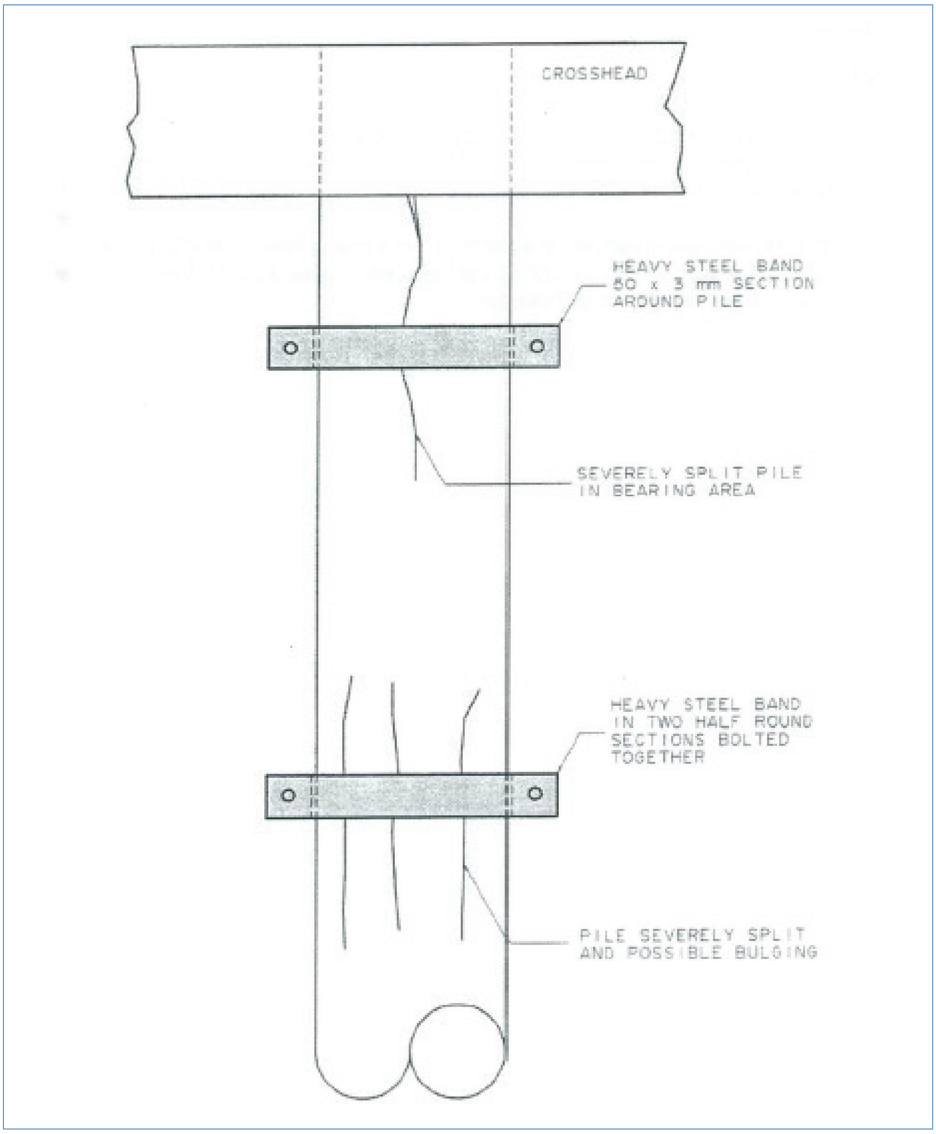


Figure 3-35: Repair of splitting timber sections by split banding

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payments

This work shall be measured by the number of steel bands instructed to be installed and fastened.

Payment shall be full compensation for the provision of all materials, tools, and labor. There will be no direct payment for the cost of storage or hauling of the steel bands and other materials to and from the bridge or bridges to be repaired.

3.3.3.1 Repair of Severely Split Timber by Anti-Split Bolt

Definition

This is a minor repair method to arrest severe splits by stitching a timber section using fasteners to prevent further development of the splits by drawing the sections together.

Scope of Works

The repair involves the installation of a series of splints to the top and bottom of the timber section along the length of the crack and draw-up bolts placed on both sides of the timber section that can be tightened between the top and bottom splints to compress and close the split.

Required materials, tools, and personnel

i. Required material
- Anti-split bolts
- Nuts
- Splints
- Fuel

ii. Required Tool/Equipment
- Wrench
- Drilling machine
- Generator

iii. Required personnel
- Skilled personnel trained by KIHBT and registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

1. Drill the bolt hole and fit the selected bolt at the recommended position.
2. Remove loose material in the vicinity of the split using a wire brush.
3. Install the splints and fasten the nuts to the recommended tension using a wrench.

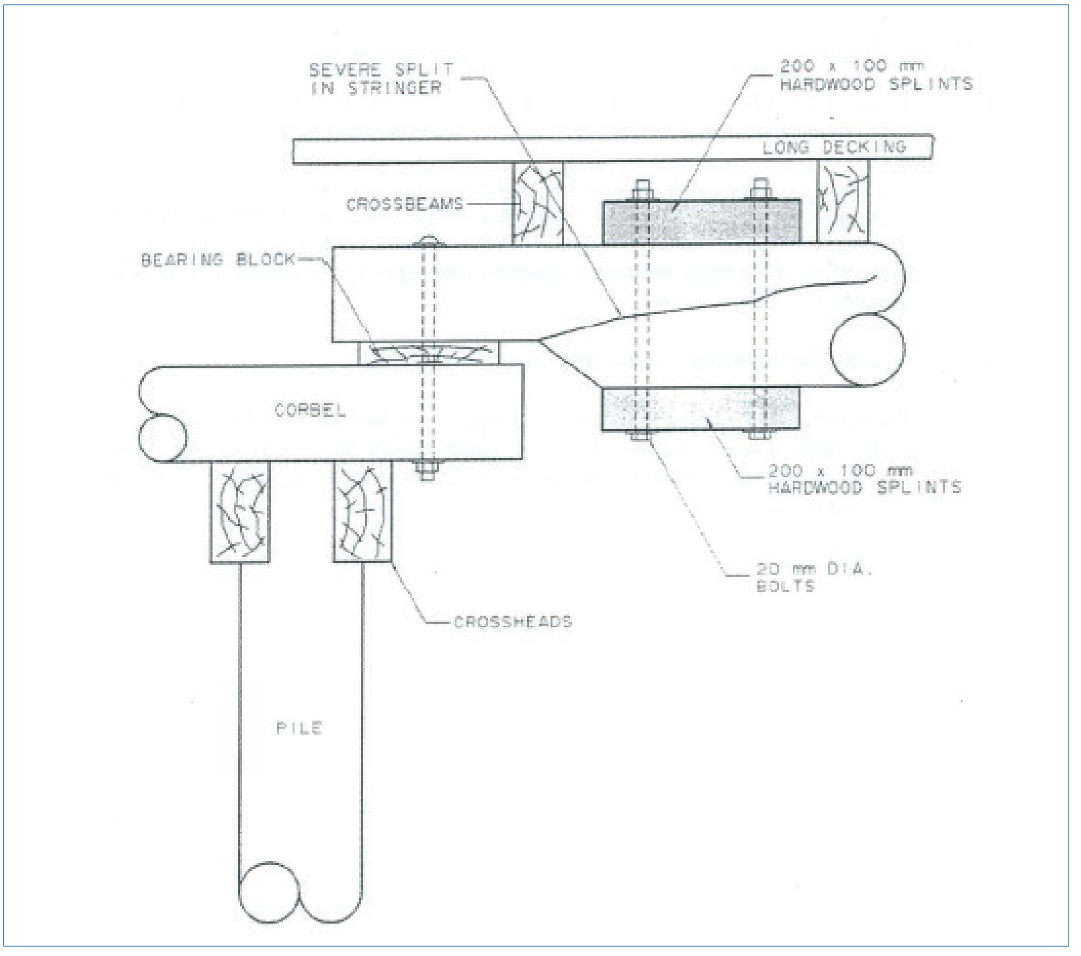


Figure 3-36: Repair of split timber with anti-split bolt

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payments

This work shall be measured by the number of fasteners instructed to be installed and fastened.

Payment shall be full compensation for the provision of all materials, tools, labor, services of the technical service advisor, and work on steel bands. There will be no direct payment for the cost of storage or hauling of the anti-split bolts and other materials to and from the bridge or bridges to be repaired.

3.3.3.2 Repairing Splitting Timber Stringer

Definition

Timber stringers consist of parallel lines of wooden beams laid over the piers and abutments in single or multiple-span bridges.

Stringer bridges can be identified by the full sawn timber stringers or girders placed in the longitudinal direction of the bridge with a transverse timber deck laid and attached to the top of the stringers.

The outside stringer on a timber bridge is more susceptible to deterioration due to its increased exposure to the elements, including rain, sunlight, and debris flow.

All dirt and loose decayed material should be removed and consideration given to adding flashing to prevent excessive wetting and further repairs if checks or splits are present.

Timber stringers suffering from severe splitting and excessive pipe rot should be replaced or supplemented.

Scope of Works

A new timber stringer or preferably a steel beam can be placed alongside the existing stringer to reduce the load it is required to carry.

Care must be taken in locating the new beam so that it does not result in the application of loads to the cantilevered portion at the end of the timber crosshead and cause failure of the crosshead. If the new beam is placed between piles, the condition of the crosshead should be assessed to ensure a shear failure does not occur, especially if the timber is short grained red gum.

An additional crosshead or other strengthening may be required.

The new beam should be placed on the span and hoisted into place through holes in the deck at each support. The new beam should be pulled tightly against the crossbeams and packed at the supports, with bolting arranged to hold the beam firmly in place.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Galvanized threaded rods or lag bolts
- Steel channels, plates, or angles

ii. Required Tools/ Equipment

- Torque wrench
- Awl
- Drill

iii. Required personnel

Skilled personnel trained by KIHBT and registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

1. Identify the area and extent of deterioration using awls and/or other non-destructive methods.
2. Using the steel elements that have been properly sized for the desired added strength and also for the recommended minimum extension of 600mm to either side of the deterioration extents, center the elements on the area of deterioration.
3. Attach the pre-drilled elements to the stringer using threaded rods extending through the stringer and elements on each side or individually using lag bolts. Pattern the rods or bolts per the designed layout. Additional holes for drainage in any members fastened to the bottom should be provided.

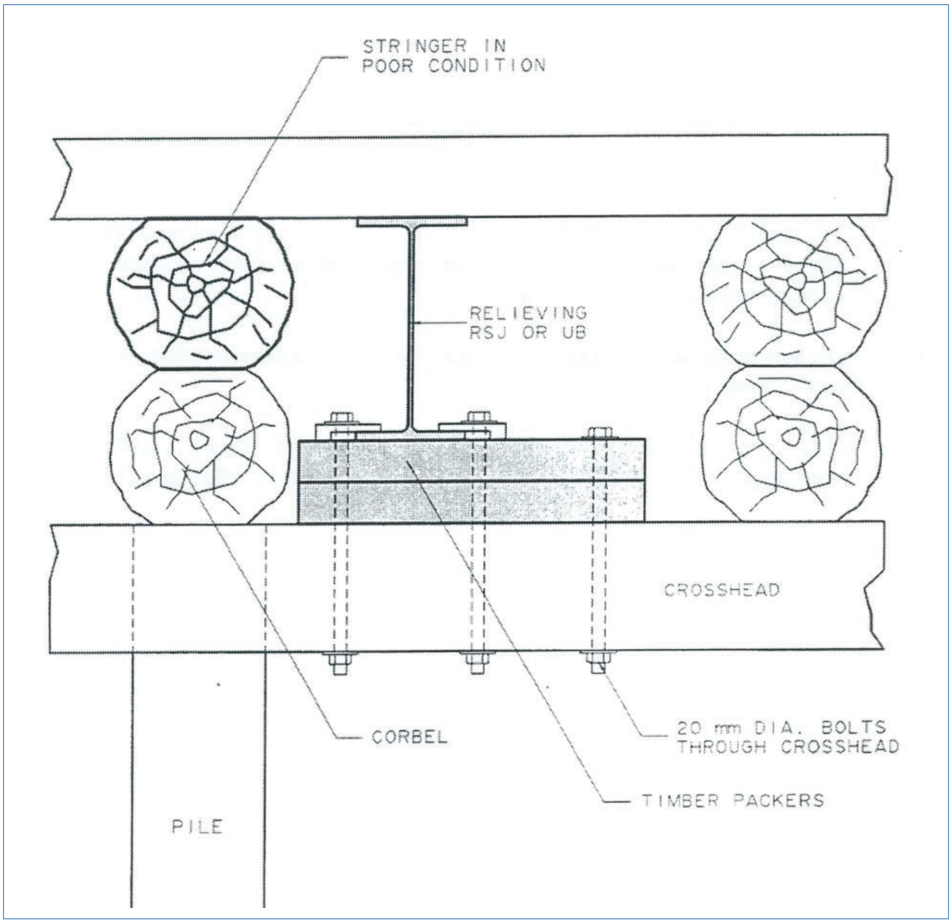


Figure 3-37: Repair of splitting timber stringer

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in number of timber stringers installed.

Payment shall include full compensation for provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.3.3.3 Repairing Split and Rotten Corbels

Definition

A corbel is a short timber member used at piers to help support the ends of timber girders. Timber corbels subjected to weathering will split and rot despite the application of petroleum jelly to seal the exposed end grain of the wood. With drying, the splits become longer and wider. Without end treatment the timber is susceptible to insect or fungal attack and timber corbels eventually fail by crushing or collapse as a result of loss of section due to piping, commonly combined with severe longitudinal splitting.

Scope of Works

Repairs should be implemented before the splitting or end pipe rot become excessive to avoid crushing or disintegration of the corbels.

Corbels that are badly deteriorated due to splitting, pipe rot or crushing should be replaced.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Lag bolts
- Fuel
- Petroleum jelly
- Circular nail plate

ii. Required Tools/ Equipment

- Drill
- Spanner
- Torque wrench
- Generator
- Scaffold/lift

iii. Required personnel

Skilled personnel trained by KIHBT and registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

1. Horizontal holes are drilled through the corbels near each end and 20 mm diameter anti-split bolts and large size washers are installed to prevent further splitting of the ends.
2. The end grain can be treated with a preservative or at least sealed with hot petroleum jelly to reduce weathering.

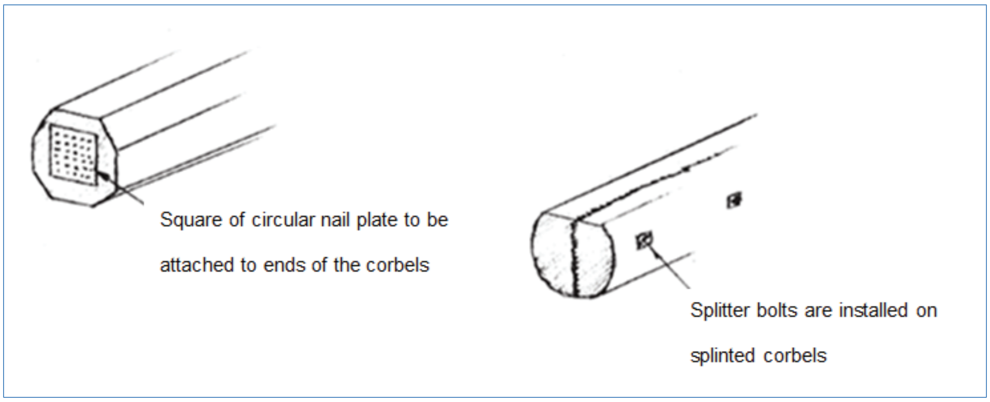


Figure 3-38: Repairing timber corbels

3. If the corbels have timber bearing blocks under the stringers, it is possible to band the ends of the corbels which is more effective than anti-split bolting.

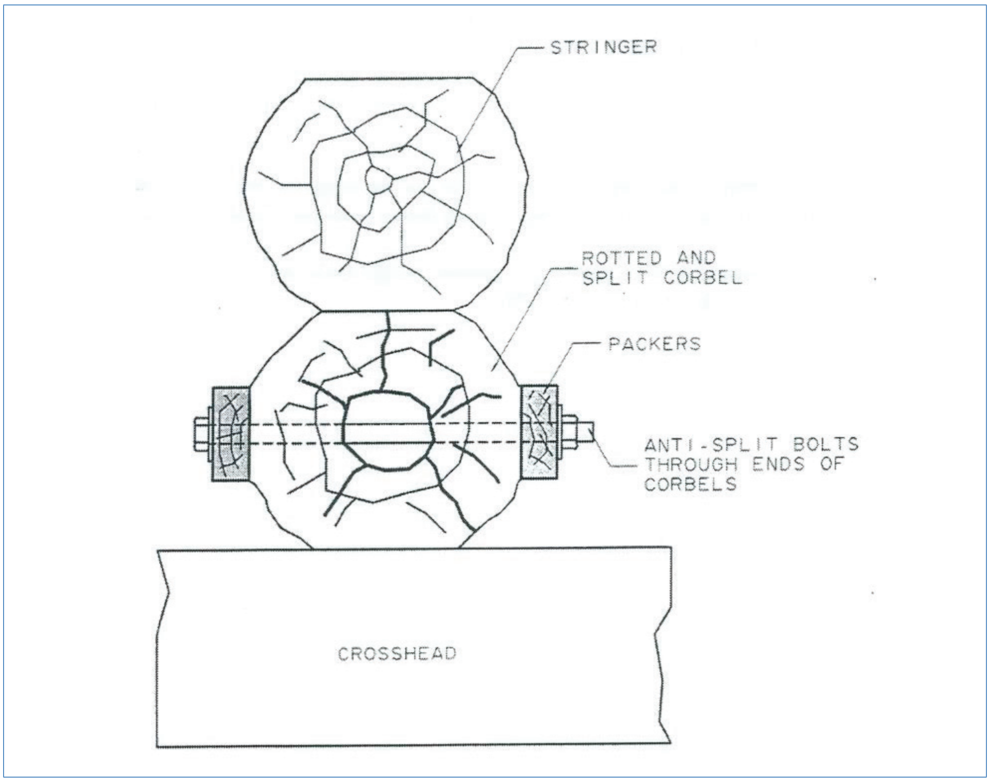


Figure 3-39: Repair of split and rotted corbels

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in number (No.) of corbels installed.

Payment shall include full compensation for provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.3.3.4 Replacing Severely Split Spiking Planks

Definition

Spiking planks can be used on timber bridges to connect the cross decking to the timber stringers without causing spike damage to the stringers. They are also used to spike timber cross decking to steel beams.

Scope of Works

The decking is spiked down at the outer girders only onto sacrificial spiking planks with no connection to the inner girders to reduce spike induced cracking of the girders.

Required Materials, Tools/Equipment and Personnel

i. Required Materials
- Timber
- Nails

ii. Required Tools/Equipment
- Hand Saws
- Hammer

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

- Spikes requiring replacement and any split and rotted portions of spike plank should be removed, simultaneously, new planks should be hammered into position.
- The new plank eventually replaces the old, by juggling the two operations.
- This operation is performed best whilst the bridge is temporarily closed for the duration of the works.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in linear meters (m).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for timber of rotting and splitting as detailed in plans and specifications.

3.3.3.5 Replacing Timber Crosshead/Cap Wales/Half Caps

Definition

The primary function of a crosshead is to transfer vertical and longitudinal loads from the girders and corbels to substructure piles. They also act in conjunction with the diagonal bracing and wales to distribute horizontal loads such as wind and debris forces through the substructure.

The weathering in the crosshead is commonly the result of moisture penetration from the ends or the surface of the member. Typical deterioration in a crosshead includes splitting, edge rot and end rot or a failure of the crosshead due to excessive load applied between pile supports.

Scope of Works

Replacing Timber Crosshead/Cap Wales/ Half Caps involves the replacement with either a new timber crosshead or a steel channel crosshead. If only one end of the crosshead is defective it may be sufficient to add a new steel channel over the damaged length rather than replace the whole crosshead.

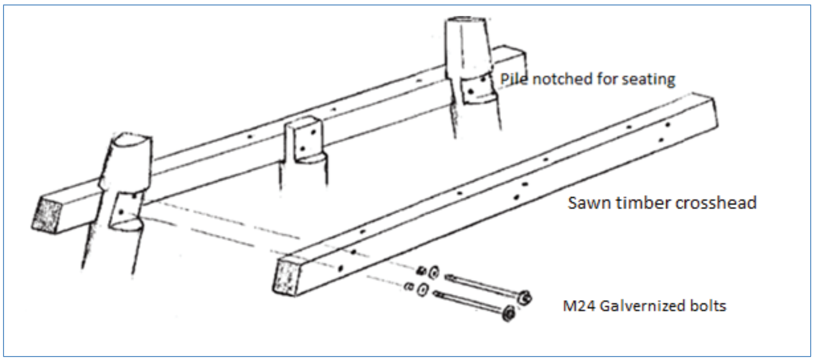


Figure 3-40: Additional timber crosshead

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Water proofing agent
- Bolts/lock nuts and washers
- Grease
- Bituminous felt
- New cross head planks
- Nails
- Fuel

ii. Required Tools/Equipment

- Brush
- Hammer
- Spanners
- Wood saw
- Wood plane
- Drill
- Generator

iii. Required personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Inspect the crosshead to identify damage due to weathering and treat the crosshead by repairing or replacing it.
ii. Recoat with a suitable waterproofing agent as necessary after brush coating a diffusing preservative over all repairs.
iii. The pile attachment bolts should also be checked for tightness to prevent differential movement between crosshead and pile. Tighten or replace bolts as necessary.
iv. If the crosshead has signs of severe splitting, edge rot or end rot it should be replaced.
v. Prop the girders to relieve loads on the crosshead. The advice of a structural engineer should be sought with the design of the temporary prop. Particular

attention should be given to bracing the props to prevent slippage, especially if traffic is permitted to continue using the bridge while it is being repaired. In general, it is considered safer to close the bridge if possible, during crosshead replacement.

vi. The girders beams should then be raised slightly to allow bolting to be released and the defective crosshead removed.

vii. The new predrilled crosshead section is lifted and slipped into position and drilled and the bolts coated with grease and retightened. The new crosshead should bear on the pile notch, or steel packers installed to provide direct bearing support. All contact surfaces should be treated with a preservative and grease, and a bituminous felt placed in the interface.

viii. The props are then removed transferring the support of the girders back to the crosshead.

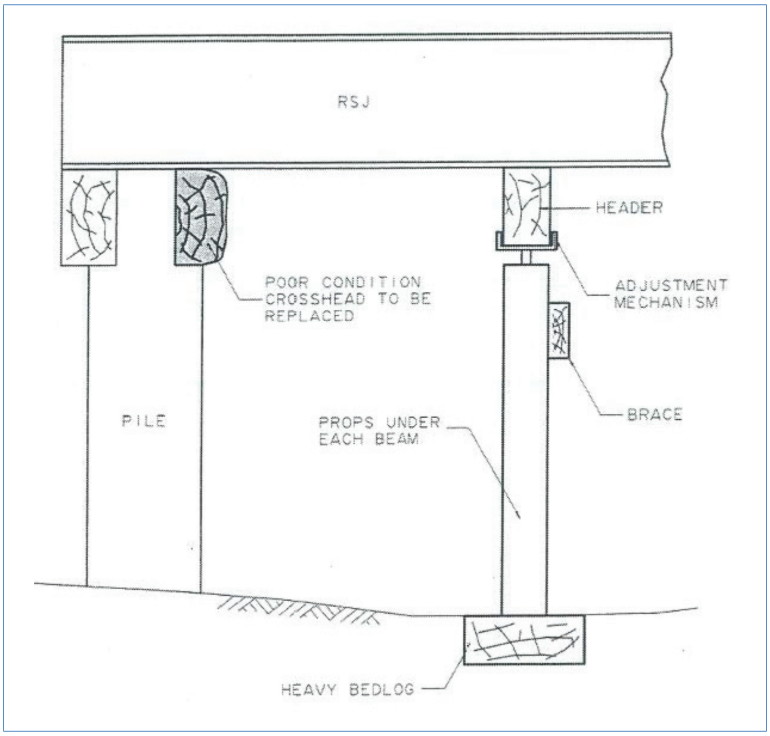


Figure 3-41: Replacement of timber crosshead

Monitoring and Evaluation

- Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be based on Linear meter (m) for replaced crosshead/Cap Wales / Half Cap

Payment shall include full compensation for the replaced crosshead/Cap Wales /Half Cap, provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.3.3.6 Repairing Timber Deck

Definition

This involves the repair of a deteriorated timber deck commonly as a result of poor drainage and general weathering.

Scope of Works

Timber decks should be checked for loose connections, dampness, decay, splitting, crushing, fastener failure, and wear. Particular attention should be paid to locations where timber decking rests on other members and it is more likely to be damp for extended periods.

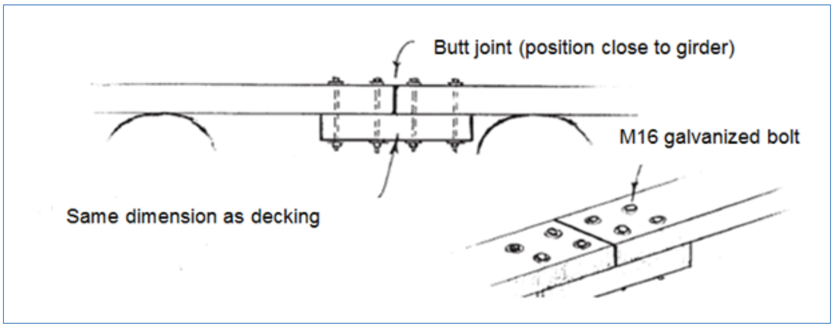


Figure 3-42: Repair of timber deck

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- New deck planks
- Bolts/lock nuts and washers
- Nails
- Fuel

ii. Required Tools/Equipment

- Hammer
- spanners
- Wood saw
- Wood plane
- Lifting jerks
- Drill
- Generator

iii. Required personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Remove wearing surface and any running planks over the defective area.

i. Release bolts and lift kerbs, where required.

ii. Check the decking planks for defects.

iii. For loose decking planks that are in reasonable condition tightening of bolts and replacement of nails may be all that is required. The bolts should be retightened against stiff steel angle cleats which will not bend as the bolt is tightened.

iv. If the area around the bolt hole is damaged then larger, heavier washers can be used to distribute the fixing load to a larger area. Heavy spring washers, lock nuts or nylon lock nuts can be used to prevent loosening of the fastener.

v. If deck planks are badly rotted, they should be replaced.

vi. Existing gaps between planks should be noted and maintained as these gaps provide air circulation and allow timber to dry out after rain.

vii. Cut out defective planks and remove bolts, cut off where required.

viii. Planks should be bolted to angle cleats at their ends and at intermediate crossbeams to hold them tightly in place and to prevent lifting under load.

ix. Replace & reinstate bolt-on kerbs as required.

x. Reinstate wearing surface.

Monitoring and Evaluation

- Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be based on square meter (m^2) for repaired deck.

Payment shall include full compensation for the repaired timber deck, provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.3.3.7 Repairing Timber Kerbs

Definition

This item defines kerbs that are constructed of timber which form an upstand at the edge of bridge. Kerbs may be formed from either hardwood or plywood construction.

If the timber kerbs are in poor condition due to severe weathering, rot and splitting, kerb connections could be loose, and the kerb may be leaning. If the kerb is in poor condition, the posts may also be loose and have limited capacity to resist road vehicle impact.

Timber kerbs serve a number of functions on timber bridges:

(1) The main purpose is to act as a containment device for vehicle wheels, generally in conjunction with a timber or steel barrier. The kerb also provides an attachment point for the associated posts.

(2) The kerb also kelps to more firmly tie down the outer ends of transverse deck planks where the kerb is located above the outer girder.

Particularly on bridges with timber rails, the kerb is probably providing greater containment capacity than the railing system itself.

Scope of Works

The most common form of timber kerb consists of two hardwood members assembled to form a 200 x 200mm section. This helps ease component supply and also simplifies formation of scuppers.

An alternative form of kerb fabricated from plywood is being successfully used and has the advantage of straightness and long lengths.

Required Materials, Tools/Equipment & Personnel

i. Required Materials

- Timber Kerbs
- Lag bolts or threaded rods
- Galvanized M20 Replacement Bolts
- Chemical Timber Surface Preservatives
- Waterproofing Agents
- CN Emulsion/Timber Oil or Thick Preservative Grease
- Bituminous Felt
- Paint
- Fuel

ii. Required Tools/Equipment

- Brush
- Screw drivers
- Drilling machine
- Circular saw
- Awl
- Rotary Hammer
- Scaffolds
- Aerial lifts
- Air compressor and tools
- Generator

iii. Required personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

Routine Main tenance

i. Routine or preventative maintenance actions for timber kerbs will generally be identified and carried out during Level 1 bridge inspections. These activities would be:
   - Tightening or replacing kerb hold down bolts.
   - Application of surface preservatives or waterproofing agents.
ii. The kerb attachment bolts should be checked for tightness as any looseness will reduce wheel impact resistance, barrier post connection effectiveness, and possibly allow decking movements.
iii. Where corrosion of bolts is evident, they should be withdrawn and replaced by galvanized bolts of the same diameter if loss of section is evident. The bolt holes through the kerbs should be coated / packed with CN emulsion or thick grease before bolt insertion.
iv. Where areas of decay or cracking are noted, these areas should be coated with a chemical timber preservative.
v. Where any active termite presence is detected during these operations, treatment shall be programmed as soon as practical.

Programmed Maintenance:

i. Where a kerb member has deteriorated to Condition State 4, its adequacy to withstand impact or to hold barrier posts will be compromised and it should be replaced. This will normally be accomplished by a full-length member in hardwood with suggested nominal gaps of 5 mm at the pier butt joins (actual gap is not critical).
ii. Unless a full bridge length of kerbing is being replaced, the cross section of the new member shall correspond to that being replaced. To maintain the line of the kerb faces, a maximum deviation of + 10mm measured by a string line on the inside face should be achieved.
iii. Because plywood kerbs will generally be of non-standard size, they would normally only be used or full bridge length replacement.

iv. The junction region of the kerb and decking is an area of very high decay potential, requiring particular attention. Timber decking should be dressed in the contact area to reduce high spots and allow the kerb to be pulled down tight.

v. All contact surfaces should be treated with a preservative and preservative grease applied. In order to remove any remaining air gaps, a bituminous felt should also be laid over the contact area. (Where a kerb is formed from 2 layers of hardwood timber, the internal contact area shall be similarly treated). The end grain of kerb timbers shall be treated before assembly because of small end gaps.

vi. When ply kerbs are used, any faces showing veneer glue lines shall be treated with sealant in order to prevent drying out and opening up due to weather exposure. Painting of the kerb may satisfy this requirement.

vii. Existing kerb attachment bolts may be used for the new kerb, unless corrosion of the bolts has occurred in which case galvanized M20 replacement bolts shall be used.

viii. All bolt holes through kerbs should be treated with a preservative and a grease or petroleum jelly applied to the bolt shank before insertion in order to improve water tightness.

ix. On bridges up to 8 metres width, the kerbs should be painted white in order to provide enhanced protection to the timber and also extra delineation for traffic. For wider bridges, painting may still be considered in order to improve member durability.

x. Consideration may be given to providing light metal spouts at scuppers to shed water away from decking ends.

Repair Method

i. If the timber kerbs are loose but in good condition, then the bolts should be retightened and additional bolts installed as required.

ii. If the kerbs are badly decayed, then they should be replaced.

iii. The deck drainage adjacent to the replaced kerbs should be inspected, cleaned, rectified as required.

Monitoring and Evaluation

Monitoring and evaluation of replaced or repaired timber kerb section by the Engineer.

Measurement and payments

Measurement shall be in linear meters (m) of the span of timber kerbs repaired.

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for Repairing of Timber Kerbs as detailed in plans and specifications.

3.3.3.8 Replacing Timber Corbels

Definition

A corbels is a projecting wall member used as a support for some elements of the superstructure.

Corbels that are badly deteriorated due to splitting, pipe rot or crushing should be replaced.

Scope of Works

Replacing timber corbels involves:

- Drilling & injecting termicide poison into timber (also adjacent areas),
- Application of chemical preservative to timber,
- Application of preservative grease to corbel ends,
- Application of chemical preservative to timber,
- Strengthening of corbel,
- Tightening of existing bolts or replace or install bolts,
- Replacement of timber corbel & Drill & inject termicide poison into adjacent timber (girders & headstocks).

Performance deteriorates greatly as the snipe depth exceeds 30%. Corbels can be strengthened with steel brackets bolted to each side of the corbel. As the corbel hogs under applied loads, the bending moment is transferred to the stiff steel C channel brackets.

This can help prevent excessive deflection, while ensuring that bending stresses developed over the shallow midpoint of the corbel do not exceed the capacity of the timber.

Required Materials, Tools/Equipment & Personnel

i. Required Materials

- Timber kerbs
- Galvanized M20 replacement bolts
- Chemical timber surface preservatives
- Waterproofing agents
- CN Emulsion or thick preservative grease
- Bituminous felt
- White paint

ii. Required Tools/Equipment

- Cordless drill
- A pry bar
- A flat and heavy scraping blade
- A reciprocating saw
- Screw drivers
- Drilling machine

- Circular saw
- Awl
- Rotary hammer
- Scaffolds
- Aerial lifts
- Air compressor and tools

iii. Required personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

1. Replacing the corbel is difficult as the stringers in both spans require jacking and temporary support. The advice of a structural engineer should be sought with the design of the temporary support system.
2. Once the spans are propped, the bolts can be cut and the defective corbel removed.
3. A new corbel of the same size is then winched into place through holes in the deck each side of the support.
4. After fixing the new corbel to the crossheads, the stringers are lowered and new bolts
5. Installed to fix them to the corbels.
6. This operation is best undertaken with the bridge closed to traffic.

Table 3-10: Repair methodology to use on timber bridges

Defect	Activities
Bolts slightly loose.	Tighten existing bolts.
Minor termite attack (active).	Drill & inject termicide poison into timber (also adjacent areas).
Minor surface decay. (May also be pipe rot up to 20% of diameter). End preservative treatment ineffective.	Apply chemical preservative to timber. Apply preservative grease to corbel ends.
Moderate surface decay. There may be pipe rot over 20% and up to 35% diameter.	Apply chemical preservative to timber.

Defect	Activities
Moderate splits or checks.	Strengthen corbel.
Bolts loose, corbel rocking under load.	Tighten existing bolts or replace or install bolts.
Heavy surface decay (marked effect on strength).	Replace timber corbel.
Heavy splitting (marked effect on strength).	Replace timber corbel.
Heavy termite attack (marked effect on strength).	Replace timber corbel & drill & inject termi-cide poison into adjacent timber (girders & headstocks).
Pipe rot over 35% and possibly in excess of 50% diameter loss.	Replace timber corbel.
Bolts very loose, corbel rocking under load and bolts may be corroded.	Tighten existing bolts or replace or install bolts.

Monitoring and Evaluation

Monitoring and evaluation of replaced or repaired timber kerb section by the Engineer.

Measurement and payments

Measurement shall be in Lump Sum (LS) for the length of the replaced timber corbels.

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for Replacing Timber Corbels as detailed in plans and specifications.

3.3.3.9 Installation of Flashing

Definition

This is the installation of flashing in timber bridges to ensure that vulnerable areas are adequately protected from water infiltration and related damage.

Photo 3-7: Photo of installed flashings

Scope of Works

Flashing is a crucial component in the construction of timber bridges, as it helps to prevent water infiltration and moisture-related damage to the structure. Proper installation of flashing is essential to ensure the durability and longevity of the bridge.

Conduct a thorough assessment of the bridge to identify areas vulnerable to water infiltration, such as joints, intersections, and areas close to the ground. Develop a detailed plan specifying the type of flashing material, placement locations, dimensions, and installation techniques.

Required Materials, Tools/Equipment & Personnel

i. Required Materials

- Water proof membranes (Aluminium, copper, galvanized steel)
- Self-tapping screws
- Nails

ii. Required Tools/Equipment

- Generator
- Saw
- Rotary hammer
- Screw gun
- Hammer

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Prepare the surface

Clean and prepare the timber surfaces where the flashing will be installed, ensuring they are clean, dry, and free of debris.

ii. Select flashing material

Choose an appropriate flashing material based on the bridge design, location, and environmental conditions. Common options include metal (e.g., aluminium, copper, galvanized steel) or flexible waterproof membranes.

iii. Cut and shape the flashing

Cut the flashing material into the required lengths and shapes based on the dimensions and layout of the bridge components.

iv. Install base flashing

Begin by installing base flashing at the base of vertical timber components to create a watertight seal.

Attach the base flashing using appropriate fasteners, ensuring a secure and stable connection.

v. Install step flashing

Install step flashing at junctions between horizontal and vertical timber components to direct water away from vulnerable areas.

Secure the step flashing using fasteners, ensuring a snug fit against the timber.

vi. Overlap and secure flashing

Ensure that the flashing pieces overlap each other to create a continuous barrier against water infiltration.

Secure the flashing in place using appropriate fasteners, ensuring a tight seal and preventing water penetration.

vii. Seal joints and seams

Apply compatible sealants or waterproofing materials to all joints, seams, and fastener penetrations to further enhance water resistance.

Ensure the sealants are applied evenly and cover all potential points of water entry.

viii. Inspect and test

Conduct thorough inspections to verify the integrity of the flashing installation, ensuring proper alignment, secure attachment, and effective sealing.

Perform water tests to validate that the flashing system effectively redirects water away from vulnerable areas.

ix. Complete installation

Once the flashing is securely in place and tested for water tightness, complete any remaining construction or finishing work on the bridge.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be in square meters and as the area instructed by the Engineer or shall be measured by the Engineer.

Payment shall be full compensation for the provision of all materials, tools, and labor.

3.3.4 Major Repair Methods in Masonry Bridges

Major repair methods in masonry bridges are: repointing stonework, replacing stonework, repair of split or cracked blocks or mortar, repair of bulging sidewall (spandrel wall), stabilising abutment or wing wall movement and repair of arch cracking.

The defects addressed in this section of the manual are listed in Table 3-11.

Table 3-11: Defects addressed in major repairs to masonry bridges

Classification	Repair / Strength-ening Method	Method	Defects Addressed
Major Repairs	Repair	Repointing stonework and replacing stonework	Loss of mortar Sectional loss Crack Water leakage
	Repair	Repair of split or cracked blocks or mortar	Crack/Split masonry Missing masonry sections
	Repair	Repair of bulging sidewall (spandrel wall)	Deformation/ Displacement of masonry blocks
	Repair/Preventive	Stabilising abutment or wing wall movement	Abnormal alignment (Plan/Profile)
	Repair	Repair to arch cracking	Crack
	Repair	Replacement of member (Section 3.4)	Abnormal deflection Inclination Abnormal alignment

3.3.4.1 Repointing Stonework and Replacing Stonework

Definition

This is the restoration of old mortar and/ or bricks that have lost their structural integrity.

The mortar between the masonry stones deteriorates with time due to weathering, water wash and moisture penetration from the fill behind the walls. When the depth of mortar loss reaches 20mm, repointing of the stonework is required. When depth of mortar loss exceeds 20mm, stone movement or crushing of the remaining mortar can result leading to slippage of stones in arches or dislodgement of stones in walls.

In some cases where aesthetics is not a concern, blocks can be replaced with concrete or stiff mortar mix. Care must be taken to ensure that the concrete does not slump or shrink away from the surrounding stones.

Photo 3-8: Missing block

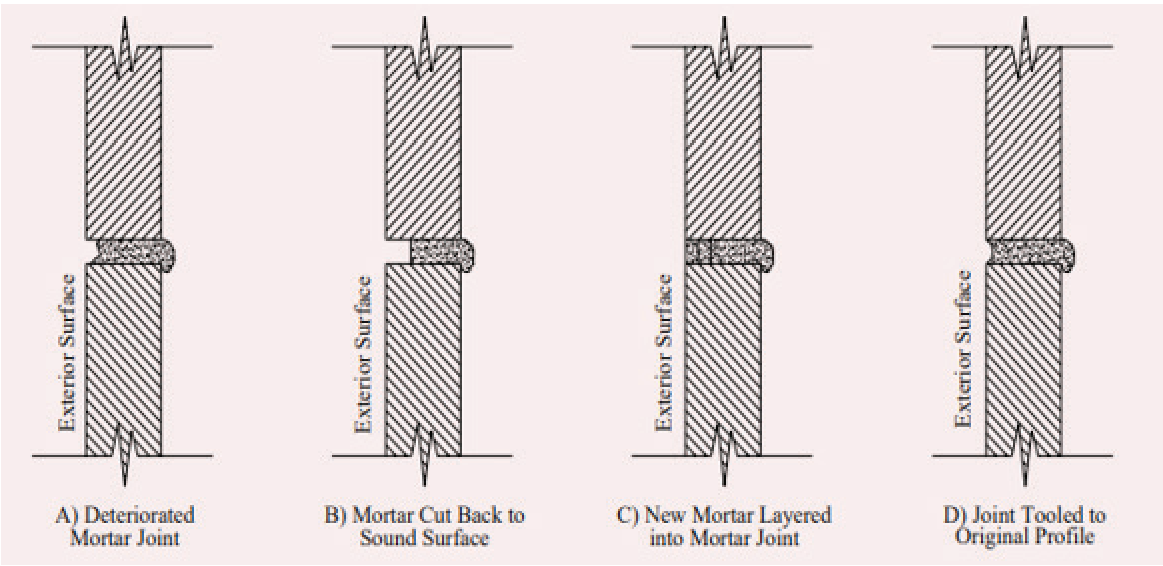


Figure 3-43: Repointing stonework

Scope of Works

This repair method involves removal of old mortar and bricks that have lost their integrity.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Ordinary Portland Cement
- Fine aggregate
- Clean water

ii. Required Tools/Equipment

- Chisel
- Wire Brush
- Small Hammer
- Mortar Mix Bucket
- Safety Goggles
- Trowel
- Scaffolding or inspection vehicle

iii. Required Personnel

- Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

1. Remove old mortar

Cut out the old mortar being careful not to damage the nearby units or to remove too much mortar at one time. Generally, the depth of cut should not exceed 20mm, or until sound mortar is reached.

2. Select the proper mortar type

As much as possible, try to closely match the mortar used in the original construction. In general, softer mortars with more lime than typical mortars serve as a more effective tuck-pointing mortar.

3. Pre-hydrate the mortar

Mix the mortar using as little water as possible and allow the mix to hydrate for one to two hours prior to repointing. Using a stiff mortar will reduce the plastic shrinkage.

4. Place new mortar

   Force new mortar into the joint in layers not exceeding 6 mm. Each layer should be thump tamped hard before subsequent layers are applied.

   Where the mortar loss is deeper than 20 mm it should be replaced with a low-pressure injection of 1:3 lime/cement:sand mix to reach the rear of the stones and backfilled to depth of 10 mm from the front face of the stone.

5. Finish tooling

   Once the mortar has sufficiently set, tool the mortar to match the original mortar.

6. Curing

   Moist curing should be provided for at least the first 3 days to prevent shrinkage cracking. The stonework should be wetted or watered a few times a day.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be square meter calculated as the area instructed by the Engineer.

Payment shall include full compensation for the removal of old mortar and/ or deteriorated bricks, surface cleaning and preparation, furnishing and placing of all materials, labour, equipment, tools, as well as construction and removal of formworks and other temporary works necessary to complete the repointing stonework and replacing stonework.

3.3.4.2 Repair of Split or Cracked Blocks or Mortar

Definition

This repair method involves restoration of split or cracked masonry.

The causes of cracking in masonry include differential settlement of foundations, thermal movement, growth of brickwork, corrosion of embedded iron or steel, impact damage and growth of vegetation in or around the brickwork.

Prior to undertaking repair of extensive cracking in masonry, the cause of the cracking should first be determined along with an assessment of what further deterioration is likely. The advice of a structural engineer should be sought in making this assessment. In addition, there should be an assessment of the significance of the existing and anticipated cracking for the load carrying capacity of the structure.

Particular care should be exercised in cases where the crack formation is comparatively recent if the cracks are live (i.e., crack width fluctuates) or the crack is seen as posing a threat to the stability of the structure.

If the cracks are known to have existed for some time without change, they may not be a source of serious concern though steps should usually be taken to repair them. Cracks that have formed due to overload tend to close and be very fine after the overload is removed and may therefore not require treatment.

Masonry arches, abutments, retaining walls, and wing walls are vulnerable to cracking due to differential settlement of the foundations. Factors affecting the stability of a masonry arch bridge include the following:

- Differential settlement within an abutment or pier may cause longitudinal cracks along an arch ring, indicating that the arch has divided into separate rings.
- Movement or settlement of the foundations of an abutment or pier may cause lateral cracks across an arch ring and settlement in the roadway, indicating that the arch has broken up into separate segments.
- The settlement at one end of an abutment or pier may cause diagonal cracks starting near the edge of the arch at the springing and extending to the centre of the arch at the crown.
- Increased flexibility of the arch ring may cause cracks in the spandrel walls near the quarter points.
- Outward movement of the spandrel walls due to the lateral pressure of the fill, particularly in cases where the traffic can travel close to the parapet may cause longitudinal cracking near the edge of the arch.
- Lateral movement of the wing walls may cause cracking and, if adjacent to the roadway, damage to the road surface.

Photo 3-9: Cracks at sidewall and loss of mortar between bricks

Scope of Work

Crack repair involves removing the existing defective mortar, cleaning with compressed air then pressure injecting a cement/lime:sand mortar mix into the crack to ensure it is fully sealed, and that full bonding to the sides of the crack has been achieved. The appropriate mixture is a 1:3 mix though as a general rule the mix should be softer and more permeable than the stonework.

Depending on the extent of the cracking, various intervention options may be employed:

1. Sealing of cracks by epoxy resin injection.
2. Repairing brickwork with epoxy mortar.
3. Installing ferro-cement plate at the corner (95% cement mortar mix and 5% wire mesh).
4. Rebuilding portion of a wall.
5. Stitching method of repairing cracks.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Ordinary Portland Cement
- Rebars
- Fine aggregate
- Epoxy Sealant
- Clean water

ii. Required Tools/Equipment

- Chisel
- Cutting disk
- Raking rod
- Wire brush
- Small hammer
- Mortar mix bucket
- Safety goggles
- Trowel
- Air Compressor
- Mortar pressure pump
- Scaffolding or inspection vehicle

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

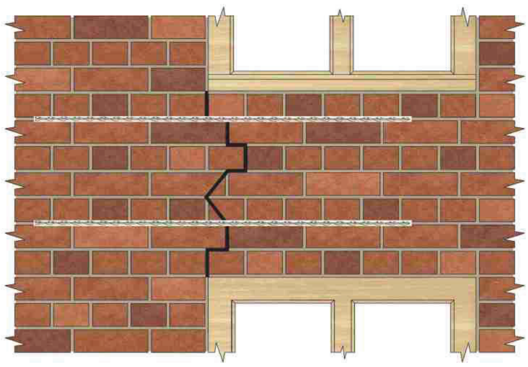
i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

1. Remove defective mortar: Cut out the old mortar being careful not to damage the nearby units or to remove too much mortar at one time. Generally, the depth of cut should not exceed 20mm, or until sound mortar is reached.
2. Clean with compressed air.
3. Moisturize the prepared area using clean water.
4. Pressure–inject cement/lime/sand mortar mix into the crack to ensure it is fully sealed, and that full bonding to the sides of the crack has been achieved. The appropriate mixture is a 1:3 mix though as a general rule the mix should be softer and more permeable than the stonework.
5. Moist curing should be provided for at least the first 3 days to prevent shrinkage cracking. The stonework should be wetted or watered a few times a day.
6. Low-pressure silicone sealant may be injected on small cracks which are not progressive.



Stitching Method of Crack Repair

Ferro–cement Method of Repair

Epoxy Resin Injection

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be square meter calculated as the area instructed by the Engineer.

Payment shall include full compensation for the cutting and prepare the cracks, surface cleaning and preparation, furnishing and placing of all materials, labour, equipment, tools, as well as construction and removal of formworks and other temporary works necessary to complete the repairing splits and cracks on blocks and mortar.

3.3.4.3 Repair of Bulging Sidewall (Spandrel Wall)

Definition

It occurs when side walls of masonry arch bridges bulges outwards due to a combination of moist infill and secondary compaction of the infill due to traffic loading. Thus bulging can cause cracking, loss of mortar and movement of stones relative to each other.

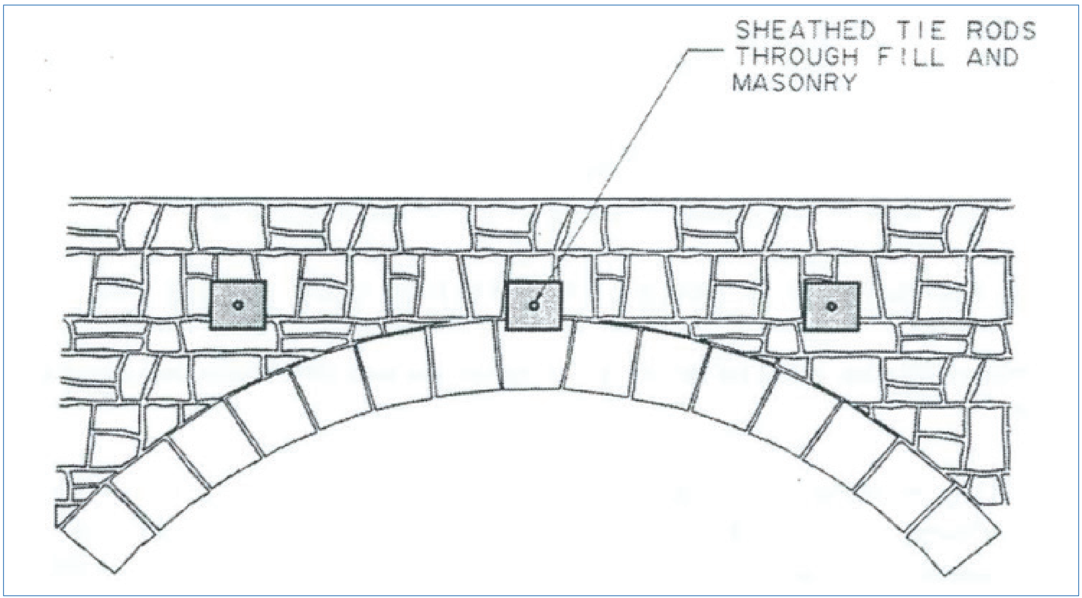


Figure 3-44: Repair to Side wall (Spandrel Wall)

Scope of Works

The scope of works on repair of bulging sidewalls (spandrel wall) entails identification and demarcation of the bulging side wall area, removal of bulging masonry stones, install tie rods to strengthen bulged sidewalls and infill material from one end to the other, fit anchor plates on both sides of the tie rods and hide with a thin veneer of stone, epoxy bonded to the plates to match masonry walls. After installing the tie rods in place, cracked mortar can be repaired in accordance to the procedures highlighted in Section 3.3.4.1 Repointing Stonework.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

i. Ordinary Portland Cement
ii. Fine aggregates
iii. Clean water
iv. Epoxy
v. Galvanized tie rods
vi. Plastic sheath
vii. Metal cover plates
viii. Masonry stone

ii. Tools and Equipment

i. Trowel
ii. Plumb bob
iii. Chisel
iv. Measuring tape
v. Brush
vi. Pressure injection pump
vii. Mortar mixing bucket/tray
viii. Low pressure injection machine
ix. Wheelbarrow
x. Water contraire
xi. Scaffolding
xii. Inspection vehicle
xiii. Pre-tensioning machine

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Works Sequence

i. Identify and demarcate bulged sections on side wall (spandrel wall)

The repair contractor should identify and demarcate all bulging sections on the side walls (spandrel walls), implement all traffic management plans and commence work and erect scaffolding/install inspection vehicle.

ii. Replace defective masonry stone

In case of any defective masonry stone on the side wall (spandrel wall), replace with suitable masonry stone and joint using mortar.

iii. Install tie rods across the side wall

Drill holes through the masonry wall and infill embankment before installing the pre-tensioned tie rods covered with plastic sheaths and anchor them on both ends using cover plates.

iv. Waterproofing and Drainage

Ensure proper waterproofing measures and drainage systems are in place to prevent water accumulation, which can contribute to further bulging or damage.

v. Repoint masonry using mortar

In case of cracked mortar joints between masonry stones, crack repair is recommended. This process involves removing the existing defective mortar, cleaning with compressed air then pressure injecting a cement/lime to sand mortar mix into the crack to ensure it is fully sealed, and that full bonding to the sides of the crack has been achieved. The appropriate mixture is a 1:3 mix though as a general rule the mix should be softer and more permeable than the stonework.

vi. Curing repointed masonry

All sections of the bulging side wall (spandrel wall) with repointed masonry repairs need thorough and continuous curing to gain strength and to minimize drying shrinkage.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be square meter calculated as the area instructed by the Engineer.

Payment shall include full compensation for the preparation, furnishing and placing of all materials, labour, equipment, tools, other temporary works necessary to complete the repair of the bulged sidewalls (spandrel walls).

3.3.4.4 Stabilising Abutment or Wing Wall Movement

Definition

The lateral earth pressure on a wing wall can cause the wall to move laterally or rotate thereby creating a large gap between it and the adjacent abutment walls and resulting in loss of embankment fill. On older bridges where the wing walls and the abutment walls are monolithic, severe cracking can occur at the junction between them. The wing walls should be restrained from further movement to prevent further damage.

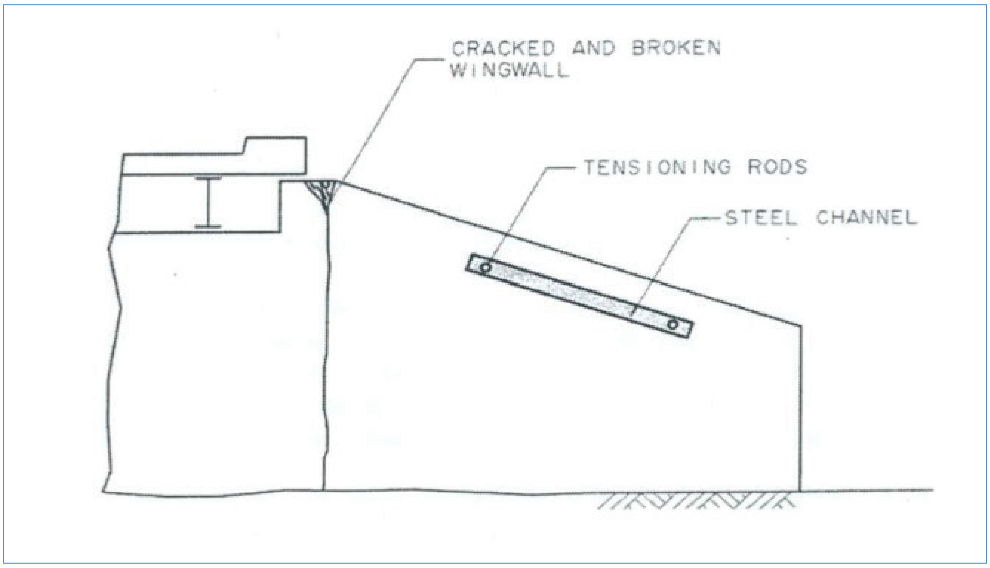


Figure 3-45: Repair to wing wall

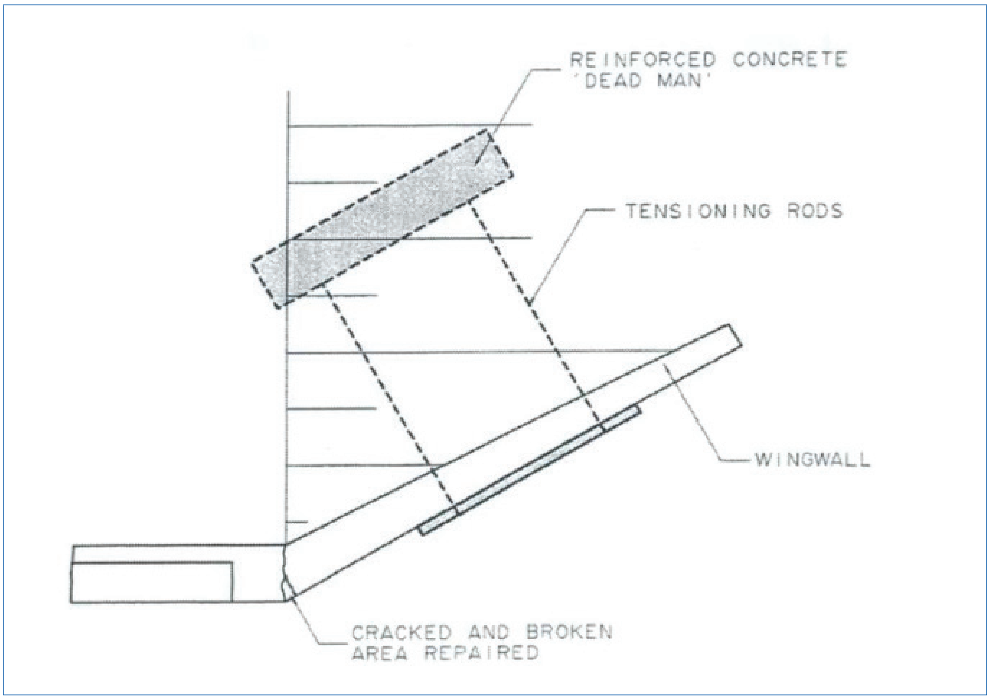


Figure 3-46: Stabilizing abutment or wing wall

Scope of Works

Repair works involve drilling/coring of holes through the wing wall, installing pre-tensioning tie rods sheathed with plastic, casting in placed reinforced concrete 'dead man' about 5 metres into the embankment behind the wall, backfilling excavated area and applying epoxy grout on all cracked areas.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

i. Portland Cement
ii. Fine aggregates
iii. Clean water
iv. Epoxy
v. Galvanized tie rods
vi. Plastic sheath
vii. Metal plates
viii. Masonry stone

ii. Required Tools and Equipment

i. Trowel
ii. Plumb bob
iii. Measuring tape
iv. Concrete/mortar mixer
v. Concrete/mortar mixing bucket
vi. Wheelbarrows
vii. Concrete mixing tray/mortar mixing pan
viii. Water container
ix. Scaffolding
x. Inspection vehicle
xi. Drilling/coring machine

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Works Sequence

i. Drill/core holes through the walls and embankment.

ii. Insert tensioning rods into holes and push them through the embankment. These rods should be galvanized and sheathed in plastic over the length they are within the embankment fill.

iii. Install by fixing the tensioning rods into a reinforced concrete 'dead man' cast into an excavated hole some 5 metres behind the wall in the embankment.

iv. After installing pre-tensioning tie rods, the excavation is backfilled with compacted fill and the cracks in the walls epoxy grouted.

NB: Other solutions to the problem include 'soil nails' and helical ties that avoid the need to excavate for and cast the concrete 'dead man'.

For smaller walls it may be more appropriate to excavate behind it and drag it back into place or simply reconstruct wall and replace the backfill. The design of the replacement wall and the selection and compaction of the fill behind the wall should be such as to avoid a repeat of the wall failure.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurement shall be based on square meters.

Payment shall include full compensation for the provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.3.4.5 Repair Arch Cracking

Definition

Arch cracking in masonry bridges refers to the development of fissures within the arch structure of a masonry bridge. Arches are a common structural feature in many masonry bridges and are known for their ability to support heavy loads through the distribution of weight along the curved shape of the arch.

The arch cracks may occur as a result of settlement and movement, thermal expansion and contraction, material deterioration, loading and overloading, seismic activity, design or construction flaws.

Scope of Works

The scope of works on the damaged arch are crack repairs, repairs on spalled areas, repointing, structural reinforcement, reconstruction if necessary, surface finishing, protective coating and curing.

Required Materials, Tools/Equipment & Personnel

i. Required Materials

- Masonry material (Quarry stone/Block/Brick)
- Mortar
- Grout
- Epoxy

ii. Required Tools/Equipment

- Raking rod
- Trowel
- Spade
- Cold chisel
- Plumb bob and line
- Spirit level

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Cleaning and surface preparation

Clean the entire arch surface thoroughly, removing loose debris, dirt, or other contaminants that could hinder proper adhesion of repair materials.

Use appropriate cleaning methods, such as pressure washing, to prepare the surface.

ii. Crack repair

For cracks:

- Rout out and widen cracks to provide a better bonding surface for the repair material.
- Apply a bonding agent to the cleaned and prepared surface to enhance adhesion.
- Fill the cracks with an appropriate repair material, such as epoxy, grout, or mortar, ensuring the material penetrates and fills the crack completely.

iii. Spall repair

If there is spalling (flaking or chipping) of the masonry:

- Remove loose or damaged material using suitable tools like a chisel or grinder.
- Apply a bonding agent to the prepared surface.
- Fill the spalled areas with a suitable repair mortar or concrete mix, matching the color and texture of the original arch.

iv. Repointing

Repoint any deteriorated or damaged mortar joints with fresh mortar, ensuring a strong and uniform bond.

v. Structural reinforcement

Reinforce the arch as needed using suitable methods, such as installing steel rods or mesh, to enhance structural integrity.

vi. Reconstruction (if necessary)

If the damage is severe, reconstruction of sections of the arch may be necessary. This could involve carefully removing and replacing the damaged masonry while maintaining the original design and appearance.

vii. Surface finishing

Match the original finish and appearance of the arch by applying appropriate finishes, textures, or coatings.

viii. Protective coatings

Apply protective coatings to the repaired arch to enhance durability, water resistance, and resistance to environmental elements.

ix. Curing

Allow the repair material to cure according to the manufacturer's instructions, ensuring proper strength and durability.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be in square meters and as the area instructed by the Engineer or shall be measured by the Engineer.

Payment shall include full compensation for the provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.3.5 Major Repair Methods in Bridge Expansion Joints

Major repair methods carried out to expansion joints are; repair of asphaltic plug joint and replacement of expansion joint.

The defects addressed in this section of the manual are listed in Table 3-12.

Table 3-12: Defects addressed in major repairs to bridge expansion joints

Classification	Repair/Strengthening Method	Method	Defects Addressed
Major Repairs	Repair	Repair to asphaltic plug joint	Water leakage Abnormal space/noise Difference in elevation Deteriorated sealant
	Repair	Replacement of expansion joint	Water leakage Abnormal space/noise Difference in elevation Deteriorated sealant Cracking on primary members Rupture/peeling off of rubber seal

3.3.5.1 Asphaltic Plug Joint

Definition

The quality of expansion joints is vital to the behaviour of the bridge and its durability. They need to be maintained by waterproofing and ensuring resistance to leakage. The most common joint sealant is asphalt which is easily damaged by repeated traffic load and aging.

The usual gap between concrete edges is around 20 mm considering a mean temperature of 27˚C and a range of ± 10˚C in Kenya. The movement of a 20 m bridge span due to changes in temperature is 12×10^{-6} / ˚C × 20 m × (± 10˚C) = ± 2.4 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 of a reinforced concrete bridge deck is below ± 10 mm.

With these considerations, the most suitable repair measure for damaged asphalt sealant is the installation of asphaltic plug joint.

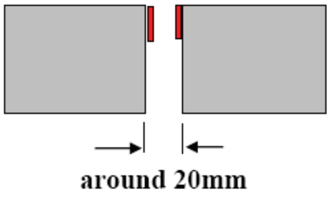


Figure 3-47: Sealant asphalt joint

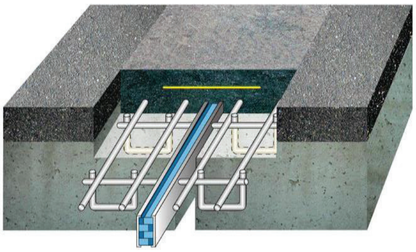


Figure 3-48: Type of asphaltic plug joint

Photo 3-10: Gap cleaning

Photo 3-11: Flexible asphalt pouring

Scope of Works

The scope of repair works on expansion joints covers both concrete 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.

Required Materials and Tools/Equipment & Personnel

i. Required Materials:

- Steel frame (welded with anchor rebar)
- Concrete anchor with steel bar
- Expansion sheet/foam
- Flexible Asphalt or asphalt-rubber chip

ii. Required Tools/Equipment

- Concrete Cutter
- AC cutter
- Electric impact hammer/small jackhammer

- Gas burner
- Asphalt mini cooker
- Surface finisher

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Dismantle existing damaged asphalt joint sealant

The damaged joint sealant shall be dismantled and removed for appropriate disposal.	

ii. Chipping surface concrete

The surface of concrete at the location of the existing damaged joint shall be chipped off for purposes of installing new steel frame and to insert the foam to narrow gap (proper gap for seamless joint is less than 25mm).	

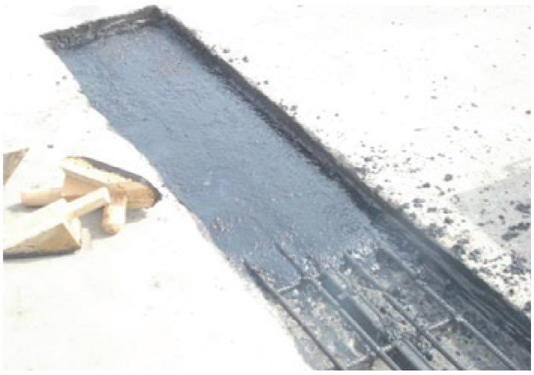
iii. Install steel frame

Steel frame shall be fabricated in a box frame and Rebar. This frame shall be fixed by welding between Concrete anchor and rebar.	

iv. Rebar anchor

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

v. Pouring flexible asphalt 1st layer

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

vi. Installation of expansion sheet

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

vii. Pouring flexible asphalt 2nd layer

Flexible asphalt (asphalt-rubber chips) shall be poured as second layer. The surface of flexible asphalt shall not be compacted until the temperature falls to room temperature.	

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurement shall be in linear meters (m).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for the repair of asphaltic plug joint as detailed in plans and specifications.

3.3.5.2 Replacement of Expansion Joint

Definition

This refers to the removal of the defective joint in parts or full, and reinstatement.

This can be either;

- Partial replacement of expansion joint,
- Full replacement of expansion joint with a similar type,
- Full replacement of expansion joint with a different type.

The behaviour of the bridges and their durability depends on the quality and maintenance of the expansion joints. 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. The expansion joint shall be replaced if it deteriorates beyond a certain level.

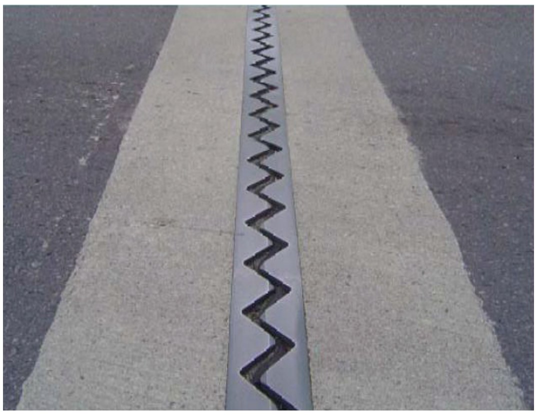



Photo 3-12: Sample of waterproof type expansion joint

Scope of Works

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. 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: >30mm at expansion gap,
- Displacement: Pourable joint sealant may be 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 maybe almost completely lost.

Required Materials, Tools/Equipment & Personnel

i. Required Materials

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

ii. Required Tools/Equipment

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

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

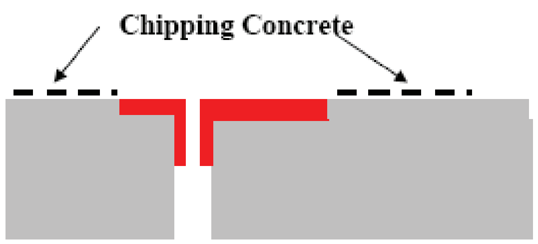
Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

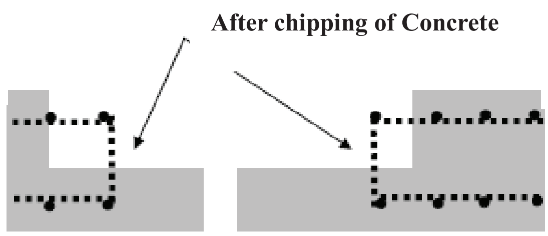
Work Sequence

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, levelled, and then cured.

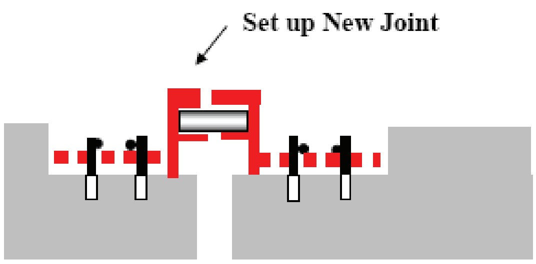
i. Cut concrete surface

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

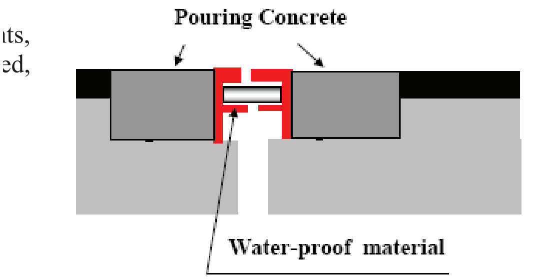
ii. Chipping off concrete/dismantling expansion joint

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 the concrete.	

iii. Set up new expansion joint

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

iv. Pouring concrete

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

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurement shall be in linear meters (m).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for replacement of the expansion joint as detailed in plans and specifications.

3.3.6 Major Repair Methods in Bridge Bearings

Major repair methods carried out to bridge bearings are; replacement of bearings, extension of bearing seat, jacking up of girders and repainting of steel bearings.

The defects addressed in this section of the manual are listed in Table 3-13.

Table 3-13: Defects addressed in major repairs to bridge bearings

Classification	Repair/Strengthening Method	Method	Defects Addressed
Major Repairs	Repair	Replacement of bearings	Cracking Sever bulging Loose connection
	Repair	Extension of bearing seat	Spalling Delamination
	Repair	Jacking up of girders	Misaligned bearings Replacement of bearings
	Repair	Repainting of steel bearings	Corrosion

3.3.6.1 Replacement of Bearing

Definition

This refers to the removal of the defective bearings in parts or full, and reinstatement.

This can be either;

- Part replacement of bearing,
- Full replacement of bearing with a similar type,
- Full replacement of bearing with a different type.

A bridge bearing is a component of a bridge which typically provides a resting surface between bridge piers and the bridge deck. The purpose of a bearing is to allow controlled movement and thereby reduce the stresses involved.

The possible causes of movement are thermal expansion and contraction, creep, shrinkage, or fatigue due to the properties of the material used for the bearing. 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 of bearing shall be implemented if existing rubber bearings already exhibited severe cracks and abnormal bulging. Old steel bearings need to be replaced especially if loose connections were observed. This repair method forms part of the jack-up girder. The capacity of the new bearing should be the same as the old bearing, subject to approval of the Engineer.

Scope of Works

- It involves utilization of jack-up girder technique to allow for replacement of bearings. The respective girder shall be jacked up from 5 mm to 10 mm with one jack stroke.

Photo 3-13: Sample of replacement of bridge bearing

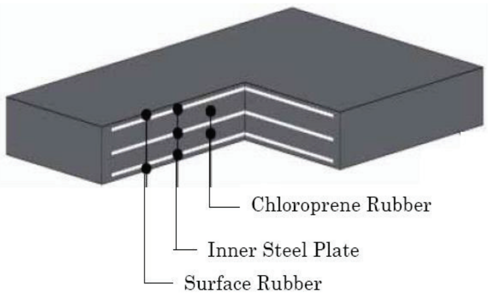


Figure 3-49: Sample of rubber bearing

Required Materials, Tools/Equipment and Personnel

i. Required Material

- Elastomeric bearing pads
- Rebars
- Mortar/concrete

ii. Required Tools/Equipment

- Hydraulic jack
- Electrical jackhammer
- Trowel

iii. Required Personnel

Skilled Personnel trained by KIHBT and Registered/Accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

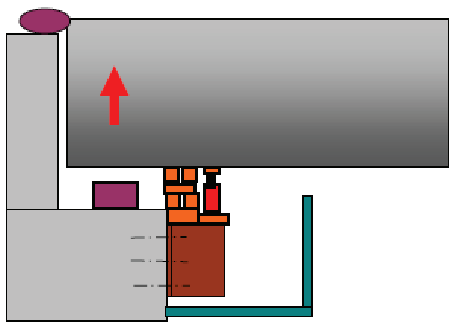
i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

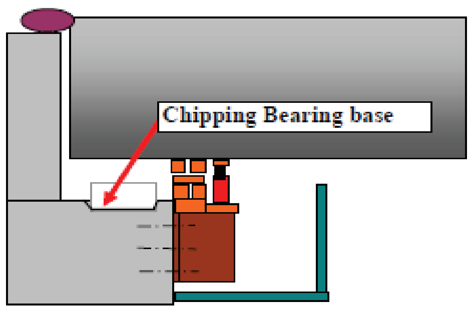
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Jack up girder

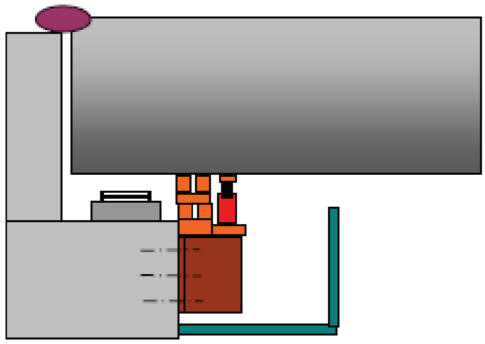
The surface of expansion joint shall be secured to provide safety for passing traffic during jacking up process. Moreover, the height difference between surface of abutment and girder shall be kept below 10 mm.	

ii. Dismantle existing bearing and chipping bearing base

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

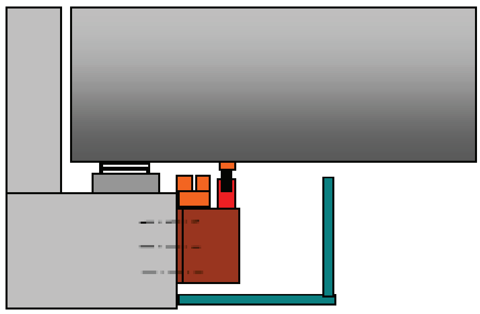
iii. Cast new bearing seat and set up new bearings

After concrete chipping and new required bed support replacement with rebar will be 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.



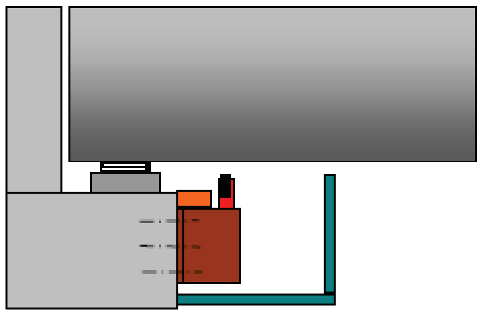
iv. Jack down girder after curing

After curing of bearing bed, 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.



v. Dismantle jacks and temporary support 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



Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurement shall be in Number of Bearings Replaced.

The Payment shall cover full compensation for furnishing, preparing, fabricating, transporting, placing and installation.

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for replacement of the expansion joint as detailed in plans and specifications.

3.3.6.2 Extension of Bearing Seat

Definition

The bearings transmit all the loads (dead load, live load, wind pressure, and others) from the superstructure to the substructure. Consequently, the reaction is concentrated near the bearing seat. This sometimes causes damage to the bearing seat.

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 will be reduced. Hence, this repair method is intended to eliminate said risk by extending further the existing bearing seat.

Scope of Works

The repair method involves:

- Complete removal of damaged concrete bearing seat if defects are noted,
- Repair of damaged concrete bearing seat,
- Anchor bars shall be connected to the existing bearing seat to extend the concrete seat width accordingly,
- Concreting the extended bearing seat.

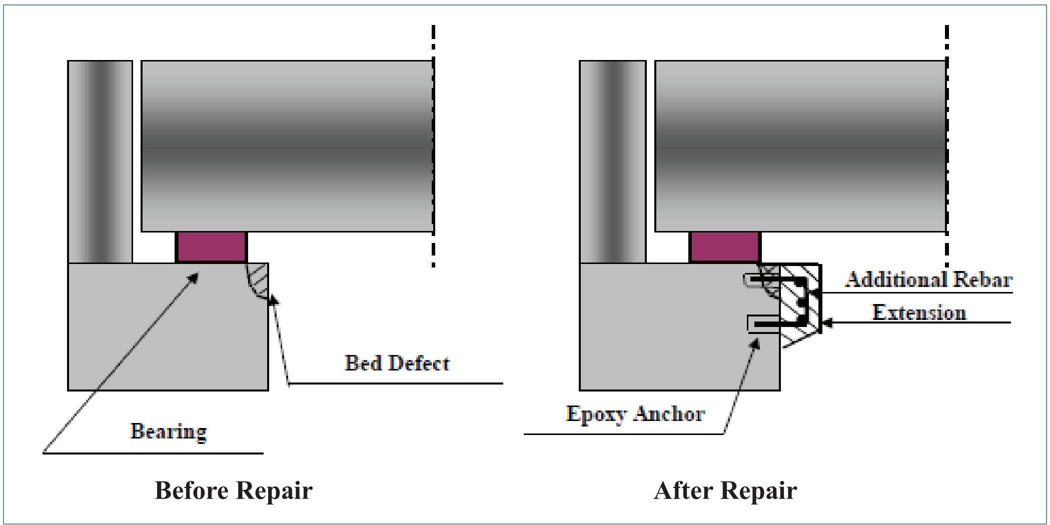


Figure 3-50: Concept of extension of bearing seat

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Primer to concrete surface (epoxy adhesive)
- Epoxy anchor bolts
- Formwork
- High strength concrete and/or grouting mortar
- New reinforcement bars to specifications

ii. Required Tools/Equipment

- Electric drill
- Electric concrete vibrator
- Trowel
- Hammer
- Concrete pump
- Water bowser
- Electric jackhammer for chipping

iii. Required Personnel

Skilled Personnel trained by KIHBT and Registered/Accredited by NCA.

Preparation for Works

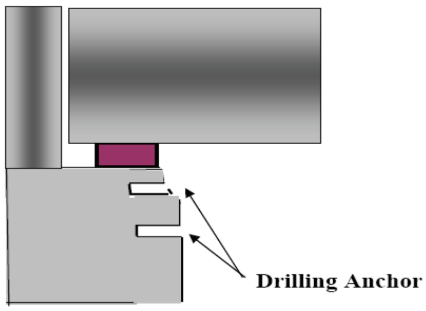
- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

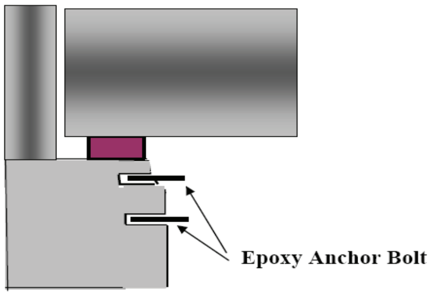
i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

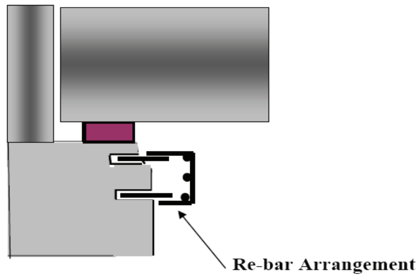
i. Chipping and drilling holes

The spalled or delaminated potion shall be removed completely by hammer chipping or electric drilling. Holes for anchor bar shall be by drilled using electric drill device. Drilling of holes shall be performed carefully in order to avoid damaging existing coping reinforcements.	

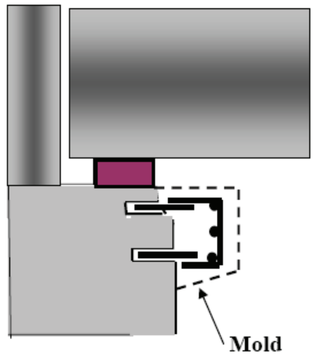
ii. Anchor bar fitting

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

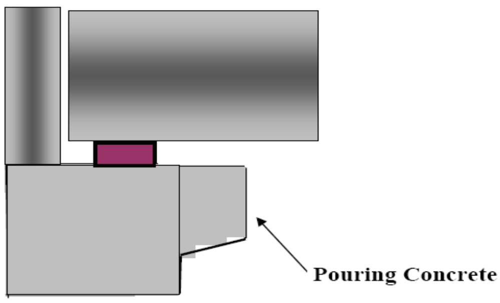
iii. Arrangement of rebars

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

iv. Formwork

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

v. Pouring 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.	

Monitoring & Evaluation

Monitoring and evaluation of repaired section by the Engineer.

Measurement and Payment

Measurement shall be in Cubic Metres (m^3).

Payment shall include full compensation for removal of deteriorated concrete, surface cleaning and preparation, furnishing and placing all materials, labour, equipment and tools as well as construction and removal of formworks and other temporary works necessary to complete this works.

3.3.6.3 Jack Up Girder

Definition

This method is applied for replacement of bearings and re-arrangement of existing bearings.

Scope of Works

The computation of jack-up reaction shall be the responsibility of the designated Structural Engineer in with an input of the Contractor's structural engineer. Once the required quantity and capacity of hydraulic jacks are determined, this repair method shall then progress. 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 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 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 3-14: Sample of replacement bearing by jacking-up girder

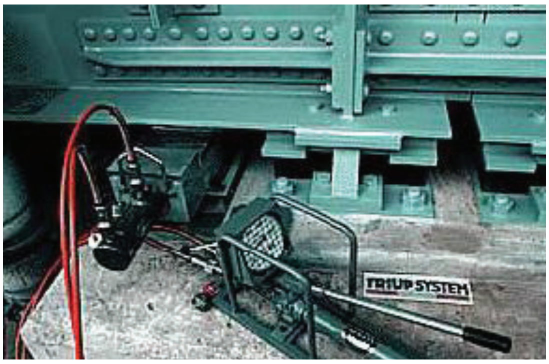
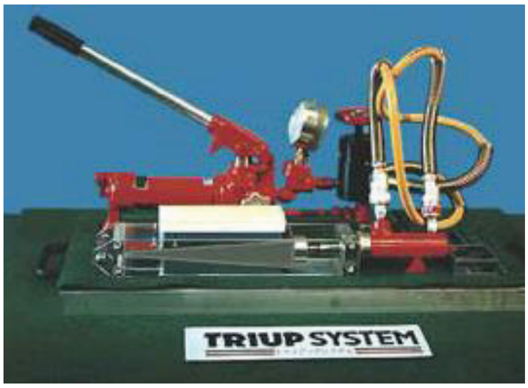
	

Photo 3-15: Hydraulic Jack	*Photo 3-16: 50 Ton Hydraulic Jack*

Required Materials, Tools/Equipment & Personnel

i. 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)

ii. Required Tools/Equipment

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

iii. Required personnel

Skilled personnel trained by KIHBT and registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

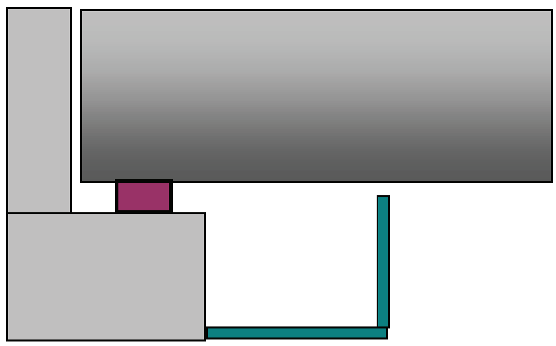
A. *Sequence of jack up method*

The procedure of Jack-up method for replacement of bearings is:

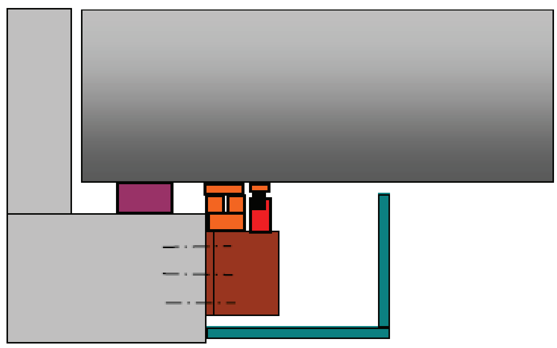
1. Assemble the scaffoldings,
2. Observation and measurement of existing bearing and site cleaning,
3. Fabrication of bearing stiffener, temporary support member and jack-base bracket,
4. Installation of jack-base bracket and welding of bearing stiffener,
5. Jack-up operations,
6. Chipping of existing concrete bearing base,
7. Removal of existing bearing,
8. Provision of new bearing base,
9. Installation of new bearing,
10. Jack down operations,
11. Verification of measurements and finishing,
12. Painting,
13. Dismantling Jack-base bracket and scaffoldings.

Below is the detailed sequence of carrying out the exercise:

i. Assemble scaffolding

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.	

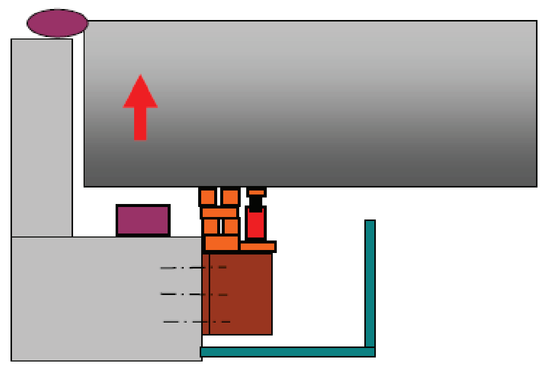
ii, Installation of Jack base frame

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.	

iii. 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.

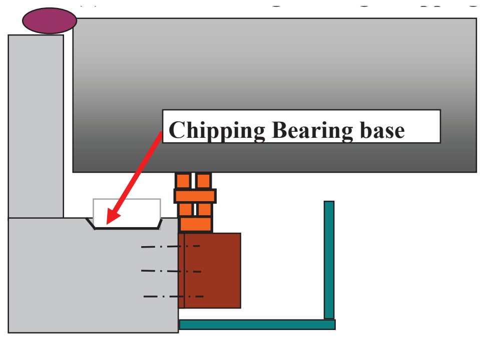
The method is repeated in gradually until enough jacking up height is achieved to allow for dismantling of the existing bearing.



iv. Chipping bearing base and remove existing bearing

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

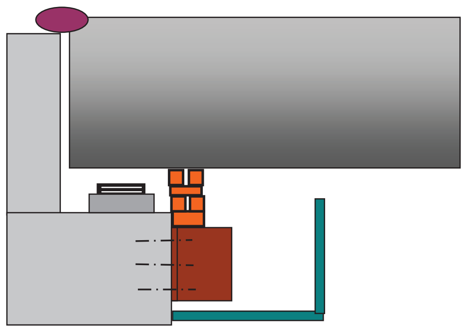
A slope between bridge approach and the expansion joint shall be maintained for passing traffic during jacking-up operations.



v. Making new bearing base

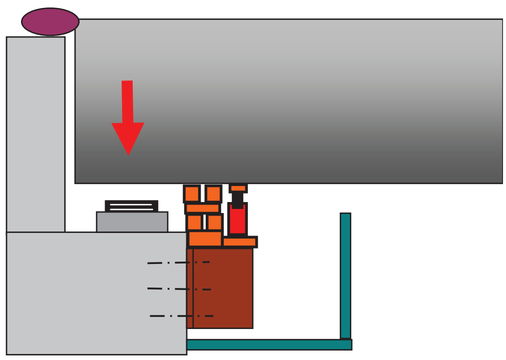
Additional re-bars for the new bearing base shall be arranged.

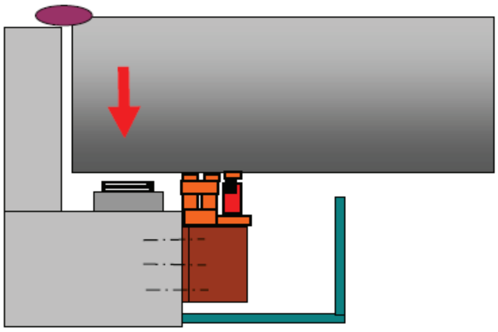
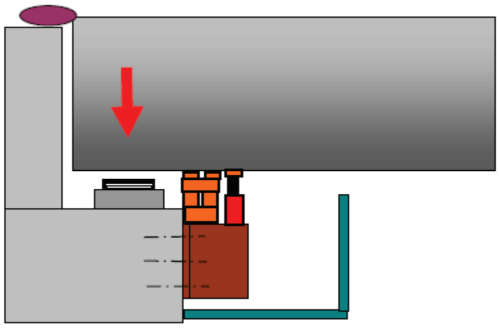
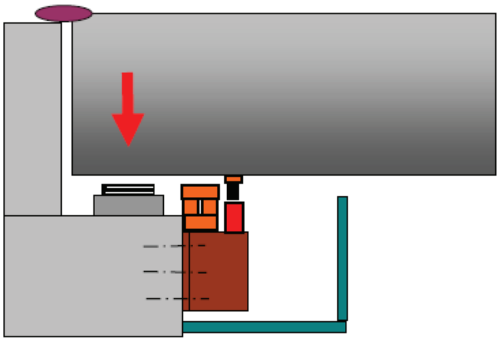
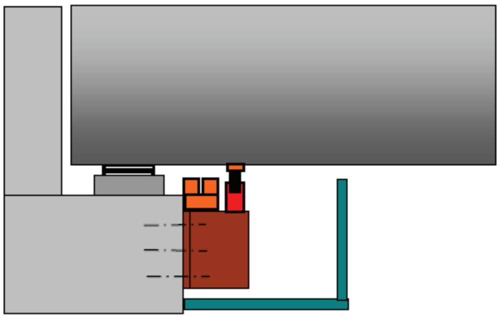
After concrete is completely placed, new rubber bearings are installed on the bearing base. During this operation, the girder shall be temporarily supported. The measurement of height, location shall be carefully verified by a designated inspector.



vi. Jack down

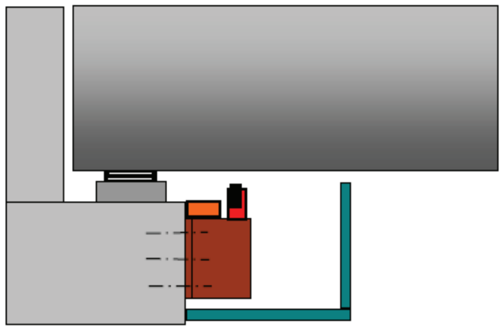
If the new bearing installed is determined satisfactory, jack down operations shall commence. It is important to maintain safety during this operation. Jacking down shall be carried out gradually while carefully removing the temporary supporting members.



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 jack and remove 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.	

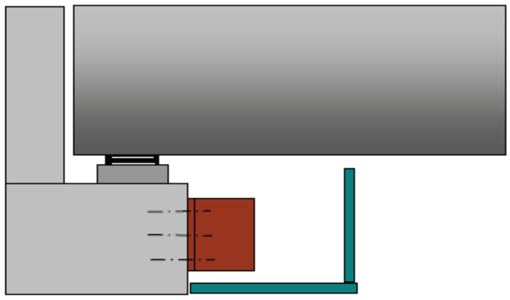
vii. Verification of measurement

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



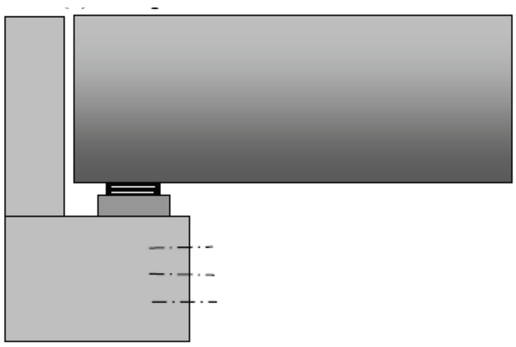
viii. Dismantle jacks and temporary supports

Jacks and temporary support materials shall be dismantled.



ix. Completion

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

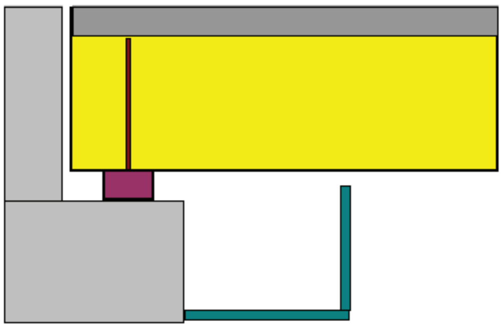


B. For steel girder

Preparation of materials, equipment and site cleaning:

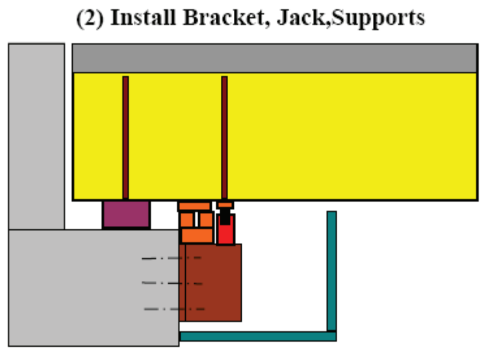
i. Installation of scaffolding

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



ii. Welding temporary jack stiffeners

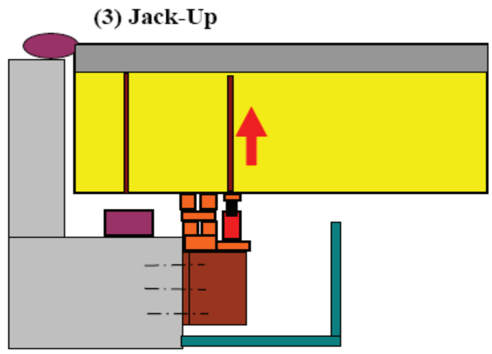
Jack stiffeners shall be welded to both sides of web plate. Jack-base bracket is installed using epoxy anchor installed at drilled holes for anchor bolts.



iii. 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.

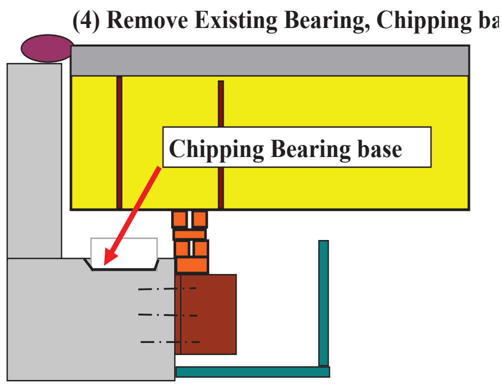
The method is repeated in gradually until enough jacking up height is achieved to allow for dismantling of the existing bearing.



iv. Chip-off bearing base and remove existing bearing

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

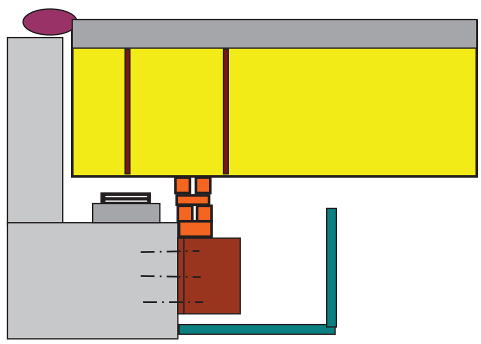
A slope between bridge approach and the expansion joint shall be maintained for passing traffic during jacking-up operations.



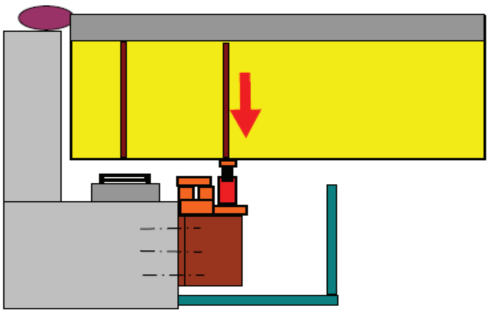
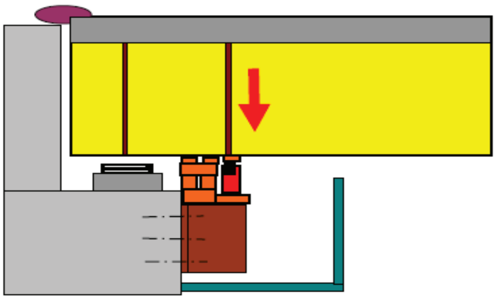
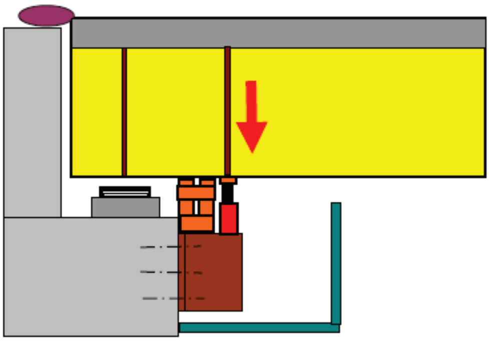
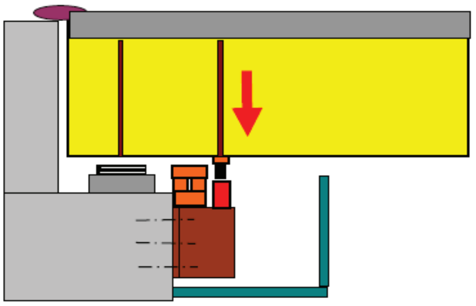
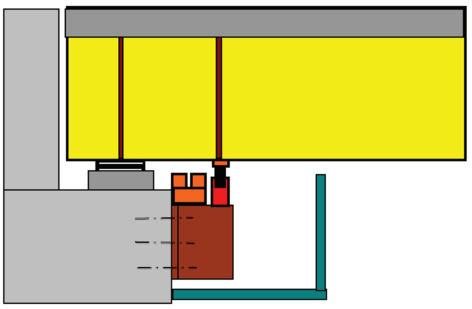
v. Making new bearing base

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

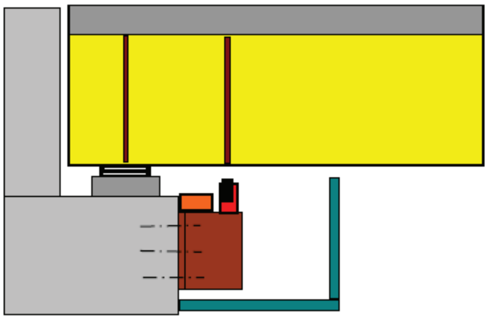
After concrete is completely placed, new rubber bearings are installed on the bearing base. During this operation, the girder shall be temporarily supported. The measurement of height, location shall be carefully verified by a designated inspector.



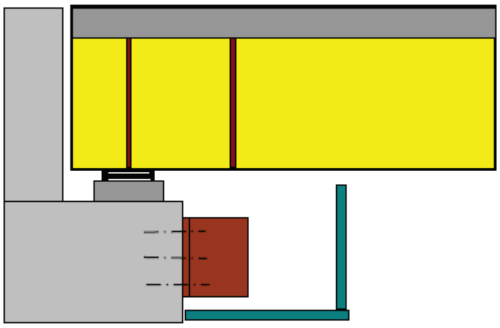
vi. Jack down

If the new bearing installed is determined satisfactorily, 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 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 jack and remove 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.	

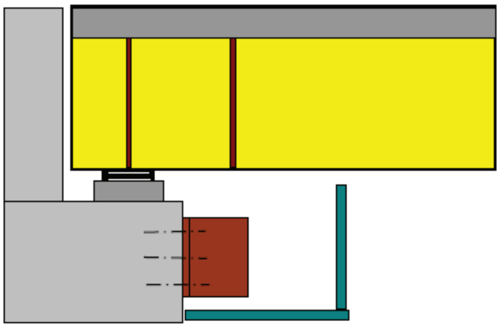
vii. Inspection of measurement

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

viii. Dismantle Jacks and temporary supports

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

ix. Completion

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

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in Number of Jacks used.

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for jacking up the girder as detailed in plans and specifications.

3.3.6.4 Repainting Steel Bearing

Definition

This refers to the application of a new coat of paint to a steel bearing surface that was initially painted.

Typically, due to the deterioration of water proofing at expansion joints over the years, steel bearings underneath the superstructure are subjected to corrosion.

Scope of Works

Steel bearings shall be subject to repainting if based on results of bridge inspection, a “Bad” rating is given due to observed severe corrosion or section loss of more than 20%.

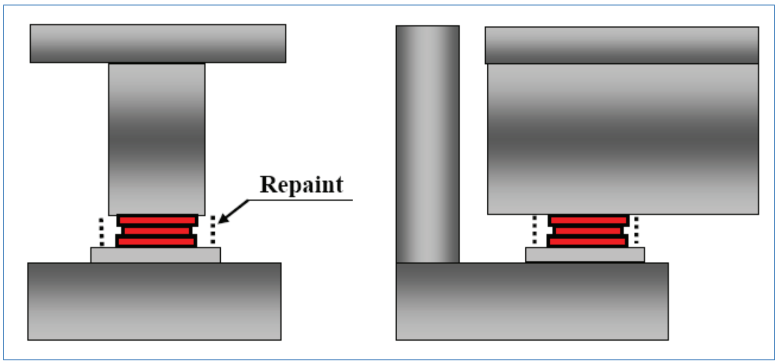


Figure 3-51: Repainting of steel bearing

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Zinc-rich base primer.
- Polyurethane Aluminium Paint – Aluminium paint shall consist of aluminium bronze powder or paste of the required fineness and composition to which shall be added the specified amount of agent component.
- Thinner.
- Modified epoxy polyimide primer.
- Anti-Corrosion paint.

ii. Required Tools/Equipment

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

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Works Sequence

This repair method is basically similar to requirements in the section of repainting and special anti-corrosion paint.

i. Scaffolding

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

ii. Surface preparation for steel bearings

Surface preparation for steel bearings is requisite to repainting required. The surface preparation classification shall be as per described in touch up painting.

The 1st Grade preparation is intended for severely corroded steel surface, where sand blast machine is utilized to achieve near white blast surface.

The 2nd Grade preparation is for fairly to badly corroded steel surface where electric disc grinder will be necessary to remove the remaining coating film.

Lastly, 3rd Grade preparation is applied to surfaces where sound coating film still remains. Cleaning for this preparation requires wire brush, scraper and electric disc grinder.

During removal of coating film, it is important to ensure that the works do not have impacts to the environment as it could scatter dust, dirt and scale that may contain lead and other harmful elements.

iii. Painting

Painting is mainly 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.

Monitoring & Evaluation

Monitoring of repainted section by the Engineer.

Measurement and Payment

Measurement shall be in square meters (m^2).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for repainting steel bearing as detailed in plans and specifications.

3.3.7 Major Repair Methods in Underpinning Foundations

The repair methods carried out during underpinning of foundations are; pit or mass concrete method, pile method, jack pile method, root or angle piling method, pynford stool method and underpinning columns/piers/piles.

Underpinning is a method used to repair and strengthen the foundation of a building or structure. During underpinning, reinforcements are positioned throughout the length or breadth of an already established base. Because of this, its weight is distributed across a larger area and rests on solid earth layers. Micro-piling and jet grouting are common underpinning methods, despite being time-consuming and costly.

The defects addressed in this section of the manual are listed in Table 3-14.

Table 3-14: Defects addressed in underpinning foundations

Classification	Repair/Strengthening Method	Method	Defects Addressed
Major Repairs	Repair	Pit Or Mass Concrete Method Pile Method Jack Pile Method Root Or Angle Piling Method Pynford Stool Method Underpinning Columns/ Piers/Piles	Settlement Lateral movement Scouring Sapping

3.3.7.1 Pit or Mass Concrete Underpinning

Definition

It involves excavating pits below the existing foundation and pouring mass concrete into the excavated pits to provide additional support and stability hence strengthening and stabilizing the existing structure.

Scope of Work

It involves increasing the size of the present foundation to specifications. Stages or pegs are used to reveal the soil beneath the current foundation. After the desired layers have been reached, the excavation is backfilled with concrete and left to dry before the next removal process can begin.

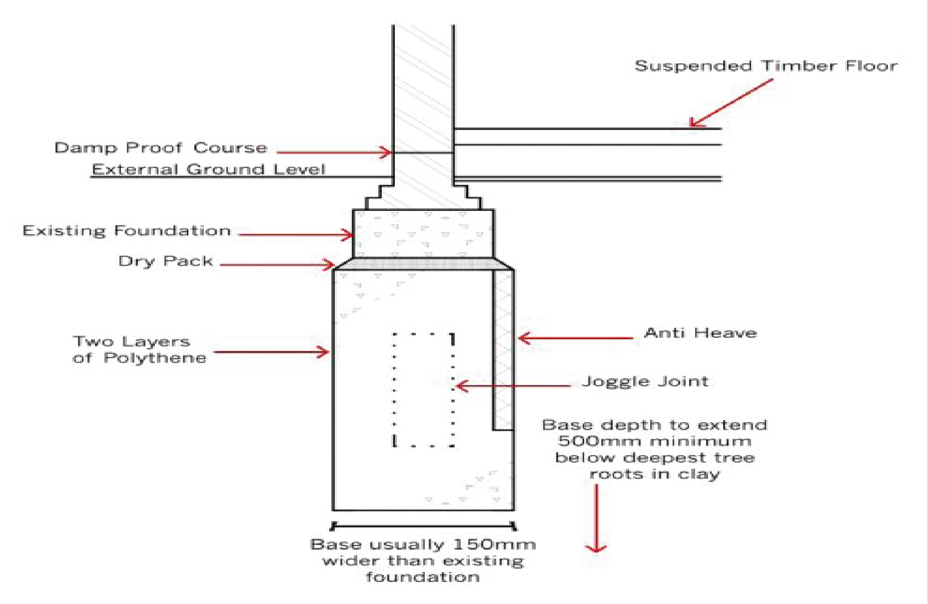


Figure 3-52: Pit or mass concrete underpinning

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Anchors or Tendons
- Formwork
- Cementitious Mortar or Adhesive
- Grout
- Reinforced concrete (Class 25)
- Concrete and steel piles

ii. Required Tools/Equipment

- Concrete mixers
- Grouting pumps
- Excavators
- Fastener devices
- Laser and spirit levels
- Hydraulic jack and pump
- Grinder
- Generator
- Welding machine
- Hammers
- Wrenches
- Pliers
- Chisels
- Saws

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Survey and marking

Conduct a detailed survey of the areas to be underpinned and mark the specific locations for the excavated pits. This should be based on engineering calculations and drawings provided.

ii. Excavation of pits

Excavate pits below the existing foundation at the marked locations. The depth and dimensions of the pits will vary based on the structural load and soil conditions.

iii. Installation of temporary support

Install temporary support structures (needles or steel beams) to ensure the stability of the existing structure during the excavation process.

iv. Excavation and cleaning

Carefully excavate the pits, removing any loose or unstable soil to create a clean surface for pouring the mass concrete. Remove any debris or loose material from the pits to ensure a solid foundation. Compact the resultant surface.

v. Preparation for concrete pouring

Place a layer of blinding concrete (Class 15) or a suitable levelling material at the base of the excavated pits to provide a stable foundation for the mass concrete.

Install reinforcement bars (rebar) if specified in the design to enhance the structural strength of the underpinning.

vi. Concrete mixing and pouring

Prepare the mass concrete mix of Class 25, pour the mass concrete into the excavated pits, making sure it completely fills the pits and forms a solid foundation. Concrete should be evenly distributed and compacted to eliminate air pockets.

vii. Curing and setting

Allow the mass concrete to cure and set according to the recommended curing procedures to achieve the desired strength and stability.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be made as guided and instructed by the Engineer.

Payment shall be made based on all activities involved during the entire process of underpinning.

3.3.7.2 Pile Underpinning

Definition

The Pile Method of underpinning is a technique used to strengthen or stabilize the foundation of a structure, typically when the existing foundation is inadequate or unstable.

Scope of Work

This method involves driving or installing piles into the ground beneath the existing foundation to transfer the load of the structure to a more stable and stronger layer of soil or rock.

The borehole is normally supported by piles that have been under-reamed. Steel or concrete "needles" are regularly driven into the wall and connected to the foundation piles. These metal or cement piles serve as a support structure and a pile cap. Water-logged soils, clay, and shaky bearing stratum are ideal conditions for installing underpinning piles.

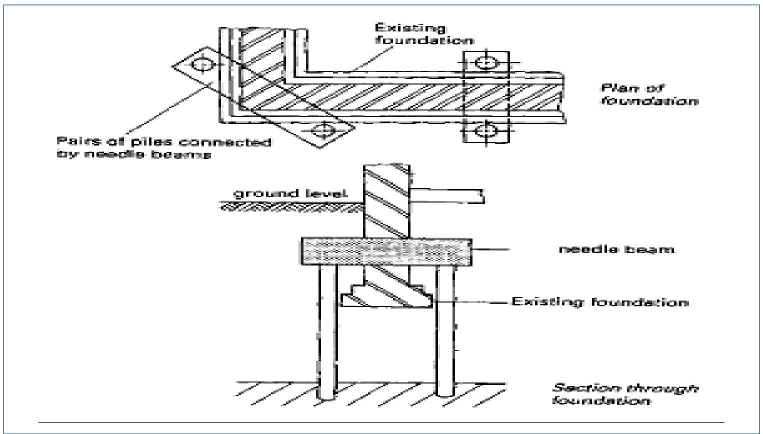


Figure 3-53: Pile method of underpinning

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Anchors or Tendons
- Formwork
- Cementitious Mortar or Adhesive

- Grout
- Reinforced concrete
- Concrete and steel piles

ii. Required Tools/Equipment

- Concrete mixers
- Grouting pumps
- Excavators
- Fastener devices
- Laser and spirit levels
- Hydraulic jack and pump
- Grinder
- Generator
- Welding machine
- Hammers
- Wrenches
- Pliers
- Chisels
- Saws

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Preparation and excavation

Clear the area around the foundation and mark the locations where the piles will be installed.

Excavate holes at each marked location to the specified depth where the piles will be inserted.

ii. Pile installation

Install the piles using appropriate techniques such as driven piles, drilled piles, or screw piles depending on the design and site conditions.

Drive or drill the piles into the ground to reach the desired depth and ensure they are properly embedded in the stable soil or rock.

iii. Load transfer and testing

Gradually transfer the load of the existing structure onto the newly installed piles, ensuring a smooth and controlled transition of the load.

Conduct load tests to verify the load-bearing capacity of the piles and adjust the installation if needed to meet the required standards.

iv. Additional structural support

Integrate additional structural elements, such as caps, beams, or tie beams, to connect and distribute the load among the piles and provide additional stability.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be made as guided and instructed by the Engineer.

Payment shall be made based on all activities involved during the entire process of underpinning.

3.3.7.3 Jack Pile Underpinning

Definition

The Jack Pile Method of underpinning is a technique used in construction and foundation engineering to strengthen or stabilize an existing structure's foundation. This method involves driving steel piles into the ground and using hydraulic jacks to raise and support the foundation. It's designed to provide additional support and stability to an existing foundation that may have settled, weakened, or requires reinforcement.

Scope of Works

The jack pile is driven in to the foundation. The pile depth may be adjusted to suit the underlying soil, jack pile underpinning is silent, vibration-free, and adaptable. Since the pile caps are cast directly onto the jack pile heads once the hydraulic jacks have been removed, the condition of the existing foundations is critical.

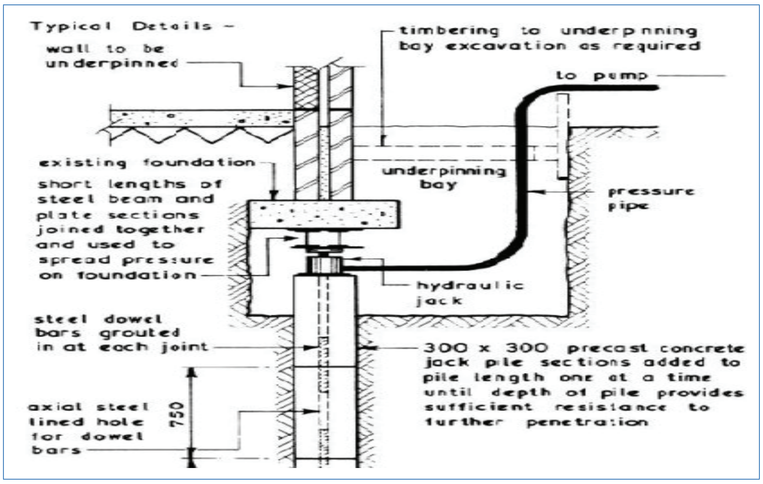


Figure 3-54: Jack pile method of underpinning

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Anchors or Tendons
- Formwork
- Cementitious Mortar or Adhesive
- Grout
- Reinforced concrete
- Concrete and steel piles

ii. Required Tools/Equipment

- Concrete mixers
- Grouting pumps
- Excavators
- Fastener devices
- Laser and spirit levels
- Hydraulic jack and pump
- Grinder
- Generator
- Welding machine
- Hammers
- Wrenches
- Pliers
- Chisels
- Saws

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Site preparation

Develop a detailed plan, considering soil conditions, structural load, foundation type, and the number and location of piles required.

Mark the predetermined locations for pile installation around the perimeter of the existing foundation based on the project plan.

ii. Pile installation

Use specialized equipment to drive steel piles into the ground at these marked locations until they reach stable soil or rock.

iii. Hydraulic jacking

Place hydraulic jacks on top of the driven piles to support the existing foundation and prepare for the lifting process.

Apply hydraulic pressure to the jacks to gradually raise the foundation and transfer the load from the original foundation to the newly installed piles.

iv. Gradual lifting and load transfer

Incrementally lift the structure using the hydraulic jacks, monitoring the process to ensure even and controlled lifting.

As the structure is lifted, observe the transfer of the load from the weakened foundation to the new piles beneath, providing support and stability.

v. Levelling and alignment

Adjust the lifting process to achieve the desired elevation and alignment of the foundation.

Ensure the structure is levelled evenly, correcting any settlement issues or irregularities in the original foundation.

vi. Additional structural support

Depending on project requirements, add additional structural components such as caps, beams, or tie beams to enhance the support and connectivity between the piles and the structure.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be made as guided and instructed by the Engineer.

Payment shall be made based on all activities involved during the entire process of underpinning.

3.3.7.4 Root or Angle Piling Underpinning

Definition

Root or Angle Piling is a technique used in foundation engineering to stabilize or strengthen the foundation of a structure, especially when dealing with challenging soil conditions or where deep foundation support is required. This method involves installing piles at an angle to provide additional lateral stability and load-bearing capacity to the structure.

Scope of Works

Line pairs of reinforced concrete piles are often installed or driven at right angles to one another. Predrilling using an air-flushed percussion drill reinforces the brick wall without disturbing the subfloor. It might be challenging to install angle piling inside a wall. As a result, they are stacked closely together to ensure their stability.

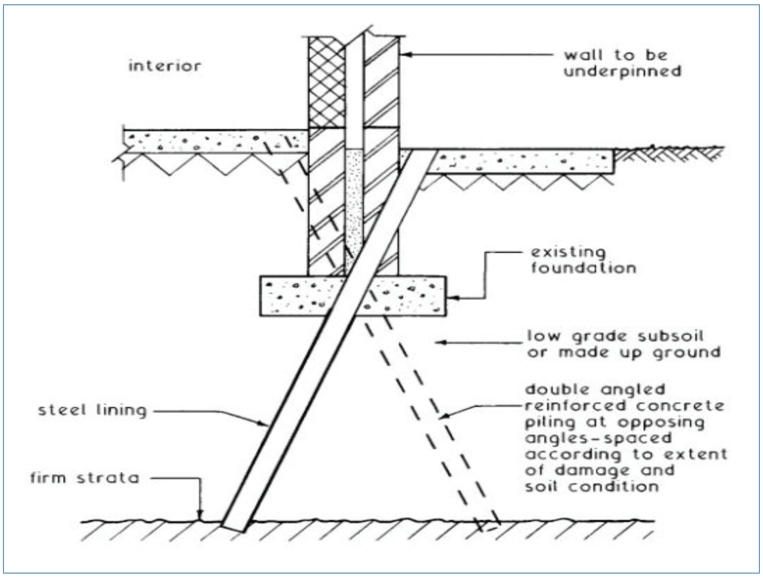


Figure 3-55: Root/angle piling method

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Anchors or tendons
- Formwork

- Cementitious mortar or adhesive
- Grout
- Reinforced concrete
- Concrete and steel piles

ii. Required Tools/Equipment

- Concrete mixers
- Grouting pumps
- Excavators
- Fastener devices
- Laser and spirit levels
- Grinder
- Generator
- Welding machine
- Hammers
- Wrenches
- Pliers
- Chisels
- Saws

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Site preparation

Analyze the structural load requirements and determine the appropriate inclination angles for the piles based on the site conditions and engineering calculations.

ii. Design of inclined piles

Design the inclined piles considering the required inclination angle, length, diameter, and reinforcement details based on the site-specific data and load-bearing capacity requirements.

iii. Pile installation setup

Set up the necessary equipment and machinery for pile installation, ensuring they are in proper working condition and comply with safety standards.

iv. Excavation and drilling

Excavate or drill holes at the predetermined locations and angles based on the design specifications for the inclined piles. The holes should be inclined relative to the vertical axis.

Ensure the holes are clean, free of debris, and penetrate to the stable stratum.

v. Pile installation at an inclined angle

Install the piles into the inclined holes, following the specified angle determined during the design phase.

Drive or install the piles to the designed depth, ensuring they reach a stable soil or rock layer.

vi. Grouting or filling

Fill the drilled holes with grout or concrete to secure and reinforce the inclined piles, providing additional stability and strength.

vii. Load transfer and connection

Connect the inclined piles to the structure's foundation or superstructure using appropriate connectors, caps, or beams to transfer the load effectively.

Ensure a strong connection between the piles and the structure for proper load distribution and stability.

viii. Load testing and verification

Conduct load tests on the installed inclined piles to verify their load-bearing capacity and performance.

Adjust the installation or reinforcement if needed based on the test results to meet the required standards.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be made as guided and instructed by the Engineer.

Payment shall be made based on all activities involved during the entire process of underpinning.

3.3.7.5 Pynford Stool Underpinning

Definition

The Pynford Stool Method is a type of underpinning technique used to support and stabilize existing structures that have experienced subsidence or require additional foundation support.

This method is primarily used to stabilize and strengthen foundations of existing structures, particularly in situations where conventional underpinning methods are not suitable or practical.

Scope of Works

When the current foundations are in poor form, this method can be employed to underpin the wall in one continuous run without using needles or shoring. The resulting reinforced concrete beam could be sufficient to distribute the weight of the existing wall, or it could be used in conjunction with other underpinning techniques, such as regular piles or jack piles.

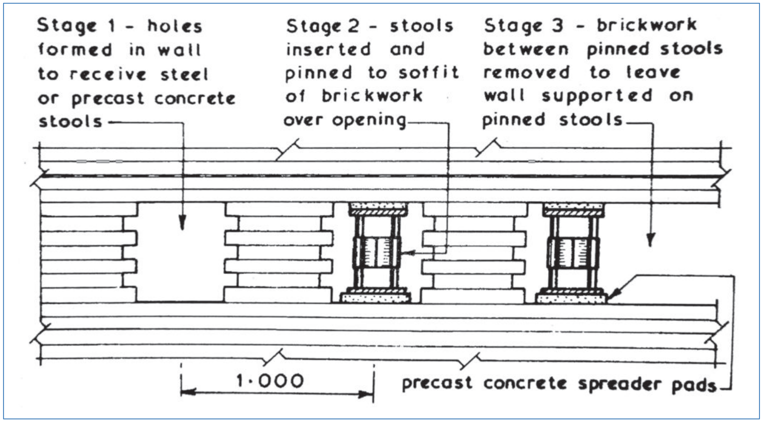


Figure 3-56: Process of Pynford stool underpinning (1/2)

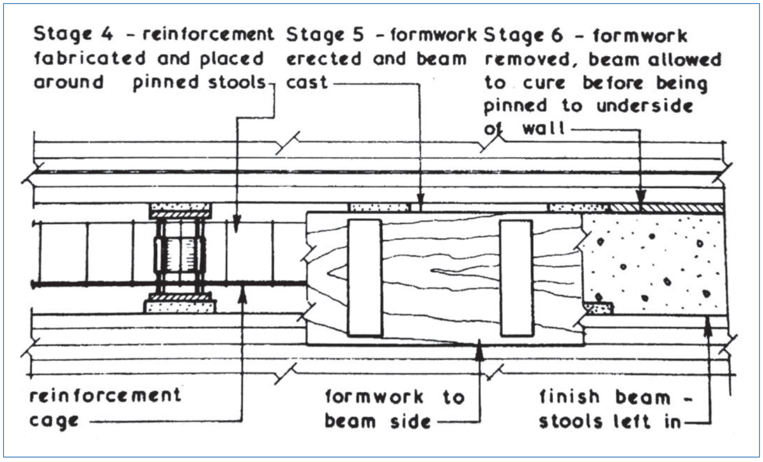


Figure 3-57: Process of Pynford stool underpinning (2/2)

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Anchors or Tendons
- Formwork
- Cementitious Mortar or Adhesive
- Grout
- Reinforced concrete

ii. Required Tools/Equipment

- Concrete mixers
- Grouting pumps
- Excavators
- Laser and spirit levels
- Hydraulic jack and pump
- Grinder
- Fastener devices
- Generator
- Welding machine
- Hammers
- Wrenches
- Pliers
- Chisels
- Saws

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Preparation of site

Clear the work area and ensure access for equipment and machinery. This includes removing obstructions and preparing the foundation area for the underpinning process.

ii. Excavation

Excavate around the existing foundation to expose the foundation footings or base, allowing for access to install the Pynford stools.

iii. Installation of pynford stools

Construct the Pynford stools by drilling or driving reinforced concrete piles into the ground at strategic locations and depths based on the engineer's design.

iv. Grouting and reinforcement

Fill the Pynford stools with grout to reinforce and secure them in place. The grout provides stability and helps distribute the load evenly.

v. Load transfer

Gradually transfer the load of the existing structure onto the newly installed Pynford stools. This may involve carefully jacking and supporting the structure while gradually transferring the load.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be made as guided and instructed by the Engineer.

Payment shall be made based on all activities involved during the entire process of underpinning.

3.3.7.6 Underpinning Columns/Piers/Piles

Definition

Underpinning columns, also known as underpinning piers or foundation underpinning**,** refers to a structural reinforcement technique used to strengthen and stabilize the foundation of an existing building or structure. The procedure for underpinning columns involves reinforcing and stabilizing an existing building or structure foundation by installing additional support columns or piers.

Scope of Works

Once the columns' loads have been removed, they can be supported in the same way as walls are with conventional or jack piles. When dead beaches are used, beam loads are taken off the columns, and the real column weight is transferred by two beams resting on a collar at the base of the column shaft.

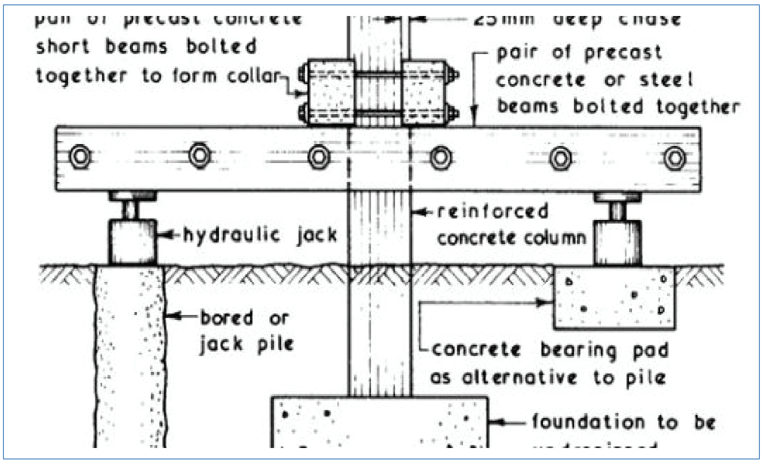


Figure 3-58: Underpinning columns/piles

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Formwork
- Cementitious Mortar or Adhesive
- Grout
- Reinforced concrete
- Helical piles-screw like steel shafts
- Epoxy resin

ii. Required Tools/Equipment

- Concrete mixers
- Grouting pumps
- Excavators
- Piling rig
- Rotary drill
- Hydraulic jack and pump
- Laser and spirit levels
- Grinder
- Generator
- Welding machine
- Hammers
- Wrenches
- Pliers
- Chisels
- Saws

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Site preparation

Clear the work area around the foundation, ensuring there is adequate space for machinery and equipment. Remove any obstructions and debris from the work area.

ii. Excavation

Excavate the area around the existing foundation in a controlled and systematic manner to expose the foundation to the required depth. Excavation is typically done in sections to maintain stability.

iii. Foundation reinforcement

Install the additional support columns, piers, or piles to reach a more stable soil layer or rock. The type of columns used may vary based on the engineer's design and the specific soil conditions.

iv. Column installation

Install the chosen columns or piers in the excavated holes. Depending on the type, this may involve drilling, driving, or other installation methods. Ensure the columns reach the recommended depth for stability.

v. Grouting or filling

Fill the holes around the columns with grout or concrete to provide additional stability and ensure the columns are firmly positioned.

vi. Load transfer

Gradually transfer the load of the existing structure onto the newly installed support columns. This is typically done in a controlled and monitored manner to ensure the structure remains stable throughout the process.

vii. Verification and adjustments

Verify that the structure is now supported by the newly installed columns and that the load is adequately distributed. Make any necessary adjustments to achieve the desired level of stabilization.

viii. Backfill and site cleanup

Backfill the excavated area around the reinforced foundation with suitable materials and compact it properly. Clean up the work area and restore the site to its original condition.

Monitoring & Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be made as guided and instructed by the Engineer.

Payment shall be made based on all activities involved during the entire process of underpinning.

3.3.8 Major Repair of Bridge Approach Slab Settlement

Definition

The difference in elevation between the approach pavement and the bridge deck results from a complex interaction between the bridge structure, backfill soils and foundation soils; poor drainage is one contributing factor. The settlements can result in unsafe driving conditions, rider discomfort, structural deterioration of bridges and long-term maintenance costs.

Cohesive soils are greater contributors to bridge approach settlement than granular soils because cohesive soils are frost-susceptible, absorb water, settle over time and may become weaker when wet.

The major repair methods carried out for the settlement of the bridge approach slab are; mud jacking/slab jacking and polyurethane concrete raising method.

The defects addressed in this section of the manual are listed in Table 3-15.

Table 3-15: Defects addressed in major repairs to bridge approach slab

Classification	Repair/Strengthening Method	Method	Defects Addressed
Major Repairs	Repair	Mud jacking/slab jacking method. Polyurethane concrete raising method.	Settlement

Scope of Works

Polyurethane concrete raising and mud jacking are two methods used to raise and support sunken or unstable settlement on concrete slabs, by drilling holes and pumping material under the concrete slab.

i. Mud jacking/slab jacking method

Mud jacking – also known as slab jacking or concrete lifting, is a proven, cost-effective method for raising and levelling settled concrete. Tilted sidewalks, uneven patios and cracked driveways are just a few of the problems that can be fixed with this repair method.

ii. Polyurethane concrete raising method

Polyurethane foam method, uses the concrete slab itself as a means of delivering poly foams that raise concrete slab, fill voids, and stabilize soils.

Required Materials, Tools/Equipment & Personnel

i. Required Materials

Mud jacking/slab jacking method

- Concrete

Polyurethane concrete raising method

- Polyurethane foam

ii. Required Tools/Equipment

Mud jacking/slab jacking method

- Concrete drilling machine
- Hydraulic mud jacking pumps
- Mounted paddle grout mixers

Polyurethane concrete raising method

- Concrete drilling machine
- Polyurethane foam injection system with air-purged gun
- Polyurethane concrete raising systems
- Foam slab jacking pumps

iii. Required personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

3.3.8.1 Mud Jacking (Slab Jacking) Repair Method

Mud jacking, also referred to as slab jacking, concrete raising or pressure grouting, is the process of raising concrete slabs by hydraulically pumping a grout mixture, usually sand based material infused with Portland cement, under the slab of concrete.

Work Sequence

There are three-steps for mud jacking /slab jacking process for concrete repair. These include:

i. Drill mud jacking holes in the concrete slab

To start the mud jacking process, the concrete repair contractor drills several holes in the slab. The holes must be strategically patterned, to effectively raise the slab back to an even position. In most cases, the mud jacking holes will be placed about 600mm to 1200mm apart.

These holes are usually about 50mm in diameter. The number of holes needed for a mud jacking project will vary, depending upon the extent of the concrete damage.

ii. Pump mud jacking slurry through the holes

For the next step in mud jacking, Portland cement is combined with water and other materials, such as sand, dirt or limestone aggregate. This mud-like mixture is then hydraulically pumped under the concrete through the drilled holes.

The mud jacking slurry spreads out under the concrete slab as it is pumped, filling empty spaces or voids to stabilize the soil foundation. Once the voids are filled, the cement mixture becomes pressurized, and this is what actually lifts the slab.

Carefully monitor the amount of slurry being pumped into each mud jacking hole, making adjustments as necessary to create an even surface.

iii. Fill the mud jacking holes and caulk the cracks

When the slab is level, the mud jacking process is finished. Clean the slurry mixture from the holes and refill them with new concrete.

Most small mud jacking projects take only an hour or two from start to finish. Larger jobs take longer, but are still usually completed within one day. Once the process is finished, the slab is ready for use after waiting for a few hours before putting any significant weight on the concrete.

Once the mud jacking is done, the remaining tasks include caulking any cracks within the concrete approach slab that may exist to prevent water penetration under the approach slab resulting in additional soil erosion, which can lead to further concrete slab damage.

3.3.8.2 Polyurethane Concrete Raising Method

Polyurethane foam method, uses the concrete slab itself as a means of delivering poly-foams that raise concrete, fill voids, and stabilize soils.

Raising concrete with polyurethane foam is done with incremental injections. Lifting foam will fully expand within 10-15 seconds allowing one to monitor the raising and preventing over raising the slab.

Using an air-purged gun to deliver foam under the slab. This equipment will keep the injection port open between injections, allowing the foam to fully expand before injecting more foam material.

Work Sequence

i. A 16 mm hole is drilled through the slab into the subgrade.

ii. A tapered delivery port is installed into the 16mm hole.

iii. The injection gun is connected to the port.

iv. The injection gun delivers the polyurethane material through the port and slab.

v. Expansion of the material occurs within seconds, compressing loose soils and raising concrete.

Monitoring and Evaluation

Monitoring and evaluation of the repaired bridge approach slab section by the Engineer.

Measurement and payments

Measurement shall be in Lump Sum (LS) for the repaired bridge approach slab section.

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for repairing the bridge approach slab as detailed in plans and specifications.

3.4 REPLACEMENT OF STRUCTURE

Definition

Replacement of a structure is the construction of a new structure as a whole or in part, to perform the functions of an old/dilapidated existing structure that can no longer serve its purpose or provide the utility required.

Replacement in parts can be replacement of bridge deck, joints, bearings, sidewalks, railings, overhead lighting, signs etc.

Scope of Works

The works shall entail replacement of an existing structure with a new one of required load carrying capacity and serviceability.It can be replaced as a whole or in parts. Where the new structure is to be constructed at the location of the existing one, then a temporary passage has to be provided for diversion of traffic to pave way for construction.

The procedure for execution are as outlined in Section Three of this manual.

Required Materials, Tools/Equipment & Personnel

i. Required Materials

- Fuel
- Gravel
- Steel
- Concrete
- Timber
- PVC

ii. Required Tools/Equipment

- Excavator
- Roller/Vibratory compactor
- Concrete mixer
- Poker vibrator
- Air compressor
- Tippers
- Excavators
- Cranes
- Grader
- Wheel loaders
- Hydraulic jack
- Concrete mixer
- Welding machine
- Hammer

iii. Required personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

For the case where the new structure is on a new location;

- Site clearance,
- Excavation for structure,

- Construction of the sub-structure components,
- Construction of superstructure components and approaches,
- Installation of road furniture,
- Protection works, and;
- Handover for maintenance.

For the case where the new structure is on the same location;

- Demolition of existing structure, and spoil to designated area,
- Excavation for foundations,
- Construction of the sub-structure components,
- Construction of superstructure components and approaches,
- Installation of road furniture,
- Protection works, and;
- Handover for maintenance.

Monitoring and Evaluation

Monitoring of replaced section by the Engineer.

Measurement and payments

Measurements to be done as per specifications and payments to be made based on interventions undertaken on the structure.

3.5 EMERGENCY BRIDGE REPAIR

Definition

It is maintenance required when an asset suffers an unexpected breakdown or change in condition that results in an immediate threat to health and safety. Emergencies always happen without warning, so this type of maintenance cannot be scheduled, but having properly prepared and executed preventive maintenance program will eliminate almost all emergency maintenance, the emergency occurrences that remain can then be handled under this repair.

Scope of Works

Emergency means stressful events that can cause greater damages. Emergency Maintenance (EM) is a type of maintenance intervention that is performed immediately the event occurs. EM is performed to restore the structure back to its normal working condition, it may involve replacement of damaged parts, strengthening or such works aimed at restoring use and ensuring safety.

There can be two types of situations of failures:

- **True emergencies** – These are failures that are very critical and cause greater damage to system. These failures are required to addressed immediately after failure occurs so that its negative impact can be minimized. These failures are considered true emergencies.

- **Non-emergencies** – These are failures that are not critical and causes do not cause greater damage to system. These failures do not require to be addressed immediately after failure occurs and can be addressed later whenever possible. These failures are considered non-emergencies.

This emergency repair process outlines repairs to be done under true emergency situations such as:

- Major repair/replacement of slabs,
- Major repair/replacement of railings,
- Major repair/replacement of piers,
- Repair rehabilitation or new construction of check dam when the bridge is at risk from scour,
- Remedial measures as maybe advised by experts after investigations.

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Steel members
- Concrete
- Hardcore
- Culverts
- Gabion boxes
- Formwork
- Warning tapes

ii. Required Tools/Equipment

- Tippers
- Excavators
- Cranes
- Grader
- Wheel loaders
- Hydraulic jack
- Concrete mixer
- Welding machine
- Hammer

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

1. Reporting the emergency occurrence.
2. Inventory of the bridge structure – to conduct an engineering survey of the structure and take immediate steps to shore it up. Roads, entrance and exit ramps and any other adjacent structures that might have been impacted should be inspected and evaluated.
3. Limiting access to the structure – as soon as a bridge emergency occurs, inspectors and engineers must work closely with police and local transportation workers to limit access to the damaged bridge.
4. Planning and budgeting of the works – The works budget will be developed and a systematic emergency budget plan held by the road agency to ensure that the emergency is well addressed.
5. Installation of temporary support – Install temporary structural support, including shoring and bracing, to protect response and recovery workers.
6. Work implementation – This shall involve undertaking works to meet the emergency needs. These works could involve demolitions, new constructions and the like, to ensure restoration of the structure utility.

Monitoring and Evaluation

Monitoring of repaired/replaced section by the Engineer.

Measurements and Payment

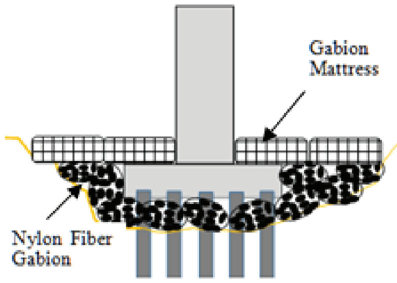
Measurements to be done as per specifications and payments to be made based on interventions undertaken on the structure.

3.6 REPAIR/RESTORATION OF PROTECTION WORKS

Definition

Repair to protection works on structures is the use of engineering and non-engineering measures to restore surfaces or installations upstream and downstream for continued protection against excessive wave action, erosion or adverse effects of rapid drawdown. Several defects occur on protection works as shown in Table 3-16.

Table 3-16: Common defects on protection works

Defect	Cause	Mitigation	
Damaged slope protection around the abutment/ pier	• Scouring • Rapid river flow • Improper construction-failure to provide foundation for slope protection	• Provision of gabion boxes • Stone pitching • River training • Provision of foundation to the protection work • Vegetation control • Slope patching	
Local scouring around the pier	• strong stream flow • Weak riverbed materials • Improper foundation.	• Provision of gabion boxes • River training • Proper reinstatement around foundation structures	
Damaged slope protection around the abutments	• Inadequate compaction of slope embankment • Strong stream flow • Insufficient flood drains	Slope patching.	
Local scouring to piles	Strong river flow	• Provision of gabion mattress as a standard repair method • Provision of nylon fibre gabion where the river bed shape is complicated	

Defect	Cause	Mitigation	
Deterioration of columns, piers and piles	• Adverse weather conditions • Lack of proper maintenance	Jacketing • Reinforced concrete jacketing • Steel jacketing • Fibre reinforced polymer jacketing • Glass fibre reinforced polymer jacketing	
Erosion of slopes/ embankments	• Absence of slope protection • Steep gradient, nature of embankment material	• Stone pitching • Grassing • Provision of gabion boxes • Slope stabilization	
Exposed concrete piles	• River bed degradation • Scouring • Lack of protection around piles	• Restoration of river bed level • Provision of gabion boxes • Concreting around the piles	
Slope failure	• Saturation of soils • Steep slope gradient	• Slope stabilization, • provision of weep holes,	

Scope of Works

Slope protection works generally involve determination and execution of mitigation measures to protect structures. All mitigation measures proposed for slope protection works are described as follows in Section 3.6.1.

3.6.1 Mitigation Measures

3.6.1.1 Slope Protection with Foundation Supported by Piles

Definition

This involves reinstatement of the damaged substructures foundation caused by scouring, rapid river flow, or improper construction and change in river course among others.

Slope protection around the substructures is often damaged due to scouring, rapid river flow, or improper construction. In most of the defective cases, foundation for the slope protection was not provided; hence, the protection eventually fails due to either sliding or scouring. Repair involves provision of appropriate foundation at its base.

Scope of work

The foundation should be a concrete base with wooden piles. The piles are normally driven to a minimum depth of 2.0 m. The foundation is usually placed at 1.0 m level below the river bed as shown in the Figure 3-59;

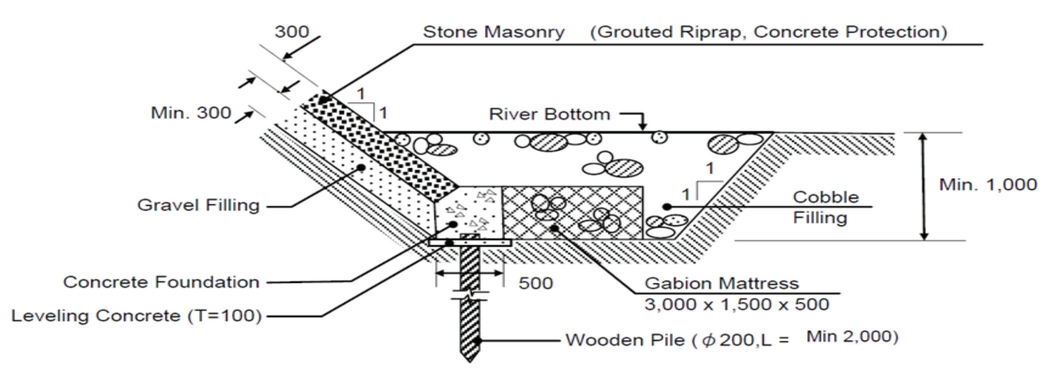


Figure 3-59: Foundation on pile for slope protection work

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Stone masonry
- Cobble stones
- Sand bags
- Gravel
- Gabion mattress
- Sheet piles
- Rock fill gabions
- Concrete with minimum steel reinforcements
- Filter fabric sheet (under gabion mattress)

ii. Required Tools/Equipment

- Vibratory compactor
- Dump truck
- Wheelbarrows
- Masonry tools

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

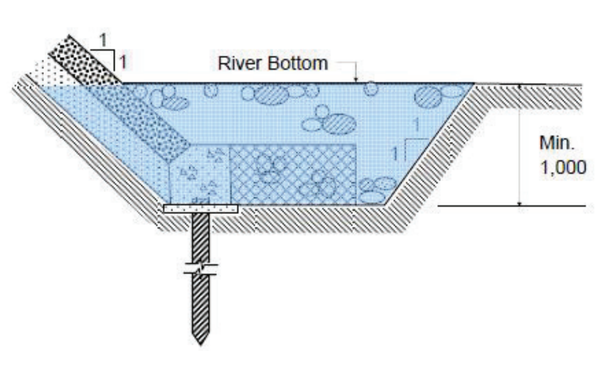
Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

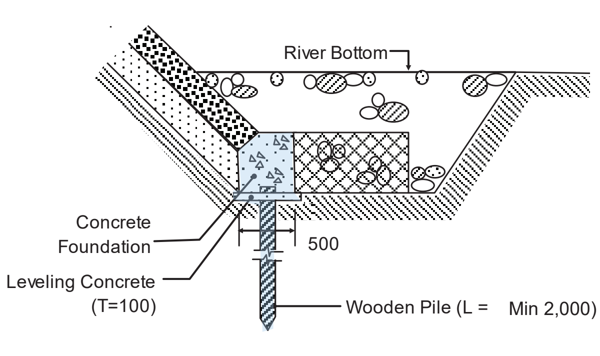
i. Excavation of scoured area

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



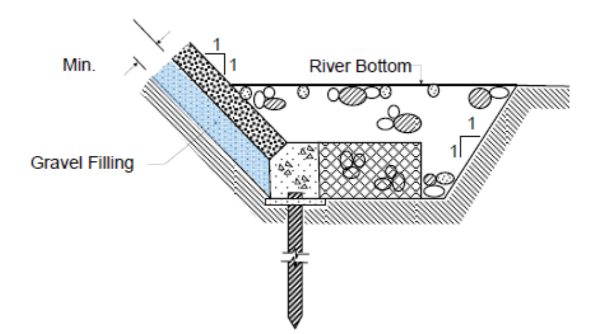
ii. Placing concrete foundation

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.



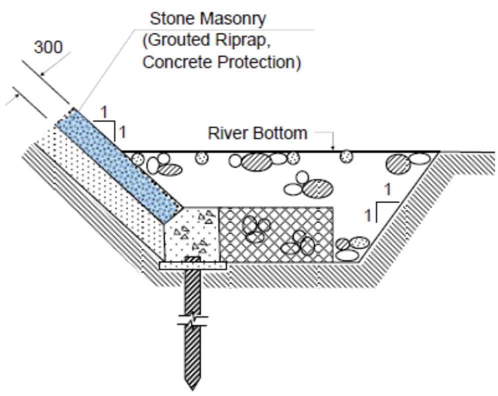
iii. Compaction of backfilled gravel

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.



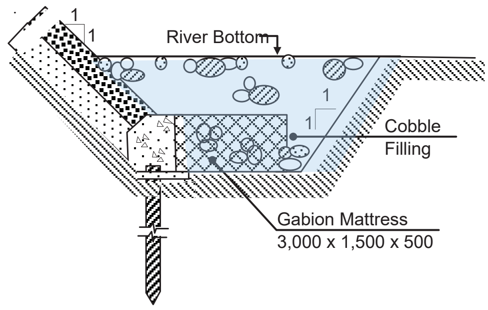
iv. Placing masonry stones

Select appropriate masonry stones from the variety of slope protection works such as stone masonry, grouted riprap and concrete masonry.



v. Installation of gabion mattress and backfill with rock

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.



Monitoring and evaluation

Monitoring of repaired section by the Engineer.

Measurement and payment

Measurement shall be based on lumpsum amount.

Payment shall include full compensation for provision of materials, labour, tools equipment and other necessary accessories to complete the works.

3.6.1.2 Gabions

Definition

Gabion units consist of wire gauge filled with specified material used to prevent erosion or retain slope. Each unit is sub divided into compartments normally to give cells 2m x 1m in plan. Local scouring around the pier and abutment footing and high embankments often occurs due to strong stream flow, weak riverbed materials and type of foundation. The area also used to prevent erosion and scouring on culvert inlets and outlets. The worst damage that could occur due to scouring is the exposure and weakening of bridge abutment and 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.

Scope of works

As a simple and effective repair method, gabion mattress Pier, abutment footing, culvert inlet/outlet, stabilizing slopes of bridge approaches.

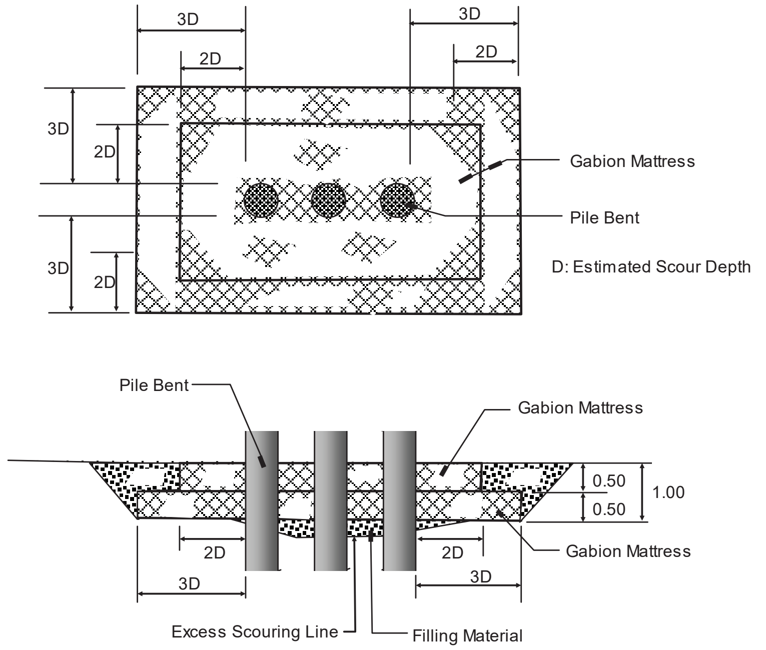


Figure 3-60: Application requirement for standard gabion mattress

Required Materials, Equipment/Tools and Personnel

i. Required Materials

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

ii. Required Tools/Equipment

- Vibratory compactor
- Dump truck
- Wheelbarrows
- Concrete mixer
- Porker vibrator
- Sledge hammer
- Pick axe

iii. Required Personnel

Skilled person trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

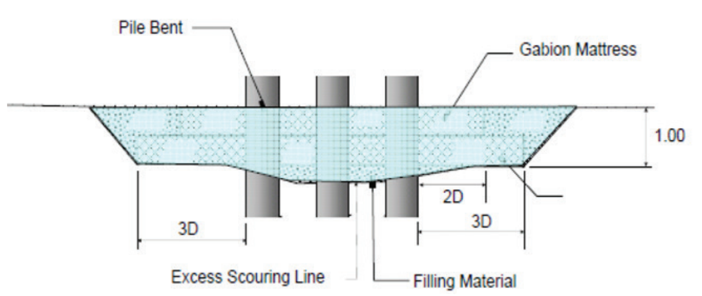
Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

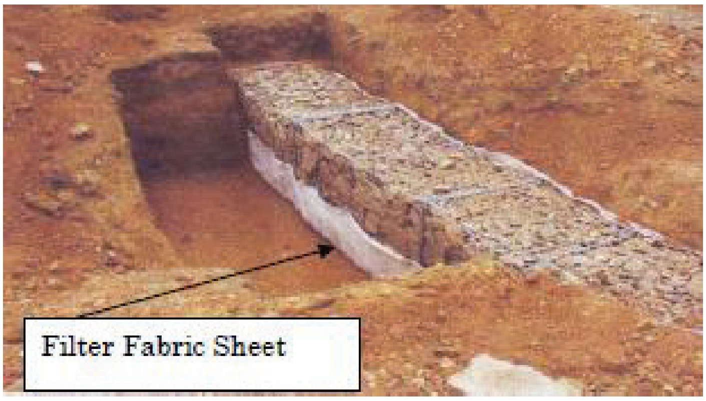
i. Preparation of the bed area for gabion installation

Preparation of bed area for gabion installation by such as excavation, backfill and compaction.



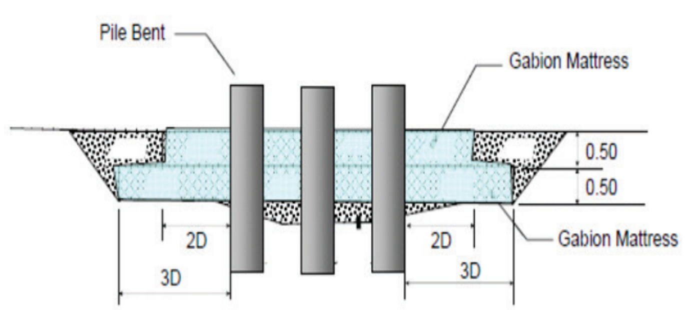
ii. Placing filter fabric sheet

A filter fabric sheet shall be spread tightly and pegged with material approved by the engineer. The filter fabric sheet shall be placed with a minimum 30cm overlap.



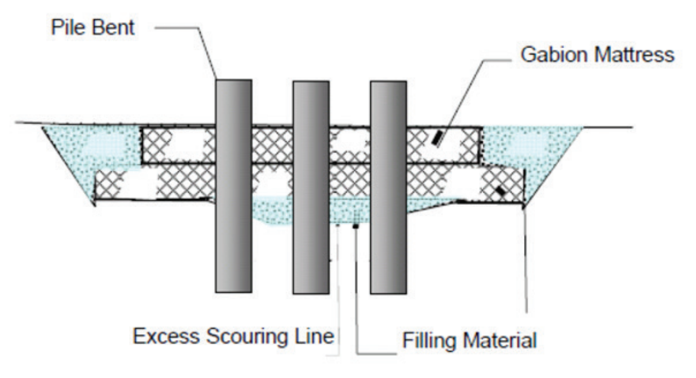
iii. Installation of gabions

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.



iv. 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.



Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurement shall be based on square meters for the gabion mesh and cubic metres for the stones.

Payment shall include full compensation for provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.6.1.3 Slope Patching

Definition

Slope protection around the abutment is a restorative measure for a damaged slope due to inadequate compaction, stream flows or insufficient flood drains or accidents.

Scope of Works

Slope patching is an effective method that can be adopted to repair the 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 3-42. New masonry patched into the excavated portion shall consist of 300 mm gravel filling and 300 mm masonry material.

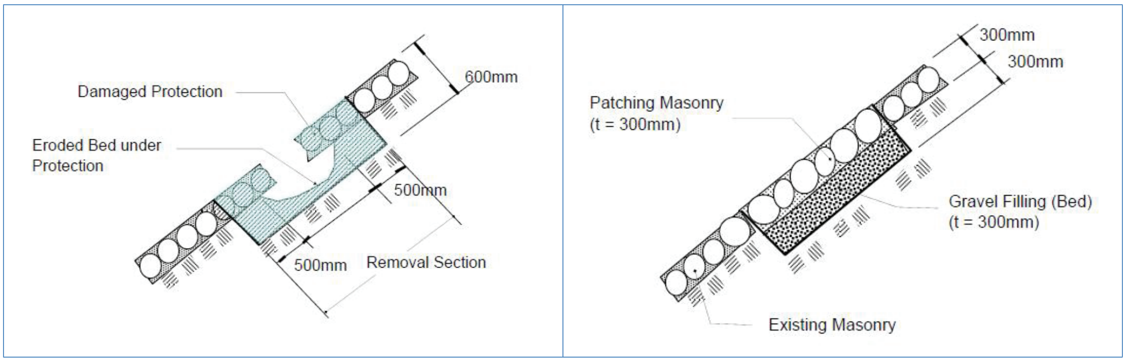


Figure 3-61: Repair requirements to damaged masonry protection

Required Materials, Equipment/Tools & Personnel

i. Required Materials

- Masonry materials to specifications
- Crushed stone
- Gravel
- Mortar

ii. Required Tools/Equipment

- Vibratory compactor
- Dump truck
- Wheelbarrows
- Masonry tools

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

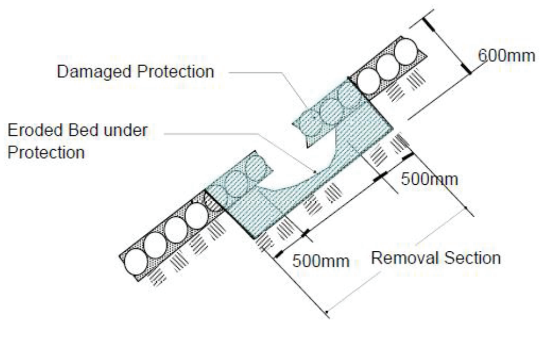
- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

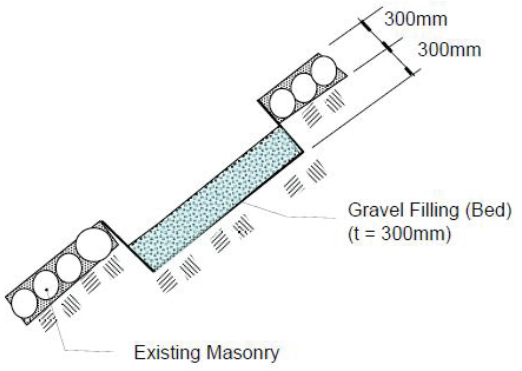
i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

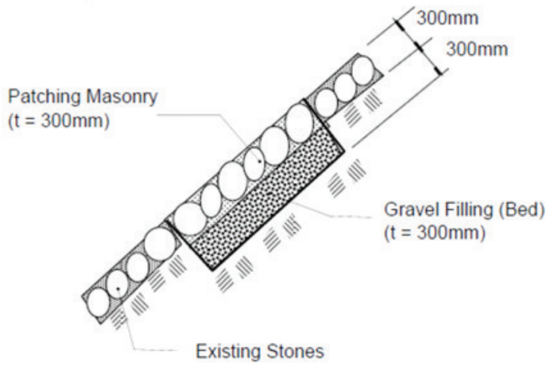
i. Removal of damaged protection

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

ii. Fill and compact gravel

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.	

iii. Patching

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

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurement shall be in square meters (m^2).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for slope patching as detailed in plans and specifications.

3.6.1.4 Nylon Fibre Gabion

Definition

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, abutment footing, slope foundation, inlet and outlet of culverts, eventually leading to undermining of the base and failure of the bridge. Gabion Mattress shall be applied for this defect as standard repair method. Nylon fibre gabion is used for prevention of scour on pier foundation and other underwater structures particularly if the river bed shape is complicated. Thus, protection against local scouring is intended to eliminate or minimize future damage to the bridge substructure.

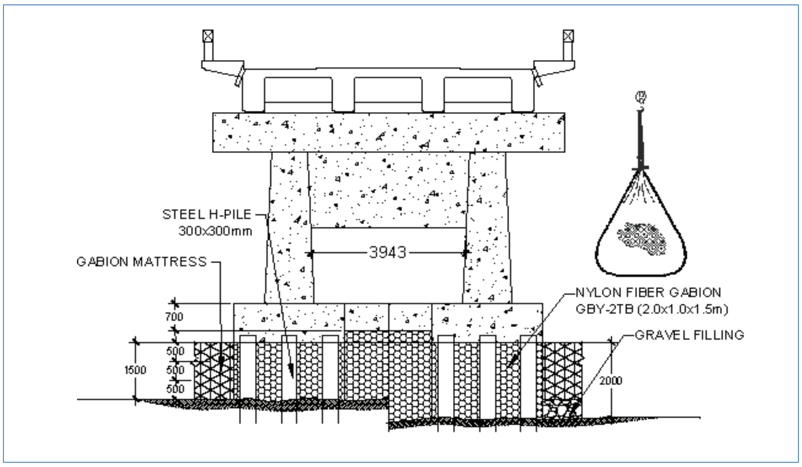


Figure 3-62: Illustration on use of nylon fibre gabion

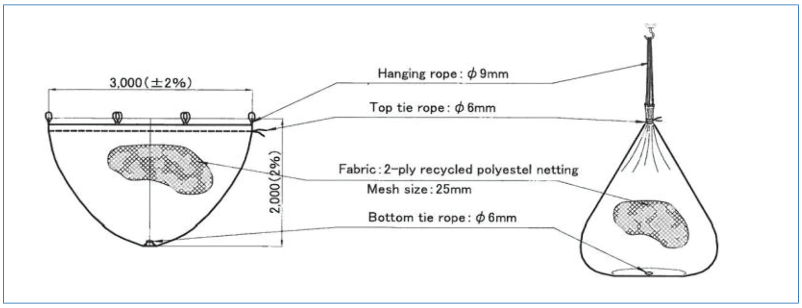


Figure 3-63: Filling of nylon fibre bag

Scope of Works

It consists of a bag body formed by knitted fabric made of nylon. The bag is filled with boulders or stones which are also used for conventional box-type zinc-coated wire gabions. The nylon fibre gabion is flexible and conforms to the shape where it is placed. The nylon netting allows water passage through bag body ensuring that pressure of flowing water does not affect the bag and keeping the scour prevention materials (boulders) from being carried or swept away by the water.

Required Materials, Equipment/Tools and Personnel

i. Required Material

- Nylon Fibre Gabion
- Knitted fabric material
- Rock Fill (Boulders)
- Backfill Materials

ii. Required Tools/Equipment

- Backhoe or crane
- Vibratory compactor
- Dump truck
- Wheelbarrows

- Concrete mixer
- Porker vibrator
- Sledge hammer
- Pick axe

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Place boulders into nylon fibre gabion bag

Boulders to be used shall conform to broken rock requirements gabions in Standard Specifications for Road and Bridge Construction.

When filled, nylon fibre gabion weighs 2 tons with equivalent size of 3m x 2m and volume of about 1.24 m^3.

ii. Transport to scoured area

After filling with boulders, the nylon fiber gabion shall be transported to scoured area by mechanical means. (back hoe and crane)

iii. Place nylon fibre gabion using backhoe

Using backhoe lay gabions in scoured portion. Continue laying up to designated elevation.	

N/B: After installation of nylon fiber gabion, gabion mattress shall be placed as surface layer. Requirement of installation is the same as that of gabion mattress as in Section 3.6.1.2.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurement and Payment

Measurement shall be in cubic meters (m^3).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for nylon fibre gabion as detailed in plans and specifications. Any other items of work not covered in this shall be determined by the Engineer.

3.6.1.5 Jacketing

Definition

Jacketing is a method of structural retrofitting and strengthening that is used to increase the bearing capacity following a modification of the structural design or to restore structural design integrity due to a failure in the structural member.

Photo 3-17: Welding of reinforcement bars

Types of Jacketing

A. *Reinforced Concrete Jacketing*

In reinforced concrete jacketing, an additional cage of longitudinal and lateral tie reinforcement is provided around the pier. A concrete ring is then cast around the pier. Jacketing a reinforced concrete beam can also be done in the above manner. The stirrup in this case, is held up by drilling holes through the slab.

The reinforcement and concrete used for jacketing should be as specified by the Structural Engineer.

Photo 3-18: Reinforced concrete jacketing

B. *Steel jacketing*

Steel jacketing is an effective method to increase bearing capacity. It provides enough confinement and also prevents deterioration of shell concrete, which is the main reason for bond failure and buckling of longitudinal members of a structure.

The section of the column/pier that is defective is encased with steel plates and the gaps filled with non-shrink grout. The most commonly used strengthening technique is by use of steel strips and angles. The jacketing helps to restore strength, ductility and energy absorption capacity of columns/piers.

Steel jacketing is an effective method to remedy deficiencies such as inadequate shear strength, but it may be costly and its fire resistance has to be addressed.

Photo 3-19: Steel jacketing

C. *Fiber Reinforced Polymer (FRP) jacketing*

Fiber Reinforced Polymer (FRP) is a commonly used for retrofitting. FRP is widely used for its properties such as high strength to weight ratio, stiffness, good impact properties, high resistance to corrosion in harsh environmental and chemical condition (making it most useful is sea structure). Use of FRP causes only a minimum alteration to the geometry of the structure compared to other methods of jacketing.

Photo 3-20: Fibre reinforced polymer jacketing

D. *Glass Fibre Reinforced Polymer Jacketing*

This is the application of composite materials for jacketing developed in strengthening and retrofitting of concrete structures. The design of glass-fiber-reinforced contains basic properties under tensile, compressive, bending and shear forces, coupled with estimates of behavior under secondary loading effects such as creep, thermal response and moisture movement.

Photo 3-21: Glass fibre reinforced polymer jacketing

Scope of Works

Jacketing is particularly used in the repair of deteriorated columns, piers, and piles and may easily be employed in underwater applications. The method is applicable for protecting concrete, steel, and timber sections against further deterioration and for strengthening. Jacketing improves axial and shear strength of columns and a major strengthening of the foundation may be avoided.

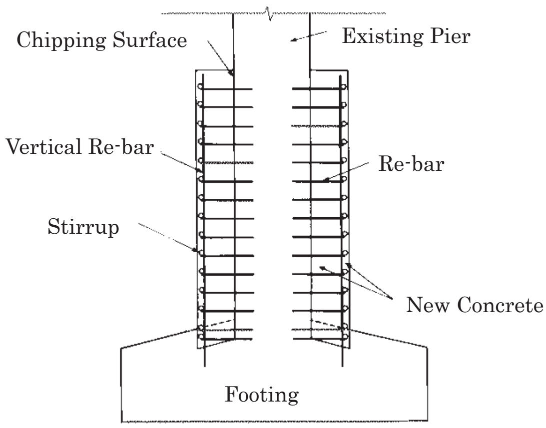


Figure 3-64: Concrete jacketing

Required Materials, Tools/Equipment and Personnel

i. Required Materials for Concrete Jacketing

- 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
- Cement
- Portland cement 13.0 kg
- Admixture 0.5kg (Silica fume)
- 10mm Crushed Aggregate 36.0 kg
- Sand (assumed with 2% water content) 18.5 kg
- Water (maximum) 5.4 liters
- Super plasticizer (nominal) 25ml
- Formwork
    - Steel formwork (Circular)
    - Plywood formwork

ii. Required Materials for Steel Jacketing

- Grout
- Steel plates

iii. Required Materials for Fibre Reinforced Polymer (FRP) Jacketing

- FRP
- Epoxy resin

iv. Required Materials for Glass Fibre Reinforced Polymer (FRP) Jacketing

- Glass FRP
- Epoxy resin

v. Required Tools/Equipment for Concrete Jacketing

- Drilling machine to concrete
- Concrete vibrator

vi. Required Tools/Equipment for Steel Jacketing

- Drilling machine to concrete
- Welding machine

vii. Required Tools/Equipment for Fibre Reinforced Polymer (FRP) Jacketing

- Wire brush
- Epoxy spreader

viii. Required Tools/Equipment for Glass Fibre Reinforced Polymer (FRP) Jacketing

- Wire brush
- Epoxy spreader

ix. **Required personnel**

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

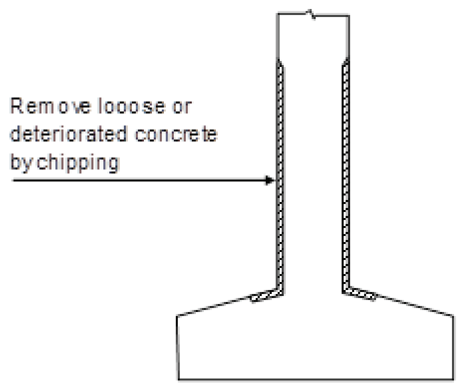
- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

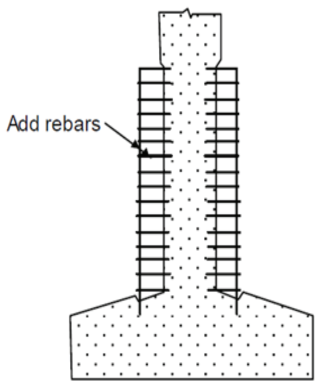
i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

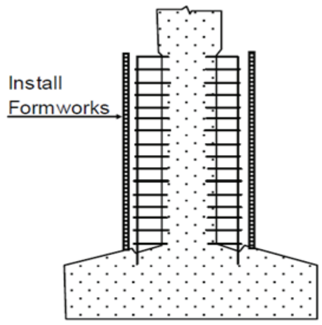
i. **Removal of deteriorated existing surface material**

All loose or deteriorated existing surface material shall be removed.	

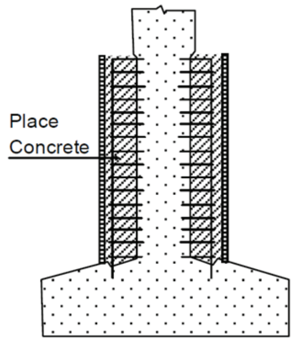
ii. **Addition of rebar, steel plate, Fibre Reinforced Polymer, Glass Fibre Reinforced Polymer**

Appropriate reinforcing materials should be fixed as required.	

iii. Setting-up formworks as applicable

Formwork for concrete jacket is commonly circular or rectangular in shape. This formwork must 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.	

iv. Placing of concrete for concrete jacketing

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 trowelling to match the adjacent existing concrete.	

v. 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.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurements shall be in tonnes of rebars & steel plate, cubic meters of concrete, and square metres for Fibre Reinforced Polymer, Glass Fibre Reinforced Polymer and formwork used.

Payment shall include full compensation for provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

3.6.1.6 Grassing

Definition

It is the provision of vegetation cover to minimize flow of surface run off on embankments.

Scope of Works

Plant and maintain grass cover for control of erosion on embankment slopes.

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Manure
- Suitable soil
- Grass seeds
- Water

ii. Required Tools/Equipment

- Hand caster
- Wheeled spreader
- Landscape rake
- Lawn mower
- Garden hose with nozzle
- Water tanker

iii. Required Personnel

Skilled and unskilled construction workers

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Works Sequence

i. Prepare slope to receive grass seed,
ii. Use mats to stabilize and plant grass seed,
iii. Water the matted area regularly,
iv. Mow and maintain slopes.

Monitoring and Evaluation

Monitoring of grassed section by the Engineer.

Measurements and Payment

Measurement shall be based on square meters.

Payment shall include full compensation for provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

Figure 3-65: Grassing on slope

3.6.1.7 Stone Pitching/Revetment

Definition

Consists of placing medium sized rock set into mortar exposing the stone and is designed to spread and direct the flow of surface run off. Stone pitching is placed on a slope with a gradient of 5% up to 35%.

Scope of Works

This technique is particularly useful on slopes with a heavy seepage problem, in flood-prone areas or where vegetation is difficult to establish, such as in urban areas. It is also useful on gulley floors between check dams and for scour protection by rivers.

Required Materials, Equipment/Tools and Personnel

i. Required Materials

- Masonry stones
- Cement- sand mortar
- Suitable fill soil
- Water

ii. Required Equipment/Tools

- Jembe/Hoe
- Spade
- Trowel
- Mason's hammer
- Slasher
- Panga

- Wheelbarrow
- Lorry
- Water bowser

iii. Required Personnel

Skilled and unskilled construction workers trained by KIHBT and accredited/ registered by NCA

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Works Sequence

i. Prepare a sound slope before constructing the stone pitching; it must be free of loose debris and topsoil, and trimmed to an even surface.

ii. Bed the stones down well into the slope surface. Excavate as necessary to ensure an even upper surface to the stone pitching.

iii. Build the stone pitching carefully, with the stones fitted together firmly, as if it is a dry masonry wall. Stones should be perpendicular to the slope, with the main point or narrow side down.

iv. In drains and gullies, a rough surface can be left to retard water flow.

v. For further strengthening it is best to plant grasses or the hardwood cuttings of shrubs through the stone pitching.

vi. Other options for strengthening are either to use a gabion mattress (0.3 to 0.5 metre thickness) instead of dry-stone pitching; or to use cement mortar (but this can impede drainage).

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payments

Measurement shall be based on square meters (m^2).

Payment shall include full compensation for provision of materials, labour, tools, equipment and other necessary accessories to complete the works.

Photo 3-22: Laying of stone pitching

3.6.1.8 Reinstatement of Damaged or Scoured River Bed Level using Groundsill

Definition

Groundsill is a river structure built across a river that aims to restore riverbed by reducing the speed of the water currents and increase the rate of sediment deposition in the upstream part of the groundsill. This is intended to secure the riverbed and hence the foundation of bridges or river structure that are upstream of the groundsill, so that building structures in the upper reaches of the river such as bridges or other water structures are safe against erosion.

Photo 3-23: Side elevation of a weir

Photo 3-24: Typical damaged groundsill

Scope of Works

It involves the restoration of the river bed to level. To raise the river bed, weir or ground sill is provided at the downstream of the damaged riverbed. The ground sill is the most appropriate method in restoring the river bed to its original level. However, it is necessary to design the scale of the ground sill in consideration with a hydrological study.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Concrete blocks or quarry stones reinforcement
- Coarse and fine aggregates
- Cement
- Water
- Rapid hardeners

ii. Required Tools/Equipment

- Excavator
- Concrete mixer
- Concrete vibrator
- Concrete pump
- Formwork
- Lorry

iii. Required Personnel

Skilled personnel works trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,

ii. Implementation safety regulations as per the traffic management plans,

iii. Adhere to all environmental, occupational, safety and health regulations.

Works Sequence

i. Observation of groundsill damage in the field

Observations of groundsill damage are carried out directly in the field to determine the development of groundsill damage from year to year using photo data from drone recordings that existed before the study was carried out will be used. By using drone photos, groundsill damage can also be observed and known.

Photo 3-25: Example of progressive groundsill damage based on field observations

ii. Groundsill damaged inventory

Based on the results of direct observations in the field and photos of groundsill damage recorded by drones from the previous year, groundsill damage can be inventoried, both for the type of damage, damaged construction, the position of the damage, and the volume of damaged construction. All groundsill damage data is recorded and collected and will be used to determine the type and method of repairing the groundsill.

iii. Revisiting groundsill planning

The existing groundsill planning data as built will be used as an initial guideline for repairing the groundsill damage.

iv. Cofferdam installation

A cofferdam is a building that functions to drain river water from upstream to downstream so as not to interfere with the implementation of groundsill construction. The installation of the cofferdam can be as shown on Figure 3-66.

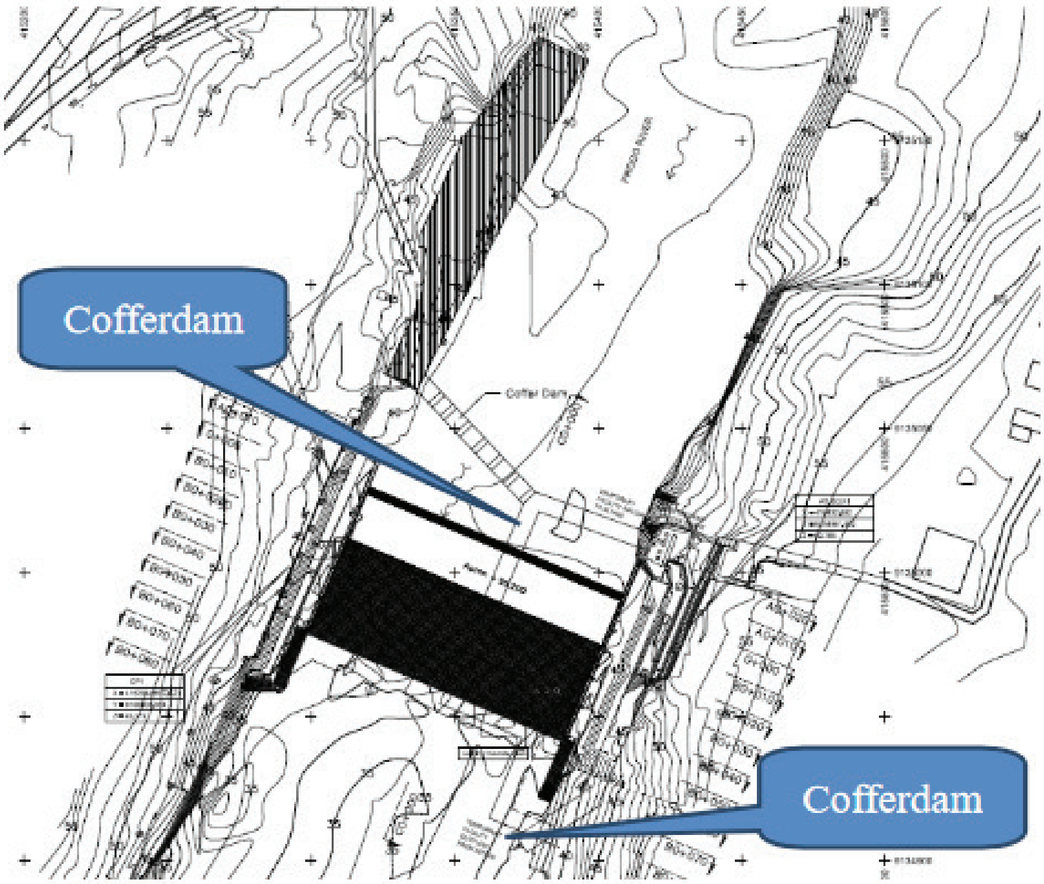


Figure 3-66: Cofferdam installation

v. Establish groundsill repair construction

By studying the initial planning of the existing groundsill as built and based on the results of the groundsill damage inventory, it can be determined that the construction of the groundsill repair can consist of:

1. *Repairing groundsill subgrade using class 15/20 concrete as blinding*

   The subgrade needs to be repaired because it will be the foundation of the groundsill concrete block.

   The subgrade of the river bed area which was originally sand is replaced with class 15/20 concrete as blinding and the lock is in the form of steel sheet piles so that they are no longer eroded by the flow of the River.

2. *Analysis of groundsill concrete blocks weighing 3.4 tons of class 30/20 concrete quality*

   The stability of the concrete block against dynamic water pressure will be checked using empirical formulas as per the Guideline for Structural Design of Groundsill.

3. *Arrangement of the groundsill downstream area*

   The new concrete blocks are installed on the damaged parts in line with the existing layout as built as at the time of construction.

Concrete blocks are cast in the groundsill area for easy mobilization as shown on Figure 3-67. Concrete blocks using concrete weighing 3.4 tons and made of reinforced class 30/25 concrete and each concrete block is connected by reinforcement.

All existing concrete blocks must be moved downstream of the groundsill in such a way that sand miners cannot approach the area downstream of the groundsill.

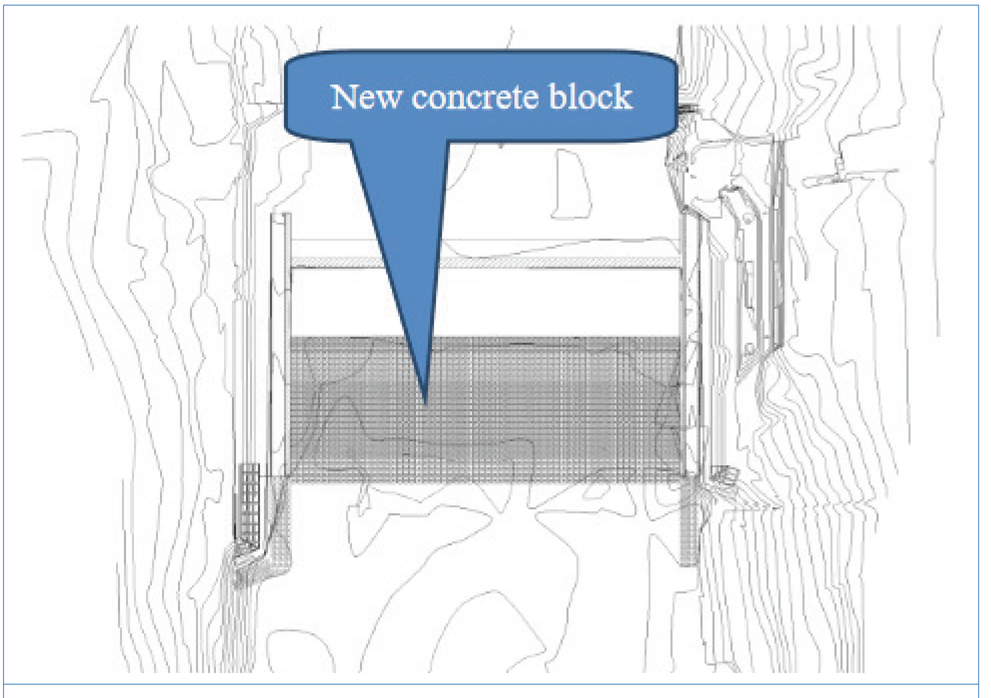


Figure 3-67: Layout concrete blocks

Monitoring And Evaluation

Monitoring of reinstated section by the Engineer.

Measurements and Payment

Measurement shall be in cubic meters (m^3).

Payment shall be full compensation for provision for all materials, equipment, labour, formwork and other related services necessary for reinstatement of river bed level as detailed in plans and specifications.

3.8 UNDER WATER REPAIRS

3.8.1 Introduction

Underwater problems can be very complex to diagnose given that they are apparently not visible to the human eye. It is important that solutions to underwater problems are based on sound engineering. There is a tendency to make the solution fit one of a few common underwater repair techniques. A major concern is that the repair may only hide a structural problem while it continues to worsen, as is the case when pile jackets are installed in a marine environment without consideration of cathodic protection systems.

For example, when contaminated concrete and corroded reinforcing steel are left in place to interface with new concrete, the corrosion process actually accelerates. Consequently, covering a reinforced concrete member with a stay-in-place form or jacket will not stop or prevent further corrosion of the reinforcement. The member may look satisfactory while it is deteriorating to an unsafe condition.

Since most bridge engineers are not divers, it is important that they understand the problems and limitations in performing an underwater repair. All repairs above water are not cost effective when performed by divers in underwater conditions. It may be less expensive to accept that the deterioration will continue and modify the load path by designing the repair to support the total load or by designing a supplemental supporting system than to remove and replace the damage.

3.8.2 Underwater Repair Methods

A. Pressure Injection of Cracks Underwater

Definition

Pressure injection can be used, within limits, against a hydraulic head provided the injection pressure is adjusted upward to counteract the pressure of the hydraulic head. The material must displace the water as it is injected into the crack to ensure that the crack is properly sealed resulting in a watertight monolithic structural bond.

Cracks expose the reinforcing steel to moisture, setting the stage for the corrosion process to begin. In saltwater environments, corrosion can occur very fast. Epoxy pressure injection has gained widespread acceptance as a cost-effective method to bond together and seal cracked structural concrete members.

Epoxies must have certain characteristics to cure and bond the cracked concrete together. Many adverse elements are present inside the concrete crack, such as water, contaminants carried by water, dissolved mineral salts, and debris from the rusting reinforcing steel.

The epoxy injection resins for cracks are formulated in low viscosity, and they do not shrink appreciably. The surface wet-ability of epoxy resin is of major importance, because the resin should displace all water in the crack and adhere to a wet surface and then cure in that environment.

Challenges to successful repair using this method include:

i. Contaminants growing inside the crack, especially those found underwater, can reduce the successful welding of cracks.

ii. Corrosion debris which can also reduce the effectiveness of pressure injection.

iii. Injection is labour-intensive. As the temperature drops below 10°C, it becomes more difficult to pump the epoxies into fine cracks.

iv. Inexperience on the part of the diver in injection and the formulation of the epoxy for injection.

v. Lack of time and / or patience which is required for the successful injection repair.

Scope of Works

The scope of the procedure is to repair cracks saturated with water with proper selection of water-compatible adhesive, normally an epoxy resin, dormant (non-moving). The procedure can also repair other small voids such as delamination or honey-combed areas near the surface of the concrete.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Epoxy resin
- Ready mixed Concrete
- Concrete anti-washout admixtures (silica fume or fly ash)

ii. Required Tools/Equipment

- Mechanical grinders and scrubbers for cleaning concrete surfaces.
- High-pressure water jets.

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Remove the salt-contaminated concrete and rust from contact with existing reinforcing steel to ensure that the corrosion damage will not continue (unless cathodic protection was used).
ii. Clean the cracks using a high-pressure water system and shape the surface of the concrete directly above the crack so that it can be sealed with a grout.
iii. Install injection ports in holes drilled to intersect the crack by a hydraulic or pneumatic drill.
iv. Seal the surface of the crack with a grout material suitable for underwater use such as a cementitious or epoxy mortar with anti-washout admixtures and accelerators. The purpose of the grout is to retain the adhesive as it is pumped into the crack.
v. Pressure inject the adhesive into the crack through the ports that are embedded in the grout at regular intervals. The injection sequence begins at the bottom and advances upward. The injection moves up when the adhesive reaches and begins to flow from the port. Epoxy resin is mixed either before or after pumping. Cracks varying in width from 0.002 to 0.25 inches may be injected successfully.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in linear meters (m).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for underwater crack repair as detailed in plans and specifications.

B. Under Water Concrete Repairs

Definition

This method is intended for undertaking major under water repairs for concrete structures.

Required Materials, Tools/Equipment and Personnel

i. Required Materials

- Pre-mixed concrete
- Permeable concrete bags
- Forms to encase damaged concrete or masonry substructure units
- Polyethylene drainage pipe (used as form)

ii. Required Tool/Equipment

- Pile jacketing forms
- Tremie Pipe
- Concrete pump
- Concrete cutter (hydraulic or pneumatic-powered concrete saws)

iii. Required Personnel

Skilled personnel trained by KIHBT and Registered/accredited by NCA.

Preparation for Works

- Provide traffic warning signs,
- Identify and cordon work area,
- Prepare diversion/lane management.

Safety Considerations

i. Provision of PPE's for the staff or labourers,
ii. Implementation safety regulations as per the traffic management plans,
iii. Adhere to all environmental, occupational, safety and health regulations.

Work Sequence

i. Construction joints between old and new concrete should be saw-cut prior to removal to prevent feather-edges using hydraulic or pneumatic-powered concrete saws and chipping hammers adapted for underwater use.

ii. Clean concrete surfaces using mechanical grinders. Surface preparation is required after concrete removal and prior to repair by removal of all loose and fractured concrete, marine organisms and silt. In order to reduce the accumulation of new surface deposits where the water is heavily laden with contaminants, repairs should be made the day of final surface preparation.

iii. Encase damaged concrete or masonry substructure units with jacketing forms.

iv. Using anti-washout admixtures (containing silica fume or fly ash), prepare concrete mix in the right ratio (depending on design strength of element under repair). A water reducer or high range water reducer may be necessary with anti-washout admixtures to maintain slump.

v. Using special techniques (e.g. tremie pipe or concrete pump for large volume repairs) to protect concrete, place the ready mixed concrete underwater with the help of a diver to position the pipe correctly.

vi. For isolated repairs concrete is placed by hand by a diver and packed or rammed for consolidation. The concrete can be delivered to the diver by bucket on a rope conveyor assembly or can be dropped to the diver in baseball-sized quantities through a pipe with holes cut in the sides to allow displaced water to escape, easing the descent of the concrete. Small quantities needed for patching can also be delivered to the diver in plastic bags.

vii. Where concrete placed in bags is used to repair deteriorated or damaged portions of concrete or masonry substructure elements underwater, small fabric bags prefilled with dry concrete mix (sand and cement only) shall be used. These shall be anchored together to form the exterior of the repair since the interior portion of the repair is already filled with a tremie concrete or dewatered and filled with concrete. The bags should be small enough to be placed in position by hand.

Monitoring and Evaluation

Monitoring of repaired section by the Engineer.

Measurements and Payment

Measurement shall be in cubic meters (m^3).

Payment shall be full compensation for provision for all materials, equipment, labour, related services necessary for underwater concrete repairs as detailed in plans and specifications.

APPENDIX: REPAIR PRINCIPLES AND METHODS FOR DEFECTS IN CONCRETE

The knowledge and expertise for this method is elaborated in EN 1504, Part 9: Products and systems for the repair and protection of concrete structures. These principles outlined and defined in EN 1504, Part 9, guide the engineer to correctly repair and protect all of the potential damage that can occur in reinforced concrete structures. Principles 1 to 6 relate to defects in the concrete itself, Principles 7 to 11 relate to damage due to reinforcement corrosion. Table 4-1 proposes assessment from the concrete condition survey and diagnosis of the concrete damage, together with the repair objectives and requirements, the appropriate concrete repair principles that can be taken into consideration.

Table 4-1: Repair principles and methods related to defects in concrete

Principle No.	Principle Definition	Method	Description
Principle 1 (PI)	**Protection against ingress**. Reducing or preventing the ingress of adverse agents, e.g. water, other liquids, vapour, gas, chemicals and biological agents.	1.1 Hydrophobic Impregnations	This is the treatment of concrete to produce a water-repellent surface. The pores and capillary network are not filled, but only lined with the hydrophobic material. This functions by reducing the surface tension of liquid water, preventing its passage through the pores, but still allowing each way water vapour diffusion, which is in accordance with standard good practice in building physics.
		1.2 Impregnations	This is the treatment of concrete to reduce the surface porosity and to strengthen the surface. The pores and capillaries are then partly or totally filled. This type of treatment usually also results in a discontinuous thin film of 10 to 100 microns thickness on the surface. This serves to block the pore system to aggressive agents.

Principle No.	Principle Definition	Method	Description
		1.3 Coating	Surface coatings are materials designed to provide an improved concrete surface, for increased resistance or performance against specific external influences. Fine surface cracks with a total movement of up to 0.3 mm can be safely repaired, then sealed and their movement accommodated by the use of elastic, crack bridging coatings, which are also waterproof and carbonation resistant. This will accommodate thermal and dynamic movement in structures subject to wide temperature fluctuation, vibration, or that have been constructed with inadequate or insufficient jointing details.
		1.4 Surface bandaging of cracks	Locally applying a suitable material to prevent the ingress of aggressive media into the concrete.
		1.5 Filling of cracks	Cracks to be treated to prevent the passage of aggressive agents should be filled and sealed. Non-moving cracks – They have been formed by initial shrinkage for example, they need only to be fully exposed and repaired / filled with a suitable repair material.
		1.6 Transferring cracks into joints	Cracks to be treated to accommodate movement should be repaired so that a joint is formed to extend through the full depth of the repair and positioned to accommodate that movement. The cracks (joints) must then be filled, sealed or covered with a suitably elastic or flexible material. The decision to transfer a crack to the function of a movement joint must be made by a structural engineer.

Principle No.	Principle Definition	Method	Description
		1.7 Erecting external panels	A curtain wall or similar external facade cladding system, protects the concrete surface from external weathering and aggressive materials attack or ingress.
		1.8 Applying membranes	Applying a preformed sheet or liquid applied membrane over the concrete surface to protect the surface against the attack or ingress of deleterious materials.
Principle 2 (MC)	**Moisture control.** Adjusting and maintaining the moisture content in the concrete within a specified range of values.	2.1 Hydrophobic impregnation	This is defined as the treatment of concrete to produce a water-repellent surface. The pores and capillary network are not filled, but only lined with the hydrophobic material. This function by reducing the surface tension of liquid water, thus preventing its passage through the pores, but still allowing each way water vapour diffusion, which is in accordance with standard good practice in building physics.
		2.2 Impregnation	An impregnation is the treatment of concrete to reduce the surface porosity and to strengthen the surface. The pores and capillaries are then partly or totally filled. This type of treatment usually also results in a discontinuous thin film of 10 to 100 microns thickness on the surface. This serves to block the pore system to aggressive agents.
		2.3 Coating	Surface coatings are defined as materials designed to provide an improved concrete surface, for increased resistance or performance against specific external influences. Fine surface cracks with a total movement of up to 0.3 mm can be safely repaired, then sealed and their movement accommodated by crack bridging coatings which are also waterproof and carbonation resistant. This is to accommodate thermal and dynamic movement in structures subject to wide temperature fluctuation, vibration, or that have been constructed with inadequate or insufficient jointing details.

Principle No.	Principle Definition	Method	Description
		2.4 Erecting external panels	As long as the concrete surface is not exposed, no water can penetrate and the reinforcement cannot corrode.
		2.5 Electrochemical treatment	By applying an electric potential in the structure, moisture can be moved towards the negatively charged cathode area.
Principle 3 (CR)	**Concrete restoration.** Restoring the original concrete to the originally specified profile and function. Restoring the concrete structure by replacing part of it.	3.1 Hand applied mortar	Traditionally the localised repair of concrete defects and damage has been undertaken using hand-placed repair mortars. Pre-batched, hand-applied repair mortars are available for general repair purposes and also for very specific repair requirements. These include lightweight mortars for overhead application and chemically resistant materials to protect against aggressive gases and chemicals.
		3.2 Recasting with concrete or mortar	Typical recasting repairs, which are also frequently described as pourable or grouting repairs, are employed when whole sections or larger areas of concrete replacement are required. These include the replacement of all, or substantial sections of, concrete bridge parapets and balcony walls etc. This method is also very useful for complex structural supporting sections, such as cross head beams, piers and column sections, which often present problems with restricted access and congested reinforcement. The most important criteria for the successful application of this type of product is its flowability and the ability to move around obstructions and heavy reinforcement. Additionally they often have to be poured in relatively thick sections without problems of thermal shrinkage cracking. This is to ensure that they can fill the desired volume and areas completely, despite the restricted access or application points. Finally they must also harden to provide a suitably finished surface, which is tightly closed and free of cracks.

Principle No.	Principle Definition	Method	Description
		3.3 Spraying concrete or mortar	Spray applied materials have also been used traditionally for concrete repair works. They are particularly useful for large volume concrete replacement, for providing additional concrete cover, or in areas with difficult access for concrete pouring or the hand placement of repairs. Today in addition to traditional dry spray machines, there are also in addition to traditional dry spray machines, there a but also much lower rebound, plus they produce less dust than the dry spray machines. Therefore, they can also be used economically for smaller or more sensitive repair areas, where there is restricted access, or in confined environments. The most important application criteria for sprayed repair materials are minimal rebound, plus high-build properties to achieve the required non-sag layer thickness. Application under dynamic load and minimal or easy finishing and curing, are also important due to their areas of use and the difficulties in access.
		3.4 Replacing elements	In some situations, it can be more economical to replace either the whole structure or part of it, rather than to carry out extensive repair works. In this situation, care needs to be taken to provide appropriate structural support and load distribution during the works, for example by using suitable bonding systems or agents to ensure this is maintained.
Principle 4 (SS)	**Structural strengthening**. Increasing or restoring the structural load bearing capacity of an element of the concrete structure.	4.1 Adding or replacing embedded or external reinforcing bars	The selection of the appropriate size and configuration of such reinforcement, plus the locations where it is to be fixed, must always be determined by the structural engineer.

Principle No.	Principle Definition	Method	Description
		4.2 Adding reinforcement anchored in pre-formed or drilled holes	The points for anchorages into the concrete should be designed, produced and installed in accordance with the technical specifications. The surface cleanliness of the grooves or anchor holes cut in the concrete should be prepared in accordance to the technical specifications.
		4.3 Bonding plate reinforcement	Structural strengthening by the bonding of external plates is carried out in accordance with the relevant national design codes The exposed surfaces of the concrete that are to receive externally bonded reinforcement should be thoroughly cleaned and prepared. Any weak, damaged or deteriorated concrete must be removed and repaired. This must be completed prior to the overall surface preparation and plate-bonding application work being undertaken.
		4.4 Adding mortar or concrete	See Principle 3 Concrete restoration.
		4.5 Injecting cracks, voids or interstices	The cracks should be cleaned and prepared in accordance and the resealing and bonding material applied to fully reinstate the structural integrity.
		4.6 Filling cracks, voids or interstices	When inert cracks, voids or interstices are wide enough, they can filled by gravity (pouring) or by using an epoxy patching mortar.
		4.7 Prestressing (post-tensioning)	Pre-stressing: with this method the system involves applying forces to a structure to deform it in such a way that it will withstand its working loads more effectively, or with less total deflection. (Note: post-tensioning is a method of pre-stressing a poured in place concrete structure after the concrete has hardened).

Principle No.	Principle Definition	Method	Description
Principle 5 (PR)	**Physical resistance**. Increasing resistance to physical or mechanical attack.	5.1 Coating	Only reactive coatings are able to provide sufficient additional protection for the concrete to improve its resistance against physical or mechanical attack.
		5.2 Impregnation	An impregnation is the treatment of concrete to reduce the surface porosity and to strengthen the surface. The pores and capillaries are partly or totally filled. This type of treatment usually results in a discontinuous thin film of 10 to 100 microns thickness on the surface. Certain impregnations can react with some of the concrete constituents to result in higher resistance to abrasion and mechanical attack.
		5.3 Adding mortar or concrete	See Principle 3 Concrete restoration. The products have to fulfill additional requirements such as resistance to hydraulic abrasion thus the engineer must therefore determine these additional requirements on each specific structure.
Principle 6 (RC)	**Resistance to chemicals**. Increasing resistance of the concrete surface to deteriorations from chemical attack.	6.1 Coating	Only high performance reactive coatings are able to provide sufficient protection to concrete and improve its resistance to chemical attack.
		6.2 Impregnation	An impregnation is the treatment of concrete to reduce the porosity and to strengthen the surface. The pores and capillaries are then partly or totally filled. This type of treatment usually also results in a discontinuous thin film of 10 to 100 microns thickness on the surface. This therefore serves to block the pore system to aggressive agents.

Principle No.	Principle Definition	Method	Description
		6.3 Adding mortar or concrete	See Principle 3, Concrete restoration. To be able to resist a certain level of chemical attack, cement based products need to be formulated with special cements and/or combined with epoxy resins. The engineer has to define these specific requirements on each structure.
Principle 7 (RP)	**Preserving or restoring passivity**. Creating chemical conditions in which the surface of the reinforcement is maintained in or is returned to a passive condition.	7.1 Increasing cover with additional mortar or concrete	If the reinforcement does not have adequate concrete cover, then by adding cementitious mortar or concrete the chemical attack (e.g. from carbonation or chlorides) on the reinforcement will be reduced.
		7.2 Replacing contaminated or carbonated concrete	Through removing damaged concrete and rebuilding the concrete cover over the reinforcement, the steel is again protected by the alkalinity of its surroundings.
		7.3 Electrochemical re-alkalisation of carbonated concrete	Re-alkalisation of concrete structures by electrochemical treatment is a process performed by applying an electric current between the embedded reinforcement to an external anode mesh, which is embedded in an electrolytic reservoir, placed temporarily on the concrete surface. This treatment does not prevent the future ingress of carbon dioxide. So to be effective on the long term, it also needs to be combined with appropriate protective coatings that prevent future carbonation and chloride ingress.
		7.4 Re-alkalisation of carbonated concrete by diffusion	There is limited long term experience with this method. It requires the application of a very alkaline coating over the carbonated concrete surface and the re-alkalisation is achieved by the slow diffusion of the alkali through the carbonated zone. This process takes a very long time and it is very difficult to control the right distribution of the material. After treatment, it is also always recommended to prevent further carbonation by applying a suitable protective coating.

Principle No.	Principle Definition	Method	Description
		7.5 Electrochemical chloride extraction	The electrochemical chloride extraction process is very similar in nature to cathodic protection. The process involves the application of an electrical current between the embedded reinforcement and an anode mesh placed at the outer surface of the concrete structure. As a result, the chlorides are driven out toward the surface. Once the treatment is completed, the concrete structure has to be protected with a suitable treatment to prevent the further ingress of chlorides (post treatment).
Principle 8 (IR)	**Increasing resistivity**. Increasing the electrical resistivity of the concrete.	8.1 Hydrophobic impregnation	A hydrophobic impregnation is the treatment of concrete to produce a water-repellent surface. The pores and capillary network are not filled, but only lined with the hydrophobic material. This functions by reducing the surface tension of liquid water, thus preventing its passage through the pores, but still allowing each way water vapour diffusion, which is in accordance with standard good practice in building physics.
		8.2 Impregnation	An impregnation is the treatment of concrete to reduce the surface porosity and to strengthen the surface. The pores and capillaries are then partly or totally filled. This type of treatment usually also results in a discontinuous thin film of 10 to 100 microns thickness on the surface. This serves to block the pore system to aggressive agents.
		8.3 Coating	Surface coatings are materials designed to provide an improved concrete surface, for increased resistance or performance against specific external influences. Fine surface cracks with a total movement of up to 0.3 mm can be safely repaired, then sealed and their movement accommodated by elastic, crack bridging coatings, which are also waterproof and carbonation resistant.

Principle No.	Principle Definition	Method	Description
			This is to accommodate thermal and dynamic movement in structures subject to wide temperature fluctuation, vibration, or that have been constructed with inadequate or insufficient jointing details.
Principle 9 (CC)	**Cathodic control**. Creating conditions in which potentially cathodic areas of reinforcement are unable to drive an anodic reaction.	9.1 Limiting oxygen content (at the cathode) by saturation or surface coating	Creating conditions in which any potentially cathodic areas of the reinforcement are unable to drive an anodic reaction. Inhibitors (added to the concrete as admixtures or surface applied on the hardened concrete as an impregnation) form a continuous film on the surface of the steel reinforcement which acts as a barrier to oxygen.
Principle 10 (CP)	**Cathodic protection**.	10.1 Applying an electrical potential	In Induced Current Cathodic Protection, the current is supplied by an external electrical source and is distributed in the electrolyte via auxiliary anodes (e.g. mesh placed on top of and connected to the reinforcing steel). These auxiliary anodes are generally embedded in a mortar in order to protect them from degradation. To work efficiently the system requires the surrounding mortar to have a resistivity low enough to allow sufficient current transfer.
Principle 11 (CA)	**Control of anodic areas**. Creating conditions in which potentially anodic areas of reinforcement are unable to take part in the corrosion reaction.	11.1 Active coating of the reinforcement	These coatings contain active pigments that function as an inhibitor or/and provide a passive environment due to their alkalinity. Although care must be taken to apply them properly, they are less sensitive to application defects than barrier coatings.

Principle No.	Principle Definition	Method	Description
		11.2 Barrier coating of the reinforcement	These barrier coatings work by completely isolating the reinforcement from oxygen or water. Therefore they require higher levels of surface preparation and application control. This is because they can only be effective if the steel is completely free from corrosion and fully coated without any defects ree from corrosion and fully coated without iso conditions. Any effective reduction in the bonding of the repair material to the treated reinforcement should also be considered.
		11.3 Applying corrosion inhibitors in or to the concrete	Applying corrosion inhibitors to the concrete surface, they diffuse to the reinforcement and form a protective layer on the surface of the bars. These corrosion inhibitors can also be added as admixtures to the repair mortar or concrete that is used for the concrete reinstatement works.

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Source: Bridge brittanica

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