Bridge Maintenance and Repair Manual

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1 Introduction

1.1 VicRoads Bridge Maintenance and Repair Manual

VicRoads Bridge Maintenance and Repair Manual (BMRM) supersedes the previous VicRoads Bridge Maintenance, Repair and Strengthening Guidelines.

The BMRM provides:

- guidance on the treatment of defects identified during Level 1 and Level 2 Inspections
- guidance for maintenance and repair activities

The scope of the BMRM does not include strengthening as this is dealt-with on a case-by-case basis.

The BMRM comprises four sections:

1. Introduction
2. Maintenance of structures
3. Repair of concrete, steel, timber and masonry structures
4. References

Appendix 1: Bridge Components – provides an illustrated guide to the major components of a bridge and the nomenclature of bridge components

Appendix 2: Durability Considerations – provides guidance on the significance of service environments and durability in the selection of materials and construction practices

1.2 Background

This BMRM should be used in conjunction with the *VicRoads - Road Structures Inspection Manual* (RSIM). The documents are complementary and are intended to provide consistent guidance on the identification and treatment of defects.

Maintenance and repair are complementary operations and are both essential components of bridge management.

Maintenance is cyclic activity which is repeated over the life of the structure. It is preventative in principle and is generally straightforward, routine and repetitive.

Repair is a non-cyclic and infrequent activity. If repeated, its scope is likely to change. Repair is remedial in nature – i.e. it is intended to restore the structure to its original condition - and is likely to be a more complex and costly operation than maintenance.

Inadequate maintenance can result in more frequent and costly repairs. It is essential, therefore, to implement systematic and regular maintenance programs to minimise the frequency and cost of repairs.

Maintenance is the recurrent activity which is required to preserve a structure so that it continues to perform its function. It involves the early repair of small, less serious defects which prevents long-term deterioration that would otherwise be more costly to repair.

The RSIM requires that Level 1 inspections are conducted on a six month to one year cycle depending on a risk assessment. Level 1 inspections serve to:

- check for visible defects which might affect structural safety and the safety of road users
- identify maintenance items that require immediate action or
- schedule routine maintenance for completion at a later date.

The RSIM requires that Level 2 inspections are conducted at 2-5 year intervals.

Level 2 inspections serve to assess the condition of structural components and are used to calculate the bridge condition rating (BCR) of the structure. Level 2 inspections can also identify maintenance and/or repairs that address a structural issue and/or prevent further deterioration.

The RSIM requires that Level 3 investigations (engineering investigations) are conducted when required to assess structural capacity in preparation for possible strengthening and to inform management options.

Where defects are identified that are not scheduled for rectification, the process shown in Figure 1 – Maintenance Selections Process of Bridges may be followed to determine the appropriate action.

The RSIM provides guidance on identification of structural and non-structural defects. Structural defects should not be repaired before obtaining structural engineering advice. If structural defects are suspected these should be assessed by a structural engineer.

Requirements for routine maintenance of structures are specified in *VicRoads' Standard Section 750*.

Guidance in the BMRM is drawn from standard practices adopted by a variety of roads management authorities, and reflects the combined experience of the Australian road authorities.

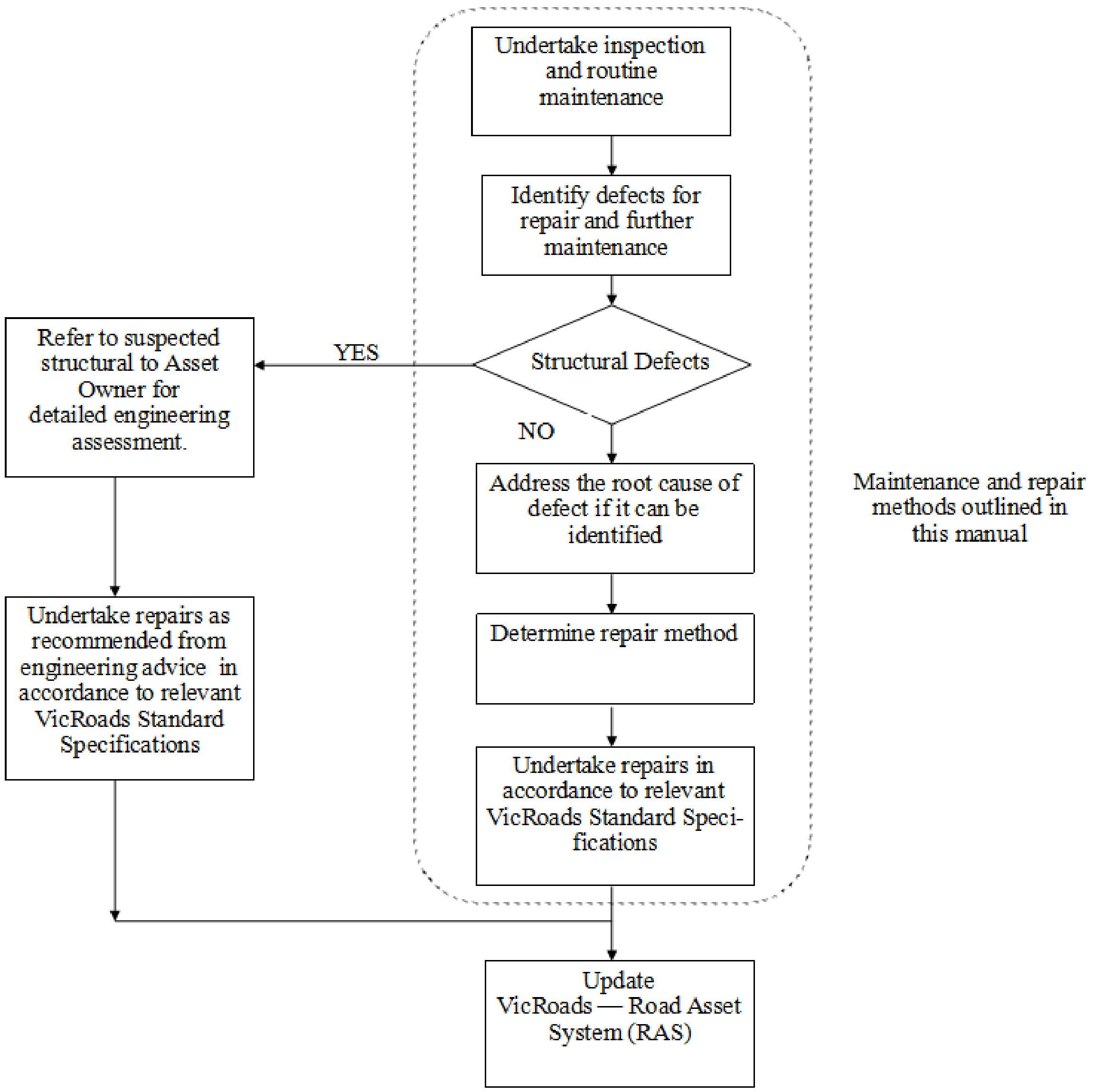


Figure 1: Bridge maintenance and repair process

1.3 Purpose

The BMRM is intended to provide guidance to asset managers regarding the maintenance and repair of existing VicRoads bridge assets to ensure that bridges are in a safe condition.

1.4 Scope

The BMRM is intended as a reference for maintenance and repair of VicRoads' bridge structures. It addresses the most common types of bridge and their modes of deterioration and outlines common treatment methods for maintenance and repair. These procedures may not cover all circumstances and are not intended to rule out alternative maintenance procedures. Specialist technical advice should be sought from Asset Services prior to use of alternative procedures.

Maintenance providers should adhere to the requirements of the BMRM when selecting the appropriate maintenance and repair method and to the relevant VicRoads Standard Sections for procedures, material selection and workmanship. If maintenance and repair methods are not covered in the BMRM, the maintenance provider shall seek direction from the asset owner.

The BMRM may be used for heritage listed structures; however, additional care should be taken to ensure maintenance or repairs are completed in a manner that is sensitive to the heritage values of the structure in terms of colour, materials and form. Heritage Victoria provides guidance on the maintenance of heritage-listed assets for minor maintenance and repairs. Heritage Victoria should be consulted for major rehabilitation and strengthening works.

The BMRM does not address repairs to fire or flood damaged structures, or the safety and environmental impact of maintenance activities. In relation to repair of fire or flood damaged structures seek structural engineering advice. Safety and environmental risk assessments must be conducted and appropriate method statements prepared for all activities described in the BMRM.

The BMRM does not include strengthening methods.

1.5 Using The Manual

The BMRM must be read in conjunction with the RSIM to provide Asset Managers, Inspectors and Maintenance Providers with a full understanding of the possible maintenance and repair treatments appropriate to the observed defects.

The BMRM addresses a selection of common treatments. It does not include all treatments that might be found necessary. In cases where the BMRM is silent, further advice shall be obtained from the Asset Manager and Asset Services.

The sketches and diagrams are general and indicative and do not provide full details the repairs.

2 Maintenance of Structures

2.1 Introduction

This section provides detailed guidance regarding maintenance activities including procedures, the types of material and equipment required.

The requirements for the maintenance of structures are stated in *VicRoads' Standard Section 750.D01 - Structures Maintenance Requirements*. Routine maintenance can be undertaken as part of Level 1 - Inspection and includes maintenance of the structure and the adjacent road reserve. The inspection should be undertaken according to the RSIM.

2.2 Maintenance Methods

2.2.1 Cleaning and Clearing

2.2.1.1 [M01] Cleaning Decks

As part of routine maintenance, bridge decks should be cleaned together with kerbs and scuppers to maintain free drainage and prevent ponding of surface water on the bridge deck.

If the bridge has a substantial depth of fill on top of the deck, the fill should be sealed for the full width between kerbs to prevent moisture ingress into the fill material. The seal should be dished around the scuppers to allow for drainage. Care should be exercised to ensure that the finish does not create a hazard to cyclists and motorists.

The requirement for road pavement maintenance is provided in *VicRoads Standard Section 750.B02 – RM 100 Sealed Surface* and *Standard Job RM116 Pavement Cleaning*.

Maintenance Method

1. Sweep loose material from parapets, railings, and sidewalks onto bridge deck. Mechanical removal devices can be utilised (i.e., street sweepers) in areas where such equipment is available.
2. Collect or remove material from the deck, joints and drains. Prevent materials from depositing in drainage systems or joints.
3. Dispose of collected material at an approved disposal or fill site.
4. Minimise the amount of debris entering the waterway. Where feasible, cover or plug scuppers to prevent debris and cleaning water from entering the stream. Temporary silt fencing or other erosion control measures may be used where necessary to prevent stream bank sediments from entering the stream.
5. Flush any supporting structural members with water whilst cleaning deck.

2.2.1.2 [M02] Cleaning Bridge Drainage Systems

As part of routine maintenance, the deck drainage system should be cleared. Bridge drainage systems consist of scuppers (piping through bridge deck) and piped gratings (open steel grid floors), open joints with troughs and all associated piping. All scuppers should be examined and cleaned as part of routine maintenance.

Poor drainage is normally due to the accumulation of antiskid material and other debris within the drainage system preventing proper draining. Stagnated water may contain corrosive chemicals that cause corrosion in the pipe and may lead to ruptures. If water with corrosive chemicals leaks through ruptures, corrosion could attack structural elements of the bridge.

Scuppers should be a minimum 100mm diameter to reduce the risk of blockage. Structural engineering advice should be sought to improve the drainage system if it is found to be deficient.

The requirement for drainage maintenance is described in the *VicRoads Standard Section 750.B03 – RM 400 Drainage.*

Maintenance Method

1. Lift the grating from the scupper (if applicable), remove debris and sediment from scupper box and pipe.
2. Lift grating over drainage pit, remove debris from pit and grating.
3. Use clean water when flushing scuppers and downspouts, remove cleanout plugs as necessary. Avoid using high-pressure water as it may damage joints or anchors.
4. Pressurised water or metal probes may only be used to remove antiskid or other debris where other methods have failed. Such methods should be accompanied by inspection and repair of joints and anchors after cleaning.
5. If debris has accumulated in down spouting it should be dislodged with low pressure water (less than 5,000 psi). The discharge of debris into the waterway should be minimised by positioning hay bales at pipe outlets or by using an in-stream silt curtain.
6. Deposit collected debris at an approved disposal or fill site.

2.2.1.3 [M03] Cleaning and Checking Expansion Joints

As part of the Level 1 - Inspections, all expansion joints (Figure 2) should be cleaned of dirt, grit, weeds, and stones. Inspection of the joints for any damage should be carried out after cleaning of the joints with compressed air.

Damage to expansion joints may occur due to;

- the impact of tyres on seals at the deck level,
- loss of adhesion between sealant and the concrete/steel joint armouring,
- cracking of the sealant due to loss of cohesion strength or inadequate tensile capacity (i.e., fluctuatons in joint gap that are not accommodated by the sealant),
- cracking of the sealant or rubber seals in joint due to heat and UV exposure or moisture, and chemicals.
- cracking and breaking up of the expansion joint nosing.
- cracking of the asphalt at the joint due to deck movement and span rotations under load.
- splitting or pulling out of rubber or neoprene glands of the retainers at the ends caused by excessive movements or incorrect installation.
- finger joints may suffer from mismatch due to lateral movements especially on curved or large skew bridges where steel angles are used to armour the expansion joints.
- angles on finger joints may have moved due to break up or failure of mortar packing supporting the angle as a result of traffic loading and vibration.

The requirement for cleaning roadside vegetation that may affect deck joints is further described in *VicRoads Specification Standard Section 750.D01 - RM 500 Vegetation*.

Figure 2: Deck expansion joints *(Georgia Bridge Manual 2012)*

Maintenance Method

1. Use brooms, compressed air or shovels to remove excess debris within the joint. Care should be taken not to damage the expansion joint materials when using a shovel. The joints can also be cleaned as part of Cleaning Decks [M01].
2. Undertake inspections of the joints immediately after cleaning.
3. Check and note any defects in joints as required by the *Road Structures Inspection Manual.*
4. Fill in any missing sections in expansion joint headers with cold mix until it can be permanently fixed.
5. Tighten any loose bolts or temporarily refix loose plates with a tack weld.
6. Cut out or remove any misaligned fingers which may pose a hazard to tyres.
7. Any defects to the joints should be repaired or replaced permanently at a later date by specialist contractors as most expansion joint systems require specialist expertise for correct installation.

NB: Joints should be checked for leakage on wet days when leaks are most noticeable.

2.2.1.4 [M04] Cleaning Abutments

An accumluation of trash and dirt on abutment caps (e.g. Figure 3) can lead to deterioration in the structure due to the effect of water, chemicals or fungi or algae. These areas are also susceptible to damage by fire or vandalism.

Figure 3: Abutment require cleaning

Maintenance Method

1. Collect and remove trash, dirt, and other debris from abutments or caps by brooming, shovelling, vacuuming, or other suitable methods.
2. Loosen dirt and debris with scrapers and stiff brushes, as necessary.
3. Wash the area with clean high pressure water if further cleaning is required.
4. Newer bridges have drains along the fender wall either draining through the wingwall or the fender wall to the subsurface draining behind the abutment. These drainage holes should be checked and care must be taken to ensure the cleaning process does not block these holes.
5. Use hay bales or silt fences to prevent discharge of loose material, grit, and debris into the waterway.

2.2.1.5 [M05] Cleaning Bearings and Bearing Seats

Any deterioration in bearing and bearing seats could result in differential settlement of the supported superstructure and overstress. Furthermore, when bearings seize up they prevent thermal movement of the structure which can result in large and damaging forces. Therefore, bearings should be cleaned of dirt, grit, and moisture build-up as part of routine maintenance. In addition, the condition of the bearing seats (mortar pedestals), steel base and bearing plates should be noted. The damage to bearings usually takes the form of scaling, pop-outs or sloughing off at the corners. Leakage of joints tends to result in accumulation of chemical-laden dirt and debris in this area and the degree of deterioration is likely to be greater closer to the point of leakage.

An efficient way to prevent bearings and bearing seats from deterioration is as follows:

- Ensure deck joints are sealed and leakage of water minimised
- Install pipes or splash plates to divert discharged from scuppers and joints.
- Clean surfaces regularly to minimise accumulation of chemical-laden dirt and debris.
- The surface should be flushed annually after the threat of snow and ice has diminished or passed.

Maintenance Method

1. Set up scaffolding, position man-lift or under bridge inspection platform as required.
2. Clean the bearing and bearing seats manually by scraping, brushing or chipping all accumulated debris.
3. Remove loose paint by dry wire brushing.
4. Flush bearings and bearing seats at piers and abutments with pressurized water to remove salt, dirt and debris which cannot be removed by manual cleaning methods.
5. Limit wet cleaning to 1.5 m on either side of the joint at the pier, unless debris in other areas requires further cleaning.
6. Use clean water when flushing bearings and bearing seats.
7. Prevent discharge of debris, especially paint debris, into waterways.
8. Use temporary silt fencing, hay bales and other erosion control measures to prevent debris and silt entering waterways.
9. Lubricate bearings where necessary

2.2.1.6 [M06] Cleaning Steel Horizontal Surfaces

As part of the Level 1 - Inspections, all steel surfaces should be cleaned to minimise the potential for corrosion.

Requirement guidelines of routine maintenance action are outlined in the *VicRoads Standard Section 750.E021*.

Maintenance Method

1. Clean the horizontal surfaces, by scraping or brushing to remove all accumulated debris.
2. Dirt material should be collected and disposed of at an approved disposal site.
3. Flush all horizontal surfaces of structural steel members with pressurized water to remove salt, dirt and debris, which cannot be removed by manual cleaning methods.
4. Limit wet cleaning of horizontal steel surfaces to 1.5 m from the abutment, unless debris in other areas requires further cleaning.
5. Use clean water when flushing the surfaces.
6. Use temporary silt fencing, hay bales and other erosion control measures to prevent debris and silt entering waterways.

2.2.1.7 [M07] Clearing Blocked and Silted Culverts

Debris and silt which are deposited in front of or inside the culverts, blocks the flow of water through the culvert. If not regularly cleaned out, the debris and silt may build up until the culvert is completely blocked. Blockage or excessive growth in the waterway downstream outlet of the structure may also lead to obstruction of flow and silting up of culverts.

It is necessary to inspect and clear the entire system including the inlet, the outlet and the length of the culvert.

Stream maintenance requirements are specified in the *VicRoads Standard Section 750.D04 –RM415 Stream Maintenance.*

Maintenance Method

1. Determine the cause of the blockage.
2. Remove the source of blockage to clear flow inlet and outlet.
3. Inspect the upstream and downstream of the structure and clear debris.
4. Cells or culverts which are blocked to half of their depth or greater should be cleaned out with shovel, scrapers or high-pressure water blast internally to allow flow through the structure, preventing ponding and further silt deposition.
5. Blocked culverts due to silting should be reported to determine whether a silt trap is required to prevent further silting.
6. Alternatively, erosion control measures should be considered at both the inlet and outlet of the culvert structure to control the amount of silt within the waterway.

NB: Works outside culvert that will disturb river banks and inlet/outlet will require permission from the relevant Catchment Management Authority.

Figure 4: Debris and vegetation built up at inlet

2.2.1.8 [M08] Removing Vegetation from Masonry Work

Growth should be removed from masonry work at abutments, piers or arches to avoid the weeds destroying the mortar and displacing the masonry blocks. (Refer to Figure 5)

Figure 5: Vegetation growth on masonry

Maintenance Method

1. It is important to kill and remove vegetation and its roots to prevent damage to the masonry.
2. Vegetation can be removed mechanically using appropriate scraping tools. For areas out of arm's reach, outreach assistance such as a pole-mounted tool or access equipment should be used.
3. Alternatively, they can be sprayed with a weed killer (Glyphosate or equivalent). However care should be exercised to prevent overspray entering waterways or impacting other plants. Over time, dead weeds should detach naturally.
4. Eliminating potential sources of water and moisture on the structure will assist in controlling and limiting potential for regrowth of vegetation.
5. Gaps between stones with depth less than 20mm can be left, however if gaps have a depth greater than 20mm they should be repointed in accordance with [RPM32] Repointing Stonework.

2.2.2 **Maintaining Pavement and Footpath Surfaces**

2.2.2.1 [M09] Sealing Cracks in Asphalt Surface

The asphalt surface on the bridge deck may be cracked. The crack can appear in the asphalt due to small movements and differential rotations of the spans under load and the influence of temperature fluctuation.

Pavement maintenance requirements are specified in the *VicRoads Standard Section 750.C01 -RM100 Sealed Surface*.

Maintenance Method

1. Except for fixed joints, cracking can indicate the presence of other problems and should be addressed.
2. The cracks should be cleaned using compressed air blast then sealed to just below road surface level with hot-poured-rubberised or polymer-modified bitumen. By sealing to just below the road, tyres will not impact the soft material and the sealant will not be expelled in the warmer weather when the asphalt expands.

2.2.2.2 [M10] Sealing Potholes and Gravel Edges on Bridge decks

A number of older type structures have gravel fill, 100 to 200mm thick, on the concrete deck. The gravel fill commonly has a sprayed seal to match the width of the road on the approaches. This leaves edges on the structures unsealed, allowing moisture penetration and weed growth due to the saturation of the gravel fill. The retained moisture permeates the concrete deck causing corrosion of the reinforcement over time. The fill may also be distorted in shape and causes cracks and potholes under the heavy truck loading, especially if the fill becomes saturated.

Figure 6: Potholes on the deck

Maintenance Method

1. All weed growth should be removed and the unsealed edges spray sealed to the kerb face to prevent further moisture ingress.
2. Deck drainage should be investigated to remove the surface water from the bridge and eliminate any water ponding to prevent any rutting and formation of potholes.
3. Surface cracking should be corrected with any crack sealant as detailed in treatment for crack repair of asphalt. Potholes should be repaired by removal of gravel in damaged area and backfilled with cold mix/hot mix asphalt (as specified), and well compacted using a vibrating plate or repeated drop weight on a heavy plate. The routine maintenance works should be undertaken as specified in *VicRoads Standard Section 750 – ROUTINE MAINTENANCE.*

NB: Care should be exercised in sealing works to not restrict the functionality of scuppers by reducing the diameter, sealing over them or affecting surface levels and hence fall towards the scupper.

2.2.2.3 [M11] Small Bridge Joint Seals

The purpose of bridge joint seals is to prevent dirt, debris, and chlorides from entering and causing deterioration of the deck and supporting bridge members. Sealing of bridge approach or deck joints with a hot pour material should be used at all bridge ends that butt against asphalt approach pavements or in concrete to concrete joints. Generally these joints are categorised as small joints (up to 20 mm wide).

These joints permit small relative movement at the interfaces due to thermal expansion and contraction, thereby reducing the potential for asphalt and concrete cracking. It is important that resurfacing works on bridges reinstates these joints otherwise there maybe random cracking at the interface between bridge and approaches.

Maintenance Method

1. Small expansion joints that are leaking badly should be replaced to protect the remainder of the structure beneath.
2. Polyethylene foam backing rods can be rammed into the joints and the rubberized or polymer bitumen poured on top and tooled, finishing at least 5 mm below road surface to prevent tyre impact on the sealant.
3. The thickness of the tooled sealant should preferably be approximately half the width of the expansion gap.

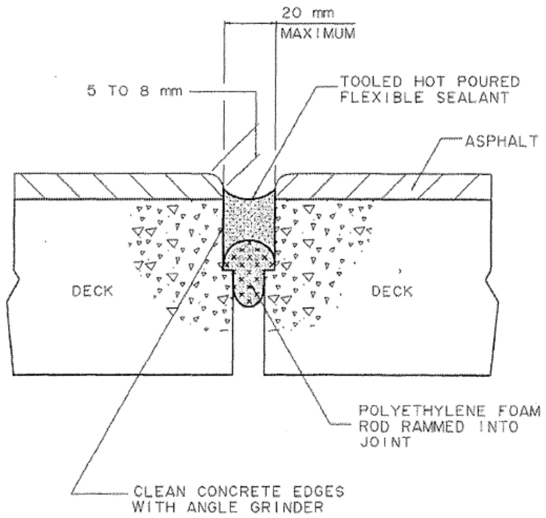


Figure 7: Diagram of typical small width expansion joint

Figure 8: Asphalt cracking exhibiting need for small width expansion joint

2.2.2.4 [M12] Maintaining Bridge Approaches - Pavement and Drainage

The 10 to 15 m length of roadway at each end of a bridge is considered as the bridge approach and can significantly influence the impact a vehicle imparts to the structure. A smooth and well-graded transition from the road to the bridge serves to minimise impact on the structure.

Poorly graded or uneven pavement which settles below the deck level may impose severe dynamic impact from heavy loads adjacent to the end of the structure.

The inspector should look for settlement behind the abutment especially where there is a large fill embankment, and also check for an even approach grade where the structure is higher than the surrounding ground. Approaches should be graded 10 to 15 m from the end of the deck so as to prevent bottoming of the truck suspension at the end of the deck.

Drainage of the bridge approaches can also be a problem when a bridge is at the bottom of a grade or when the bridge is on a grade with no drainage supplied. Surface water should be collected and discharged well before the bridge to prevent washout under the kerb or behind the wing wall.

Maintenance Method

1. Inspect bridge pavements on the approach and patch settled asphalt as required (deep patching maybe required).
2. Identify locations for patching by asphalting contractor.
3. Check whether water from the bridge deck is channelled into a drainage pit at the low end of the deck and discharged well clear of the structure. Identify pits and pipes which may require clearing of debris. Schedule a sucker vacuum truck to clear pits and flush pipes as required ensuring drainage is functional again.
4. Check for signs of staining and scouring alongside the abutment wing wall and down the abutment batter where it may scour a deep channel and damage the batter. Identify repairs to drainage facilities to avoid scouring of the wing wall and abutment batter. Otherwise install concrete a spoon drain to protect the batter and channel water in the waterway to minimise erosion.

2.2.2.5 [M13] Raising Bridge Approaches

The approach to the structure can settle below the level of the deck due to long-term settlement of the embankment fill or due to loss of fill below and behind the abutments. It can also be due to a steep rise to the bridge and large changes in the vertical alignment. This unevenness can result in impact loading at the end of the deck.

Cracks, ruts and potholes should be repaired prior to raising of the approach. Cracks, ruts, shoving and potholes may also indicate other problems such as poor pavement or subgrade or drainage problems that may require remediation. Cracking could be caused by the abutment being pushed forward by the soil pressure applied to the back of the abutment.

Maintenance Method

1. Check if approach slab is present on site. As-built drawings may not provide an accurate record of whether there is an approach slab. Verification can be performed on site by checking whether there is a secondary joint or crack across the road a few meters back from abutment or by some hand excavation beside the slab.
2. If the settlement is due to the loss of fill beneath the abutment crossheads, then that problem needs to be addressed prior to raising the bridge approach. This treatment was described in [M20] Retaining the Road Embankment under Abutment Crossheads.
3. If settlement of the approach is solely due to compaction or consolidation over time of the embankment or the original ground beneath it, then a new layer of asphalt can be placed to restore levels. The approach should be at the same grade as the bridge, for at least five metres at either end of the structure to avoid sudden vehicle impact loads at the end of the deck. The rate of grade change prior to the bridge and the speed of vehicles both influence impact loads on the end of the bridge.
4. If the settlement is large or continues after regrading with asphalt, a geotechnical investigation of the embankment and sub-soil properties may be required.

2.2.2.6 [M14] Repairing Bridge Footpath and Kerb

Footpaths should be checked for hazards. The concrete kerbs and footpath slab may be cracked, spalled, or broken due to wheel impact or due to insufficient concrete cover to the reinforcement. The ends of the precast kerb units may be spalled or broken away from the cast in-situ kerb sections. Footpath precast slabs can crack severely or suffer vehicle damage.

Uneven surfaces due to slab rotation, uneven support or errors with the original levels can present hazards to pedestrians. A large step at the end of the deck where it abuts the approach footpaths can also be hazardous. Asphalt and macadam footpaths can become uneven with cracking, heaving, shoving, broken up areas or pooled water. Furthermore, the steel armouring (edging) retaining the asphalt or macadam may become loose, dislodged or corroded over time.

A large gap, e.g. in the expansion joint or joint between precast concrete footpath slabs over the top of embedded services, could permit a high heel to slip into the joint gap causing a fall. If the units have a differential in the height of 10 mm, this could present a tripping hazard.

VicRoads Standard Section 750.B outlines the maintenance requirement for pavements.

Maintenance Method

1. Badly spalled or broken out areas should be re-cast or patch repaired in accordance with [RPM09] Spalling and Scaling Repairs.
2. Steps in precast slabs should be ground down to reduce the risk of pedestrians tripping on the steps. Alternatively, the approach footpaths should be raised to the bridge deck level.
3. Badly cracked and broken slabs that have failed will require replacement. This type of work should be programmed as repair work.
4. Macadam surfaces which are uneven, very porous and leak badly should be dug out and replaced with asphalt or concrete to minimise future maintenance.
5. Steel armouring should be secured or replaced to retain the infill; uneven asphalt should be repaired to provide a smooth well-drained surface.

2.2.3 Maintaining Approach Barriers and Structure Barriers

2.2.3.1 [M15] Maintaining Bridge Approach Guardfence

VicRoads Standard Section 750.A provides requirements for the maintenance of guardfence under the item *RM612 – Guard Fence or Wire Rope Safety Barrier*. All posts and railing bolt connections should be checked as part of Level 1 - Inspections.

Guard fence should be installed on the approaches to all bridges. The few exceptions being very wide bridges with footways in the metropolitan area or in low speed environments where the alignment is straight. Guard fence should have sufficient strength to prevent vehicles penetrating the railing or the railing being severely deflected and consequently guiding the errant vehicle directly into the end of the bridge endpost. New guard fence should have steel posts more closely spaced as it approaches bridge parapet (e.g. 1 m spacings) and more widely spaced further away from the bridge. However, many older existing bridges have built with the posts at 2.0 or 2.5 m centres. These guard fences will commonly only have sufficient strength for the light weight errant vehicles with low impact speed and slight angle of impact (Figure 9). The current standard drawing (SD4084) for bridge approach guard fence can be found on the VicRoads Website.

Figure 9: Damage to guardfence on bridge approach

Structures with posts at larger than ideal spacing should be upgraded to provide more closely spaced posts with additional posts installed near the end of the bridge railing. When replacing guard fence, the current standards should be followed. On some older structures, the approach guard fence is supported on timber posts which do not meet current standards and tend to deteriorate due to rotting and termite attack.

Maintenance Method

1. Any damage to the posts and rails due to traffic impact should be repaired or the damaged members replaced depending on the severity of the damage.
2. Loose bolts should be retightened.
3. Missing bolts and washers should be replaced immediately.
4. Timber posts and timber spacers which exhibit rotting, severe weathering, leaning, should be replaced. Similarly, any loose or settled posts should be replaced.
5. Steel posts that exhibit leaning, are loose or have settled substantially with the embankment should be replaced with new steel posts.
6. Severely corroded guard fence or posts with section loss greater than 30 percent should be programmed for replacement.
7. Connections on existing or replaced guard fence and posts should be retightened.
8. Missing or broken delineators should be reinstated on the guard fence.
9. Where the height of a guard fence does not meet current standards, it should be modified to bring it to the correct height above the road pavement with new connections or posts as required.

2.2.3.2 [M16] Maintaining Timber Railing

Timber posts and railing may be split, rotted or have loose connections. All bolt connections at the posts and railing should be checked as part of Level 1 - Inspections. Rails and posts should be assessed and any that are not in reasonable condition should be listed for possible repair or replacement.

Maintenance Method

1. Any damage to the posts and rails due to traffic impact should be repaired or the damaged members replaced depending on the severity of the damage.
2. Lose bolts should be retightened.
3. Missing bolts and washers should be replaced immediately.
4. Severely split rails or posts should be replaced. Connections on existing or replaced rails and posts should be retightened. The bridge railing should be cleaned, primed and repainted so that it is readily identified.
5. Deteriorated railing should be programmed for replacement.
6. Posts that are leaning, rotted, severely weathered or substantially settled should be replaced, and the bridge railing and the approach guard fence reconnected.

Figure 10: Timber Railing post requiring replacement.

2.2.3.3 [M17] Maintaining Steel Railing

The railing may be damaged due to corrosion or vehicle impact. In some cases, timber posts and timber blockouts may be severely rotted. Concrete posts may be damaged especially where the steel tube rails are slotted into the posts (Refer Figure 11).

Figure 11: Steel Railing with concrete post requiring crack and patch repairs.

Prior to any work on steel railing on the bridge the existing paint should be checked to determine whether it is lead paint. Handheld lead test kits can be used to determine whether lead is present. If lead is present works should be done in accordance to *AS4361.1 – Guide to hazardous paint management*.

Refer to Standard Section 631 – Protective Treatment of Steelwork.

Maintenance Method

1. Any damage to the posts or rails due to traffic impact should be repaired or the posts or rails replaced depending on the severity of the damage.
2. Corroded or rusted areas should be cleaned to bright metal using an angle grinder and the areas prime coated. A separate prime coat should be applied to all the railing followed by a top coat. The finished coating should match the existing paintwork.
3. If the concrete posts have severe cracking, they should be injected with epoxy in accordance with [RPM02] Repair of Inactive Cracks.
4. If the concrete posts are spalled, they should be patch repaired around the tube rail using a polymer modified cementitious mortar in accordance with [RPM09] Spalling and Scaling Repairs.
5. If the base of the concrete posts are severely cracked, they should be epoxy injected or broken out and patch repaired.
6. Corroded guardfence should be replaced with new steel sections where section loss is greater than 50 percent.
7. Severely rotted timber posts and blockouts should be replaced with galvanized steel channel sections.

2.2.3.4 [M18] Maintaining Concrete Railing

The concrete posts and precast reinforced concrete rails may be heavily cracked and spalled due to impact damage or insufficient concrete cover to the reinforcement.

Refer to *Standard Section 687 – Repair of Concrete Cracks.*

Refer to *Standard Section 686 – Coating of Concrete.*

Maintenance Method

1. Any damage to the posts and rails due to vehicle impact should be repaired or the posts or rails replaced depending on the severity of the damage.
2. The precast concrete rails and posts with spalling should be broken back, the reinforcement thoroughly cleaned and primed followed by patching in accordance with [RPM09] Spalling and Scaling Repairs with a polymer modified mortar. If the spalling is extensive, it may be more economical to replace the rail.
3. If the concrete rails or posts are severely cracked, they should be epoxy injected to restore strength and integrity in accordance with [RPM02] Repair of Inactive Cracks.
4. If the base of the posts are severely cracked, they should be epoxy injected or broken out and patch repaired.
5. If the bridge is narrow, then consideration should be given to modifying the railing to prevent possible snagging of the vehicle on the posts.

Figure 12: Concrete railing in need of repair or replacement and approach guard fence attached to parapet.

2.2.4 Maintaining Embankments and Batters

2.2.4.1 [M19] Embankments

The area immediately behind the abutment can affect the impact of the heavy load coming onto the end of the bridge deck. If there is settlement of the embankment at this point then the area beneath the crosshead should be inspected as the fill material could be falling through under the crosshead, creating a void behind the abutment or settlement of the roadway behind.

The void should be re-filled to restore support to the road approach embankment prior to any pavement works to adjust the road surface back to deck level.

Maintenance Method

1. Inspect embankment and identify areas where settlement has occured.
2. Inspect the abutment crosshead to determine whether there is are any voids due to loss of fill material. If voids are present, maintenance works should be undertaken at the abutment first in accordance with [M20] Retaining the Road Embankment under Abutment Crossheads.
3. Reinstate the pavement on embankment where settlement has occurred with deep asphalt patching. Any cavities identified during removal of existing asphalt should be filled with cement-stabilised sand prior to reinstating asphalt surface, as the abutment works may not have completely filled the voids behind the abutment.

2.2.4.2 [M20] Retaining the Road Embankment under Abutment Crossheads

In some instances, the batter or fill in the front and beneath the abutment crosshead may have settled or been lost. The fill at the rear of the crosshead may be beginning to fall through due to traffic loading impact and vibration. Loss of fill may also be caused by problems with road drainage and runoff or by a leaking service pipe. Loss of the supporting fill may cause settlement of the approach pavement. In such cases, support should be reinstated to prevent further settlement behind the abutments.

Figure 13: Cavity developing under abutment crosshead

Figure 14: Inside of the cavity

Maintenance Method

1. It may be difficult to replace the lost fill with new compacted fill, so a small wall can first be constructed to permit placement and compaction of material to fill the cavity.
2. The wall can be built using grouted stones or dry pack sand/cement bags stacked on top of each other between the piles or columns.
3. Sand can be packed behind by a ram before completing the top layer of the wall. The sand can also be compacted with water, which may also serve to wet the mortar bags and hydrate the mixture to form a solid wall.
4. When fill material has been lost from behind the abutment crosshead and the cavity cannot be filled and compacted by the first method, a dry pack sand/cement bag wall should be constructed in front of the crosshead.
5. Where the bag wall will be stacked more than 5 bags high; a second row of bags should be laid to stabilise the wall.
6. Fill the cavity behind with sand to a height just below the underside of the crosshead.
7. The wall should then be raised to a height 200mm above the soffit of the crosshead and a flowable grout or slurry mix vibrated with tremie to fill in the cavity. Moisture from the grout or slurry should penetrate through sand/cement bags setting the mixture to form a solid wall.
8. Once the wall and backfill have been completed and allowed to harden, the roadway behind the abutment can be repaired and the road level raised to match the bridge deck level.

The State Emergency Services (VIC) provides guidance on sandbagging and construction of sandbag walls refer *Sandbag Quick Reference Guide (SES (Vic), 2012).*

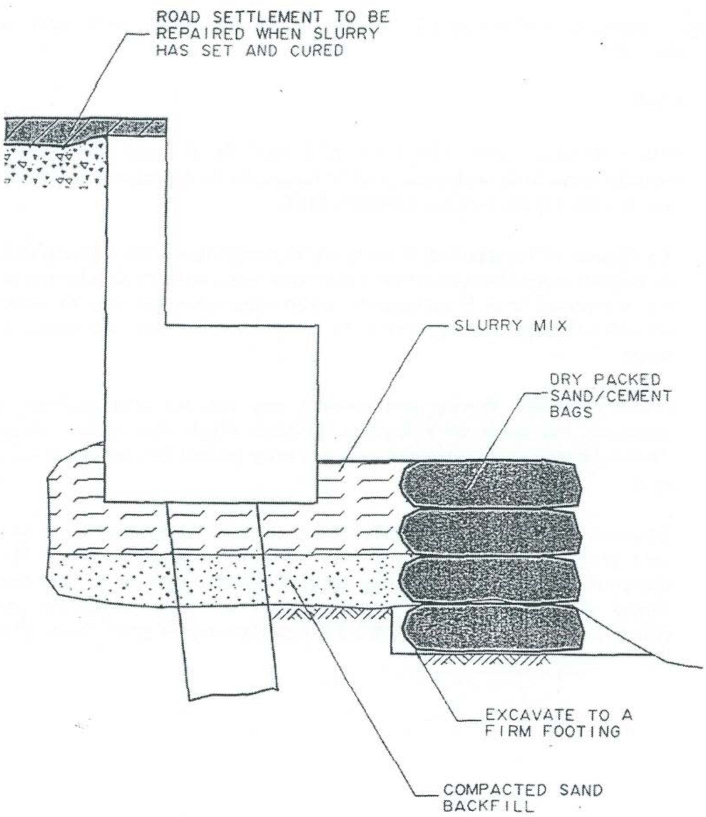


Figure 15: Retaining embankment beneath abutment crossheads.

2.2.4.3 [M21] Stabilising Batters

In some instances, the batter in front of the abutment may be showing signs of erosion or the beaching is being lost due to erosion or vandalism. In such cases, there may be deep scouring holes formed beneath deck scuppers or due to poor road drainage at the end of the deck.

Refer to *VicRoads Standard Section 713 – Beaching* provides additional requirements for works.

Maintenance Method

1. The rock beaching should be replaced with geotextile beneath to act as a moisture filter and to retain the batter fill. Rocks should be of a large size so that they are not easily dislodged.
2. If vandals are a contributing factor, then the rocks should be held down with a strong woven wire connected through driven star pickets.
3. Scour holes beneath deck drainage should be given extra protection, or additional drainage scupper piping may be required to carry water to discharge point.
4. Road drainage should be attended to if it is causing the scour, prior to the beaching repair. If there is no beaching and scouring is occurring, then the batter should be protected with beaching.
5. Four different protective forms are:
    a) stacked rocks, with grout for additional durability
    b) rock mattresses
    c) precast concrete beaching units or
    d) mortar filled or pumped fabrimat mattress.

6. The beaching should include a deep toe into the bed (typically 500mm) and have cut off trenches at the sides to prevent the stream undermining the protection.
7. Rock gabions keyed into the stream bed with geotextile behind can be used in the creek bed if the stream has cut into the batter toe leaving a vertical earth face.
8. If the stream bed is very silty or sandy, care must be taken not to bed the beaching on the silt or sand which is likely to be eroded. The beaching should be keyed into firm clay which is less likely to scour.

NB: Stabilisation works should take into account upstream and downstream conditions to ensure that the stabilisation treatment is not compromised at the ends.

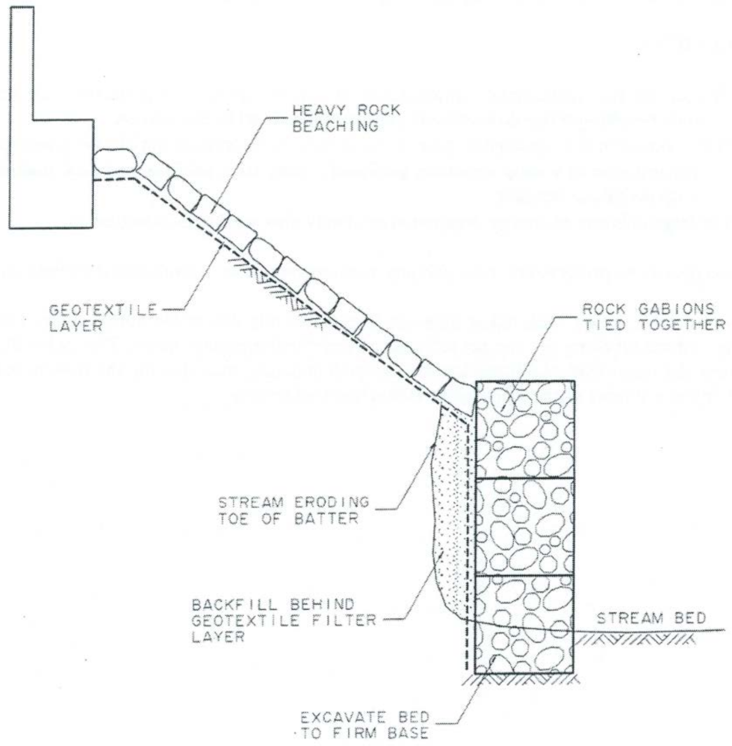


Figure 16: Batter stabilisation with rock beaching

2.2.5 Maintaining Timber Components

2.2.5.1 [M22] Checking Timber Elements and Treating Termite Activity

It is important to identify termite (white ant) activity at an early stage to lessen the damage it causes to timber components. The nests are often hidden in dead tree trunks or in the approach embankment fill.

Termite activity can be evidenced by small enclosed tunnels on the outside of the timber or more usually in piles or timber stringers. They can also be evidenced by the eaten out timber which is left as a series of fine flakes or wedges. By chasing along the wood, they may be found in the end unless they have moved on to another moist piece of timber nearby.

For maximum effectiveness, treatment should be undertaken in the warmer months when the white ants are most active. Termite treatments include:

- Arsenic powders (White arsenic or Paris Green) blown into the tunnels and galleries using small hand puffers or powder blowers. Subtle quantities are used to dust the tunnel walls lightly, with the ants spreading the arsenic as they rub against the walls and move along the tunnels.

- The soil around the piles should also be treated to a depth of 300 mm using chlorinated hydrocarbons in an aqueous solution, but this should not be used near waterways.
- Boron rods or preservatives can be inserted in the timber which preserves the wood and acts as both a fungicide and insecticide.

Further information on the management of termites in and around existing buildings and structures can be found in AS3660.2 – Termite Management.

Maintenance Method

1. Inspect timber elements and identify areas which are moist or wet.
2. Inspect these timber elements for tunnels or fine flakes or wedges as an indicator of the presence of termites.
3. If the damage is limited, the affected areas can be treated with chemicals to wipe out termites. If the damaged area is extensive, the timber should be replaced immediately. Termite affected timber should then be removed and burnt to destroy the termites.
4. If the actual nest can be found then, it provides an opportunity to wipe out the whole colony by treatment using chemicals. Eradication of termite nests is achieved by using chemical treatment or by separation of the colony from its sustaining moisture.
5. Once, the termites have been eradicated then repair and replace deteriorated timber sections.
6. Install chemical and physical barriers to prevent termites from returning and attacking timber bridge members in contact with the ground or prone to moisture or wetting.
7. One or two repetitive treatments are required, at monthly intervals, to remove the termites fully.
8. Regular monitoring is necessary until confirming that termites have been fully eradicated.

NB: Arsenic powder is a toxic substance and should be handled with care by workers. Specialist pest controllers may have more effective, efficient and safer chemical alternatives.

2.2.5.2 [M23] Checking Timber Decks for Tightness and Plank Replacement

It is important to keep the decks on timber bridges tight and in serviceable condition. Timber deck bridges are generally under-designed for current traffic loading and rely on the distribution and stress relief to carry the heavy loads, which can cause large deflections of the timber members and impose large loads on connections.

Maintenance Method

1. All bolts or spikes need regular checking and retightening especially as the frequency and weight of the loads increase.
2. Planks should span a minimum of two crossbeams to prevent the sudden collapse of the timber and should be held down near every second crossbeam to stop the plank flogging under load.
3. Planks should have a uniform thickness to provide a flat deck and stop imparting lateral movement of the tyres as the vehicle crosses.
4. Generally a coarse sprayed seal is applied to the surface which prevents slipping of tyres in wet conditions and reduces weathering of the timber. Alternatively, the planks can be treated with a wood preservative; a linseed oil wood preservative should be considered if the structure is over an environmentally sensitive watercourse.

5. Replace planks which are severely split, highly weathered, cracked through or have excessive edge rot.
6. If the planks are spiked, the state of the timber spiking plank or timber cross beam should also be assessed when replacing deck planks.

NB: Wood preservatives should be applied with care as excessive amounts may result in a slippery surface for traffic using the bridge.

Figure 17: Loose plank needs to be retightened

2.2.5.3 [M24] Checking Timber Props for Tightness

Timber props are often used to supplement piles in poor condition to support the live loads, especially at piers and abutments. The prop must have a large timber support to prevent settling under load and needs to be well connected to the bed log.

Maintenance Method

1. The detailing of the propping system should be such as to ensure lateral stability and should be designed by a suitably qualified structural engineer.
2. Sets of props should incorporate a crosshead and cross braces to provide stability and load sharing between props.
3. Fox wedges should be installed at the top of the prop to allow retightening of the support against the stringer or crosshead which may experience minor movements, settlement and vibration under load.

2.2.5.4 [M25] Sealing Timber Endgrain

Exposure of the end of a timber member to the weather permits entry of moisture, repeated wetting and drying and deterioration of the timber. In particular, the exposed end will tend to rot. The rotting progresses along the centre of the pile leading to a loss of strength. The timber endgrain should be sealed to keep out moisture to prevent further weathering.

Maintenance Method

1. Seal the endgrain of the timber by filling the cavities to block out the moisture droplets. This is best done in summer when the timber has been allowed to dry out.
2. The sealant can be a preservative such as copper naphthenate or more commonly hot petroleum jelly.
3. A galvanized metal cap may also be considered as an additional or alternative form of protection for the timber to prevent further weathering in accordance with [RPM32] Installation of Flashing.

2.2.5.5 [M26] Checking Timber Piles for Severe Splitting

Severe splitting of timber piles indicates that they are being overstressed and there is a need for upgrading or reinforcement. Areas to inspect are at the top of the pile under the loaded crosshead for indications of:

- splitting due to an edge load
- crushing under the crosshead due to deterioration of the physical bearing support. Half the crosshead width should have direct bearing support on the pile.
- pulling away of the crossheads from the pile due to lack of support
- bending of the bolts due to decay of the top of the timber pile.

Severe splitting elsewhere tends to indicate pile crushing due to heavy rotting of pile centre, known as pipe rot, and could require either steel banding or even timber splints to be installed to restore the capacity of the pile. The affected sapwood of the pile should be removed; the timbers protected and bolts installed every 600 mm with no in-line bolts to cause further splitting.

Severe splitting can also occur in heavily bolted areas due to in-line bolting. In this case,steel banding is the preferred treatment.

At the water level, heavy splitting can be caused by a combination of pipe rot and weathering due to the water wash. If the pile base is substantially smaller, then the pile should have a concrete sleeve placed around it to provide the required capacity and protect it from further deterioration.

Maintenance Method

1. Severe splitting at the top of piles can occur where the crossheads are poorly spliced with butted ends. As each side of the crosshead is loaded it simply tears the pile apart at the top.
2. The crossheads should be properly spliced with steel plates across the joint to transfer the loads from one to the other. Band the top of the pile or install anti- split bolts to hold the pile together.
3. Severe splits needed steel banded with half rounds of 75 x 3 mm cross section or have 20 mm diameter anti- split bolts installed across the split to hold the pile together (3.3.3.1: Rotting and Splitt).

If the problem is a loss of the bearing area under the crosshead, then a metre long section of decking plank can be bolted to the pile to provide the required support. The pile sapwood needs to be trimmed back before bolting on the bearing support block, and all timbers protected. Three bolts should be installed to support the block, though to avoid further splitting, they should not be in the same line.

2.2.6 **Other Minor Maintenance**

2.2.6.1 [M27] Tightening Loose Bolts in U-Slab

High strength u-slab bridges built in the early 1960's through to the mid 70's have 24mm diameter galvanized bolts between the legs to provide lateral distribution of the live load between the slabs.

These bolts tend to loosen due to frequent vibration from the live loads acting on the bridge and allow the slabs to act independently. The asphalt surface tends to exhibit fine cracks (Refer Figure 18) along the line of the slab joints. There may be moisture staining between the slabs but it is commonly minor.

Bridges carrying a large number of heavy loads or which suffer from impact and vibration from heavy loads will require more frequent bolt tightening, especially if the span lengths are 9 or 10.5 metres. Light spring washers could be used to help keep the bolts tight for a longer period without springing the u-slab legs together.

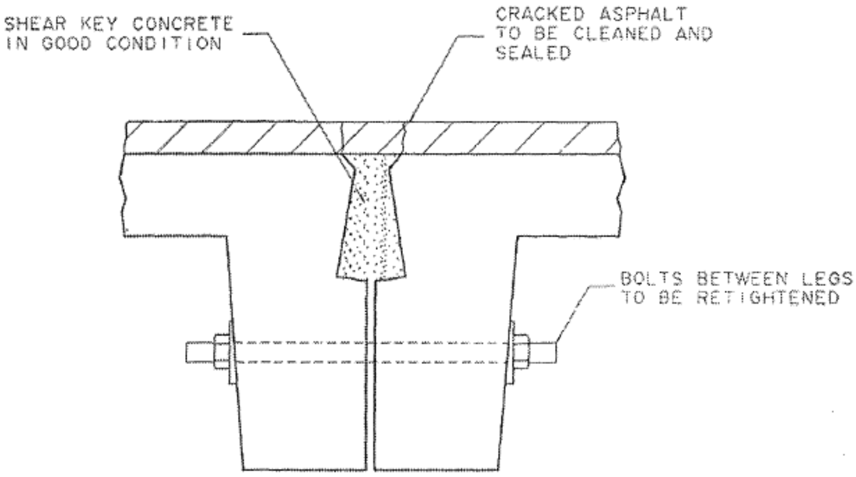


Figure 18: U-Slab bolt tightening

Maintenance Method

1. The bolts should be regularly checked as part of the Level 1 - Inspections and loose bolts identified and programmed for retightening. This can be identified by gap between nuts or washers to concrete surface.
2. Retightening should be by spanner and should be to "finger tight plus half a turn of one nut". Excessive tightening of the bolts should be avoided as it may spring the legs together causing cracking of the top deck of the u-slabs.

NB: After retightening the bolts, the larger cracks in the asphalt can be blown clean with a compressed air blast and sealed using a polymer modified or rubberized bitumen.

2.2.6.2 [M28] Tightening Other Loose Connections

Other connections in the structures may be loose allowing excessive movement to occur with the possibility of failure if the connection is completely lost. This may have been caused by vibration, loading and unloading of the bolted connection, or due to shrinkage of the timber.

Maintenance Method

1. The nut or screw should be retightened, and possibly a spring washer or lock nut installed if the looseness is an ongoing problem. A lock nut arrangement consists of a nut with half depth on the bottom and full nut over the lock nut.
2. Timber connections should be continually checked every 2 to 3 years maximum and retightened where necessary.
3. If a coach screw has been used then, the connection should be examined to determine whether the thread has ripped out of the timber. If so then, a stronger connection such as bolting completely through the member is required.

2.2.6.3 [M29] Preventing Scour in Streams and Banks

Stream beds and banks may scour downstream of the structure and restrict normal stream flow or it can occur around a group of piles, especially if the stream is sandy or silty. Culverts are a major restriction and a source of downstream scour, as are bridges with large embankments or abutments protruding into the natural stream flow path.

Stream maintenance requirement is outlined in the *VicRoads Standard Section 750.D04 – RM415 Stream Maintenance*.

Maintenance Method

1. The stream bed immediately downstream of culverts should be protected with heavy rock beaching if the culvert causes increased flow velocity.
2. If erosion has occurred to the rock beaching, remedial measures might include larger sized stones, grouting of stones in place, changes to the upstream channel to minimise the velocity of water prior to discharge downstream of the structure.
3. If the stream has a drop in level of more than 500mm, then consideration should be given to the construction of a drop structure, preferably using rock gabions and rock mattresses with geotextile beneath.
4. For large culvert, an energy dissipation pool may be required.
5. Banks can be protected by rock gabions, rock mattresses or a combination of the two.

It is preferable to use rock rather than reinforced concrete due to the tendency of the rock to settle without breaking up and not disintegrate. The rocks tend to reduce the flow velocity more effectively than smooth concrete.

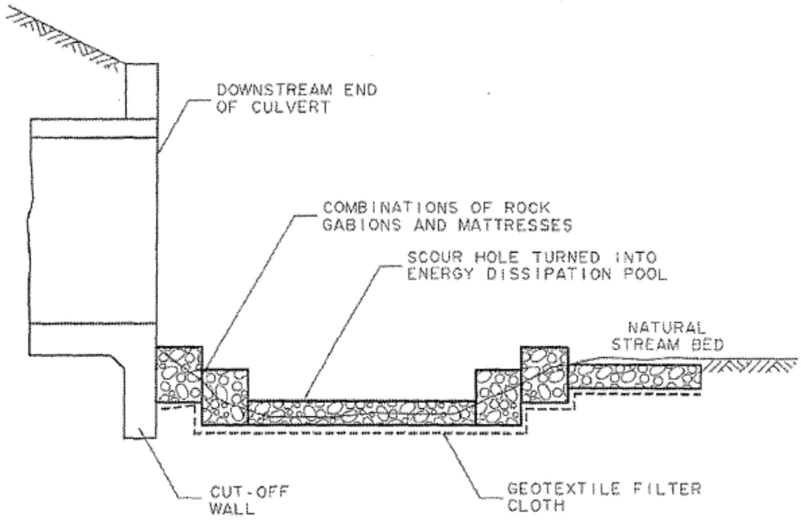


Figure 19: Scour prevention at outlet of culvert

2.2.6.4 [M30] Maintaining Bridge Drainage

Ponding of water on the deck of a bridge can cause aquaplaning of vehicles and increases the risk of water penetrating the deck concrete and causing corrosion of reinforcement. If water is ponding, additional scuppers may be required or there may be a need to clear existing scuppers. If scuppers are too small they should be enlarged. However, the advice of a structural engineer should first be obtained.

If the deck is situated on a longitudinal grade with no drainage it will can result in scouring at the end of the kerb, embankment or around the wing wall.

Maintenance Method

1. Inspect structure during or soon after rain and identify areas where water is ponding
2. Clear any blockages to existing scuppers, pits and pipes.
3. Enlarge any deficient drainage details (i.e. water may be backing up due to inadequate scupper, pipe or pit sizing)
4. Provide additional pits and extend drainage pipes beyond the end of the bridge if there are signs of scouring due to poorly directed drainage.

2.2.6.5 [M31] Extending Scuppers

Scuppers may be too short or of insufficient in length thereby leading to staining of concrete elements, rusting of steel, rotting of timber or significant erosion of the stream channel or the road embankment. Such scuppers should be considered first for extending during maintenance.

Scuppers should extend at least 50 mm beyond the concrete surface to allow stormwater and dirt to drain free and not to be deposited on the concrete surface. In some cases, the scuppers should be extended significantly, depending on the scupper design and where the moisture is draining.

Figure 20: Scupper staining bridge beam and needs to be extended

Maintenance Method

1. Inspect the underside of structure to identify scuppers which require extension.
2. Join new section pipe to existing scupper paying attention to the effect of discharge. The new section of the pipe should take into consideration the potential for damage due to vandalism and be positioned in a way that restricts access by vandals.
3. To minimise the risk of erosion, where possible the pipe should discharge directly into the stormwater system rather than onto the river banks and surroundings. Alternatively, rock beaching may be placed at the outlets of scuppers.

NB: The positioning of drainage assets should consider potential hazard or annoyance to pedestrians due to physical positioning or where path of flow may result in slippery surfaces on footpaths.

2.2.7 Maintaining Bearings

Bearings can be located on abutments, piers, and in pin or pin and link assemblies for cantilevered and suspended spans. Bearings should be inspected and cleaned as part of Level 1 - Inspections. In addition to cleaning of bearings other maintenance activities include the following:

- Repainting of steel bearings on external surfaces may be required if spot rusting or corrosion is identified.
- Lubricating the steel bearings is a programmed maintenance activity based on circumstances and conditions at each structure. The lubricant provides corrosion resistance, minimises mechanical wear and prevents dirt and contaminants at the interface of steel surfaces.
- Crack repair, spall repair and replacement of mortar bearings is a programmed maintenance activity. Timely crack repair and spall can prevent further damage to existing mortar bearing pads.

Bearings below open or defective joints require more frequent cleaning and lubrication than ones below sealed joints. This is due to runoff water, chemicals and debris affecting the bearings. Application of oil based lubricant may also be necessary where there is minimal clearance between sliding plates and the guides.

Refer to *Standard Section 631 – Protective Treatment of Steelwork.*

Sliding bearings

The most common problem with sliding plates is increased sliding friction forces caused by corrosion. If the sliding bearing is corroded, it may prevent movement and generate large restraint forces and cracking of the bridge seat.

If this occurs, the beams should be jacked up to allow bearings to be serviced. Structural engineering advice is required to minimise additional stresses or torsion to the structure during jacking. Once the bridge is appropriately raised, the bearing seat can be repaired, plate surfaces can be removed, thoroughly cleaned, lubricated, and repositioned or replaced (Figure 21). Regular cleaning and lubrication of the bearings will reduce the risk of such remedial works.

Figure 21: Sliding bearing

Roller bearings

The maintenance of roller bearings is difficult as they are usually nested and enclosed (Figure 22a & 22b) and some are enclosed in a sealed system with lubricants. Maintenance involves keeping the area around the bearing clean and painted. Lubrication is limited to keeper links and/or nesting mechanisms that require disassembly. If the rollers seize up, they should be removed and refurbished.

Figure 22a & 22b: Various roller bearing

Mortar bearings

Mortar bearing pads have been used extensively in the past with short span precast concrete units. The mortar tends to crack and crumble over time, especially with pads that are often wet or subjected to increased beam rotations.

Figure 23: Mortar bearing besides a newer neoprene bearing

2.2.7.1 [M32] Maintaining Sliding and Roller Bearings

Maintenance Method – Sliding and Roller Bearings

1. Clean Bearings in accordance with [M05] Cleaning Bearings and Bearing Seats.
2. Inspect the bearings to identify defects.
3. Crack injection and patch repair bearing seats as required in accordance with repair methods [RPM02] Repair of Inactive Cracks and [RPM09] Spalling and Scaling Repairs. Alternatively, if the bearing seat is significantly cracked and spalled it may

be more appropriate to breakout the bearing seat and replace it. It is important that any recast bearing seats are chamfered to allow free drainage away from bearings.

4. Remove minor rust and corrosion and repaint bearings. If the corroded areas are significant repainting should be undertaken by a specialist painting contractor and programmed as repair works.
5. Replace any missing nuts on steel sliding bearings. Where pins are distorted or bent seek advice of a structural engineer.
6. Apply a graphite oil or grease lubricant to two steel contact surfaces. An oil-based lubricant may be more flowable and suited to this application.
7. If the bearings are locked up, the bridge may need to be jacked up prior to the maintenance activities being undertaken.
8. Sliding bearings which have corrosion with section loss greater than 20 percent should be replaced. This will require the beam to be jacked up to remove the sliding bearing. Structural advice should be sought determine appropriate jacking loads prior to jacking bridge to replace bearings to avoid damaging bridge components.

2.2.7.2 [M33] Maintaining Mortar Bearings

Maintenance Method – Mortar bearings

1. Clean Bearings in accordance with [M05] Cleaning Bearings and Bearing Seats.
2. Inspect the bearings to identify defects.
3. Crack injection and patch repair of mortar bearing should be in accordance with repair methods [RPM02] Repair of Inactive Cracks and [RPM09] Spalling and Scaling Repairs.
4. Alternatively, if the bearing seat is significantly cracked and crumbling it should be removed and replaced.
5. A temporary packer will need to be installed if the mortar is lost. The advice of a suitably qualified structural engineer should be sought in deciding the detailing of the temporary packer.
6. Place temporary softwood timber packers and wedges tightly under the beam for which the mortar pad is being replaced. These packers should also allow beams to be raised back to the correct levels. Packers and wedges should be rammed in with a hammer. The packer and wedges are required to provide support for the beam and permit beam rotations whilst mortar bearing is being replaced.
7. The mortar bearing should then be scraped out from under the beam and the area blown clean with compressed air.
8. Construct formwork to the required dimensions of mortar bearing.
9. Wet concrete surface, followed by placement of fresh dry packed mortar. The edges of the mortar should be bevelled to ensure a satisfactory spread of load transferred to the concrete substrate below
10. Remove temporary supports and formwork once the new mortar pad has hardened.
11. If more than a few mortar bearings need to be replaced. Consideration should be given to replacing them all with neoprene bearings. It is not ideal to have different bearing materials side by side. Bearings should all be either mortar or neoprene.
12. Structural advice should also be sought determine the appropriate neoprene bearing required and how the beams would be jacked up to permit the work on the bearings.

3 Repair of Structures

Repair activities are carried out when the need arises for remedial work to prevent further development of the defect. The requirement for these repair activities are identified with level 1 and level 2 Inspections.

The following sections cover the activities, determined from the bridge inspection programme, which maintain the serviceability of the structure and fall outside the scope of the *Road/Bridge Maintenance Contracts* specified within *Standard Section 750.*

3.1 Concrete Structures

Reinforced concrete is one of the most important and potentially one of the most durable composite building materials used in the construction industry. Similar to every construction material, concrete also undergoes natural deterioration during its life. The rate of degradation is mainly influenced by the quality of the constituent materials themselves, environmental conditions, variations in the quality of concrete and the standard of workmanship during construction.

Deterioration of concrete is of both internal and external origin. Deterioration of internal origin is closely linked to nature and the chemical composition of the constituents of the concrete (cement, aggregates, water, admixtures and steel reinforcement). Also, the concrete can deteriorate from internal chemical reactions such as alkali-aggregate reaction. Many instances of corrosion in reinforced concrete are due to detrimental substances (e.g. chloride, sulphate ions) used as additives of concrete in past. However, regulations in this area are currently very strict, and the relevant standards have either totally banned or severely limited the concentration of corrosive substances such as chlorides in the constituent materials of concrete.

Sound design and construction practices are important to the achievement of durable concrete. Structures that have been designed and constructed with durability in mind should be able to withstand the influences that cause wear and deterioration and provide the required level of serviceability and reliability, thereby minimising the need for costly maintenance, repair, and replacement.

Construction techniques, practices, and standards should be selected so as to maximize the level of durability of concrete structures. The primary factors affecting the durability are:

- cement content or other binders such as blended cement
- water/cementitious material (W/C) ratio
- control over batching and mixing
- the method of pouring and compaction and
- the timing and effectiveness of curing.

These factors all affect concrete permeability, density, compressive strength, and durability. Clean and correctly positioned and restrained reinforcement is necessary to achieve the required bond strength and concrete cover. Compliance with design and construction specifications and adequate overall quality control is essential.

The durability of concrete structures relies on good planning, design and construction practices, as well as ongoing systematic inspection, assessment and maintenance activities. Durability considerations are important to avoid costly inspection, assessment, maintenance, repair, and replacement, and to reduce the whole of life cycle cost. The consequences of not achieving the required level of durability is ongoing maintenance and recurring problems, inconvenience to the travelling public, potential safety problems and increased whole of life cycle cost.

3.1.1 Deterioration of Concrete Structures

There are many sources of defects in concrete structures and factors that can initiate concrete deterioration and lead to the requirement for repairs. The main cause of deterioration in reinforced concrete is de-passivation of the reinforcement resulting in corrosion of reinforcement. Once de-passivation occurs, the steel is prone to corrosion due to the presence of oxygen and moisture. Cracking and spalling of the concrete can then result from the increased volume of steel corrosion product which creates bursting pressures cracking and spalling.

There are many factors that can contribute to de-passivation:

- Structural deficiency - the result of inadequate design or poor detailing
- Unsatisfactory construction - poor workmanship (honeycombing, porous or permeable concrete), placement of concrete in high temperatures, inadequate curing (plastic and restrained shrinkage and settlement)
- Chemical attack - due to the effect of substances such as acids, sulphates, chlorides, soft water, grease, and oils, which increase the risk of corrosion
- Mechanical damage - abrasion or spalling of concrete cover, or erosion
- Mechanical damage - abrasion or impact on reinforcing steel during construction
- Insufficient curing - curing is inadequate or not carried out
- Insufficient early strength – loading applied to the concrete before adequate concrete strength has developed
- Insufficient cover to the steel reinforcement - the concrete cover provides a physical barrier against the effect of aggressive agents such as chlorides, carbon dioxide, oxygen, and moisture. Under certain conditions, lack of a cover or damage to the cover reduces the effectiveness of the concrete in providing physical and chemical (e.g. highly alkaline environment) protection against corrosion of the steel.

3.1.2 Causes of Deterioration in Concrete

3.1.2.1 Introduction

The rate of deterioration of concrete, including corrosion of reinforcement is dependent on environmental effects (i.e. exposure to the effect of water, air, chemicals, physical and mechanical abrasion), the physical properties of the concrete, and the construction practices adopted.

Where possible, reference should be made to atmospheric corrosive maps and data available on exposure conditions, to assist in selecting the most appropriate solution for either new concrete construction or repaired and protected concrete.

The quality of the cover concrete (outer 20 mm) is vital to providing the required level of protection to the steel reinforcement. In exposed situations, the use of controlled permeability formwork liners can reduce surface blemishes and enhance durability.

3.1.2.2 Deterioration of Internal Origin

Shrinkage or swelling that is caused by the internal chemical reaction can initiate cracks on the surface of the concrete or within the concrete. The effect on deterioration of the constituents of concrete are summarised as follows:

(a) Cement and other cementitious materials; cracking may result from higher percentage of expansive cement, heat generation from hydration of concrete, or excessive drying of fresh concrete.

(b) Aggregates: certain aggregates react with the alkali present in cement to form a gel that swells by absorbing moisture, resulting in pop outs or cracks leading to efflorescence that may destroy the structure.

3.1.2.3 Deterioration of External Origin

The physical properties of concrete are a major influence in the rate of deterioration of concrete from external origins. Factors that affect deterioration of external origin include permeability, compressive strength, density, aggregate size and distribution, cement content, water-to-cement ratio and mix design generally. Permeability is controlled by the mix constituents (i.e. cement content, water-to-cementitious material (W/C)) ratio, concrete cover, and the standard of compaction and curing. High strength concrete is more resistant to penetration of corrosive agents. High-density concrete is more impermeable. Better compaction contributes to higher density and strength. A well graded and uniformly distributed aggregate within the concrete assists with providing a well compacted, dense and impermeable concrete. Low cement content results in higher permeability, lower alkalinity and lower strength. Higher water-to-cementitious material (W/C) ratio results in higher permeability, higher porosity, and greater drying shrinkage. Use of water reducing admixtures, super plasticisers, fly ash, slag, silica fume, and lower sand content facilitate the reduction of water content.

3.1.2.4 Protective Coating of Concrete

Protective coatings can provide extra protection and increase the durability of new structures as well as existing structures for which significant deterioration has not yet occurred. Protective coatings can enhance the appearance of patch repaired concrete and the concrete surrounding the patch repair.

The key performance requirement of the coating is its ability to reduce permeability and restrict the ingress of chlorides, carbon dioxide, and other aggressive liquids or vapours. Effective coatings maintain the concrete at low moisture content and delay the initiation of corrosion. They limit ingress to the interface between patch repair material and the original concrete.

The selection of protective coatings and decorative coating and their application should have regard for the performance requirements of the coatings (Table 1 of Appendix 2: Durability considerations). These requirements include surface preparation, method and timing of application, surface moisture condition of concrete and quality control testing.

In general, pigmented coatings provide a better standard of protection and decorative finish and are more durable than un-pigmented coatings. Ideally coatings should be sufficiently elastic to bridge over small cracks in the concrete or repair mortar.

Depending on the level of protection being sought, the thickness of the protective coatings can range from several hundred microns to 6 mm to 8 mm. Types of material employed include epoxy, polyurethane, polyvinyl, acrylics, asphalt, chlorinated rubber, vinyl ester or derivatives of these containing sand fillers or glass reinforcement. These coatings should not be vulnerable to attack by the chemicals they are intended to resist, and they should perform satisfactorily over the required range of operating temperatures. Other properties required for the coatings include poor permeability, excellent bond, and good elastomeric properties.

3.1.3 Repair of Defects in Concrete

3.1.3.1 Repair of Concrete Cracks

Repair of cracks in concrete reduce the rate of deterioration due corrosion of reinforcement and the resulting volumetric change associated with the corrosion product which may lead to further cracking and spalling. Selection of the repair method should be based on an understanding of the causes of the cracking. It is important to identify, photograph and record details of cracks during the visual inspection (e.g. location, extent and orientation). A crack gauge, feeler gauge or machinists steel ruler can be used to measure the width and a piano wire can be used to measure the depth of the crack.

Figure 24 illustrates a variety of crack types and their cause. If cracks are minor (i.e. less than 0.2 mm wide), autogenous healing can sometimes close the crack. Autogenous healing normally takes place within the first few days of the life of the structure and can be improved by keeping the structure moist, particularly when it is kept under compression.

VicRoads Standard Section 610 – Structural Concrete specifies permissible crack widths. For precast pre-stressed concrete elements, the crack width at the concrete surface should not exceed 0.1 mm. Consideration should be given to appropriate remedial measures during construction if these crack widths are exceeded having regard for the requirements of *VicRoads Standard Section 610* and *VicRoads Standard Section 687–Repair of Concrete Cracks*.

Refer to *Standard Section 687 – Repair of Concrete Cracks.*

Refer to *Standard Section 686 – Coating of Concrete.*

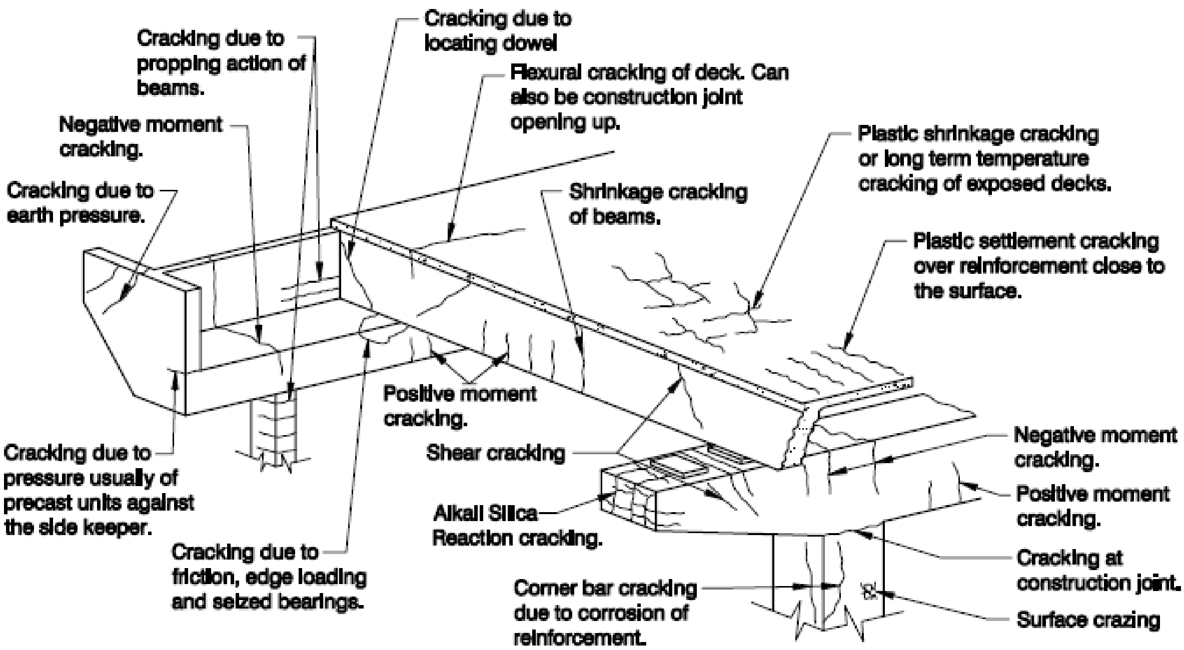


Figure 24: Various types of cracks in bridges

Typical crack repair methods and applications are described below:

(a) Resin Injection of Cracks

Low-Pressure Injection: Proprietary injection kits are used with firm and sustained hand pressure until no further resin can be injected into the crack.

Multicomponent Injection: Procedures are based on the results of testing to confirm the discharge pressure and ratio of adhesive components to be used.

(b) Routing and Sealing of Inactive or Dormant Cracks

The crack should first be enlarged along its exposed face and a V-shaped groove with a minimum surface width and depth of 10mm formed to act as the sealant reservoir. The reservoir should be filled with an appropriate sealant. This method is suitable for inactive and non-structural cracks.

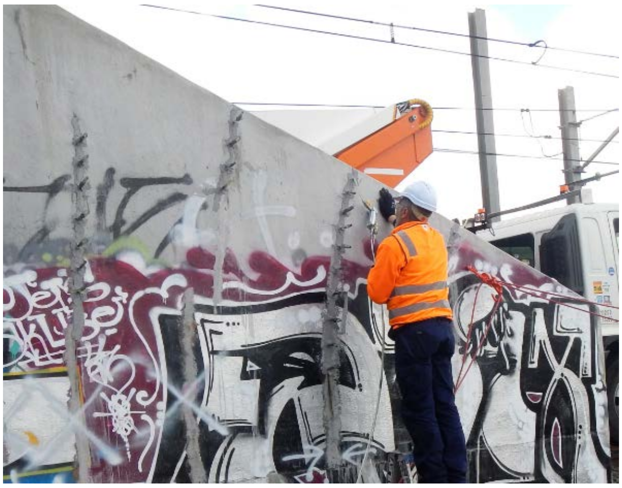


Figure 25: Crack repair - Resin injection

Figure 26: Crack repair - Routing and sealing

(c) Flexible Sealing for Live or Active Cracks

Where cracks are live or active, a rectangular reservoir with a minimum width to depth ratio of two should be formed. A bond-breaking polyethylene tape or equivalent should be placed over the crack at the bottom of the reservoir prior to the application of the flexible sealant.

(d) Gravity Feed

Horizontallly positioned cracks can be filled and sealed using a suitable low viscosity resin. The resin can be poured/spread onto the surface or placed into a formed reservoir.

(e) Coating Over of Shallow Cracks

Inactive cracks with a width of less than 0.2 mm may be coated over with a protective, or decorative coat system provided such cracks are not associated with earth or water retaining concrete components.

(f) Stitching of Cracks

This crack repair method may be used where restoration of the tensile strength is required across major cracks. Holes are drilled on both sides of the crack and cleaned in accordance with *VicRoads Standard Section 687*. U-shaped metal legs (stitching) are then anchored in the holes with an epoxy resin-based bonding system.

3.1.3.1.1 [RPM01] Surface Preparation for Crack Repair

Prior to undertaking any crack repairs the concrete surface should be cleaned to permit inspection and measurement of the crack length and width and to determine whether the cracks are active or inactive cracks. These measurements assist with determining the extent and cause of the cracking.

Repair Method

1. Remove all traces of deteriorated concrete, paint, dirt, oil, grease and efflorescence using oil-free compressed air or high-pressure water blasting.
2. The cracks and concrete substrate for a minimum of 50mm either side of the cracks should be reasonably clean and free from loose materials.
3. Both surfaces of the crack must be allowed to dry thoroughly or dried out by accelerated means prior to the application of materials. However, for repair with dampness-tolerated materials, the surface does not have to be dry.
4. Air blast cracks and treat surfaces with a clean and dry (filtered) compressed air to ensure complete removal of all dust and loose particles. This cleaning should remove impurities that inhibit wetting and adhesion or penetration by the crack-filling material.
5. When repair work is completed and fully cured, the appearance of the concrete surface should be finished by grinding and the application of a surface treatment if required.

3.1.3.1.2 [RPM02] Repair of Inactive Cracks

Inactive or dormant cracks are cracks, which are not opening and closing or extending with time.

A protective coating system can be used to repair inactive non-structural cracks with a maximum width of 0.2 mm, provided such cracks are not associated with earth or water retaining concrete components. Protective treatments or decorative coating systems including their mixing and application should comply with all requirements of *VicRoads Standard Section 686.*

Inactive or dormant cracks equal to or greater than 0.2 mm wide should be repaired in accordance with the requirements of *VicRoads Standard Section 687* prior to being coated. Protective or decorative coatings should be compatible with any previously applied crack fillers or sealers.

For inactive cracks with minimum 0.3 mm width and up to 1mm, resin injection is the most common repair method (Figure 27). This treatment should effectively restore the structural adequacy of affected members by strong bonding of elements.

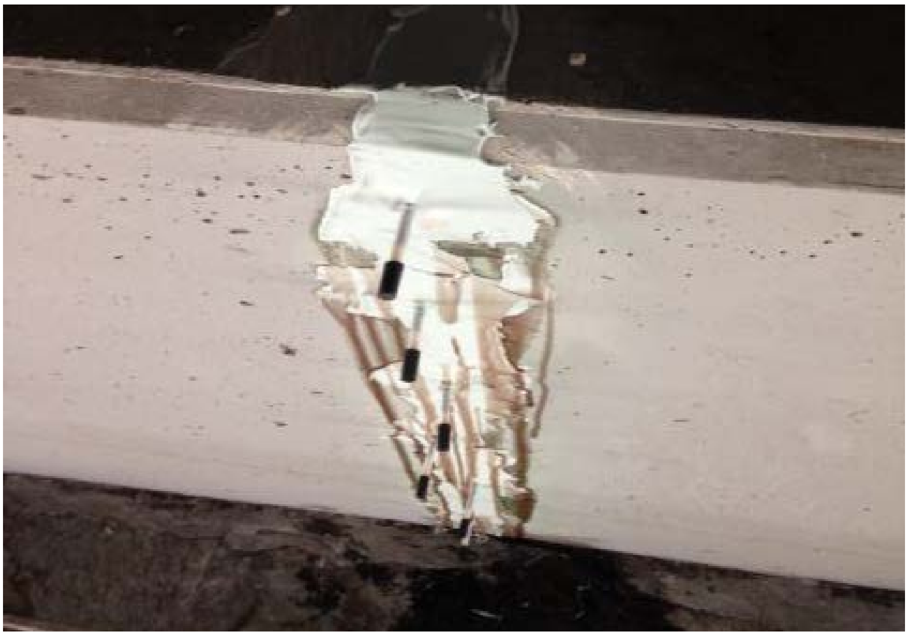


Figure 27: Injected cracks with epoxy resin through ports

It may be necessary to seal the reverse face of the cracked structure to prevent the resin flowing out. Although thixotropic resins can be used, they cease to flow when the injection pressure is released (i.e. when resin reaches the reverse side of the crack). Crack injection is particularly useful in cases such as retaining walls or ground slabs where sealing of cracks on the reverse side is impractical.

Injection pressure should be maintained so that the resin penetrates the crack. The most effective epoxy injection is carried out with pressures at the injection ports ranging from near zero (i.e. 0 to 300 kPa) to about 1000 kPa and certainly not exceeding 2068 kPa (300 psi).

The appropriate injection pressure depends on the equipment used (i.e. proprietary injection kits, grease guns) and the success of the outcome is dependent on the experience and knowledge of the operator. Excessive pressure is likely to force the resin along the path of least resistance, thus leaving voids and it can result in additional crack formation, particularly in the case of transverse cracks. The main feature of the method is that the ultra-low viscosity epoxy resin is injected under a relatively low constant pressure (i.e. in the order of 300 kPa) over several hours.

In the case of wide cracks, specially formulated injection materials with no shrinkage properties are commercially available which ensure that no loss of adhesion occurs from the bridging of wide cracks.

Other specially formulated epoxies such as filled liquid epoxy systems or epoxy paste are also available which can be applied manually to effectively seal wide cracks in both horizontal and vertical surfaces. Such materials are particularly suitable for much broader cracks or joints as well.

Cracks on horizontal surfaces can be repaired by simpler methods as follows

- A dam is formed on each side of the crack with a mastic sealant
- Premixed liquid epoxy or sealant is poured into the dam and allowed to penetrate the cracks by gravity. The dam increases the size of the reservoir so that topping up is less frequent.
- Finally, surface appearance should be restored.

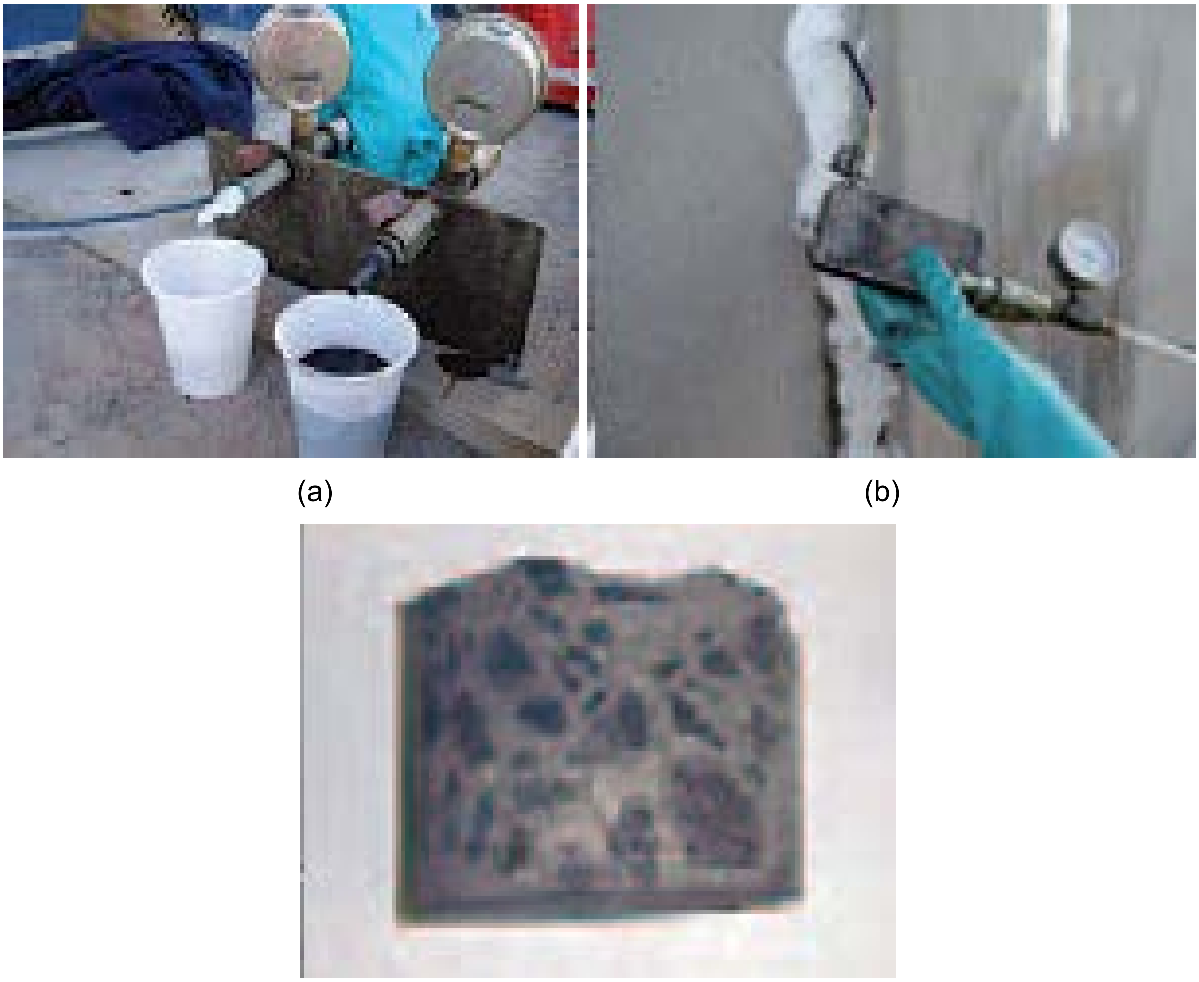
When the volume of repair material is significant, it may be economical to open out the fracture and repair the area with cementations mortar followed by appropriate curing to prevent premature drying out and subsequent cracking.

Refer to *Standard Section 686 – Coating of Concrete*

Refer to *Standard Section 687 – Repair of Concrete Cracks*

Repair Method

1. Complete surface preparation in accordance with [RPM01] Surface Preparation for Crack Repair.
2. Holes are drilled at 150 to 200 mm centres for insertion of injection ports.
3. Injection ports are placed over cracks and fixed in position using a suitable surface sealant and locating pins to ensure correct positioning. If the structure is cracked full thickness injection ports are fitted to both sides of the structure, with those at the back positioned midway between those in the front.
4. Seal the surface of all cracks between injection ports using a suitable surface sealant. Seal both sides of any cracks all over the structure if possible (i.e. back face of concrete against fill). Avoid blocking the port holes with the surface sealant.
5. Allow the surface sealant to harden.
6. Mix the low viscosity epoxy resin in accordance with manufacturer's instructions and commence injection from lowest port, particularly treating vertical cracks.
7. Inject epoxy resin into the lowest port until it begins to flow out of the adjacent port.
8. Detach the connecting tube and close off the first injection port.
9. Inject epoxy resin through the adjacent second port until it flows out of the third.
10. Follow the same procedure until all injection ports are injected. Allow the injected system to harden.
11. Remove injection ports and fill any holes or voids with surface sealant and allow hardening.
12. After hardening, remove surface sealant by grinding to restore the appearance of the surface (apply surface treatment if it is part of the repair process or if warranted).
13. Perform quality assurance for resin injection procedure including verification of epoxy penetration depth, component ratio and injection pressure.



(a) (b)

(c)

Figure 28: (a) Ratio test for two components, (b) pressure test for epoxy resin, and (c) verification of penetration depth for injected resin.

3.1.3.1.3 [RPM03] Repair of Active Cracks

Cracks for which the width fluctuates with changing loads or temperatures are called active or live cracks and should be treated in the same was as movement joints. Such cracks should not be filled with rigid materials, as the treatment is unlikely to be successful and may generate new defects either in the repair material or elsewhere in the surrounding concrete substrate. Active or live cracks that are wider than 0.2 mm should be repaired in accordance with *Clause 687.10 of VicRoads Standard Section 687 - Repair of Concrete Cracks*.

The advice of a structural engineer should be sought in deciding the appropriate treatment of active cracks. When deciding repair material and procedure for active cracks, it is important to appreciate the cause of the of the cracking.

To prepare for the repair a recess is cut along the line of the crack using a power hammer, fitted with a sharp chisel or crack cutter. Concrete that is carbonated or contaminated with other detrimental substances must be broken out and replaced with suitable cementitious or epoxy mortar, and the crack prepared as a flexible sealed movement joint.

Once the crack is prepared it is filled with a suitable joint sealant that will bond to the surfaces each side of the recess, but debonded from the bottom of the recess by using a bond breaking medium. Debonding the bottom of the recess prevents the crack propagating into the sealant and the subsequent failure of the sealant as a result of continuing crack width fluctuation.

The appropriate width and depth of the recess is dependent on both the total amount of crack movement (i.e. joint substrate characteristics) and the cyclic movement capacity of the joint sealant material. Expansion and contraction due to temperature changes in the concrete substrate is a common cause of crack width fluctuation. The capacity of the sealant to accommodate movement is dependent on its ultimate elongation capacity and its ability to recover when subjected to tensile or compressive strain.

The joint repair should be designed so that the movement due to factors such as concrete shrinkage and thermal changes does not exceed the cyclic movement capacity of the sealant. The joint width is a function of the magnitude of the movement.

Refer to *Standard Section 687 – Repair of Concrete Cracks*

Refer to *Standard Section 689 – Cementitious Patch Repair of Concrete*

Figure 29: Active or live cracks sealed with an appropriate flexible sealant

Repair Method

1. Complete surface preparation in accordance with [RPM01] Surface Preparation for Crack Repair.
2. Widen the crack to the required depth and width.
3. Insert a bond breaking medium into the base of the widened crack to serve as backing for the sealant (eg a proprietary backing rod).
4. Seal the crack with an appropriate flexible sealant.

3.1.3.1.4 [RPM04] Plastic Shrinkage and Plastic Settlement Cracks

Plastic shrinkage cracks are caused by rapid drying of the concrete during construction as a result of moisture loss from the surface prior to hardening of the concrete. Plastic settlement cracks typically form above reinforcing bars while the concrete is still plastic and has not hardened. These cracks can be treated as inactive cracks.

Plastic settlement cracks are a common cause of reinforcement corrosion. They should be sealed as soon as possible and before contaminants enter the cracks. Fine cracks can be treated by a suitable concrete coating.

Refer to *Standard Section 686 – Coating of Concrete*

Refer to *Standard Section 687 – Repair of Concrete Cracks*

Refer to *Standard Section 689 – Cementitious Patch Repair of Concrete*

Repair Method

1. Brush off the cracked surface with cement grout or non-shrink polymer modified grout to improve adhesion between the crack surfaces and reduce shrinkage of the grout.
2. Depending on the situation and the subsequent construction considerations, complete surface sealing using elastomeric protective coatings and waterproof membranes as required.
3. Prior to undertaking the coating works the surface should be high pressure water cleaned and allowed to dry before application of protective coating.
4. If cracks are greater than 0.2mm wide a surface coating or sealing will not be suitable and repairs should be implemented in accordance with [RPM 02] Repair of Inactive Cracks.

3.1.3.1.5 [RPM05] Shear and Transverse Cracks

Shear and transverse cracks can be either active or inactive and are caused by physical, thermal or chemically applied stresses. These cracks should be repaired to prevent further deterioration.

The advice of a structural; engineer should be sought in deciding the appropriate treatment. The cause of the shear crack needs to be determined and treated prior to the repair. If the shear cracks are caused by normal traffic loading, repairing the cracks may simply result in formation of new cracks.

However, if the crack is due to the passage of a single heavy load or some other single event, then the member can be repaired as outlined below.

Refer to *Standard Section 687 – Repair of Concrete Cracks*

Refer to *Standard Section 689 – Cementitious Patch Repair of Concrete*

Repair Method

1. The inactive crack can be repaired by epoxy injection in accordance with [RPM 02] Repair of Inactive Cracks.
2. The injection port spacing should be reduced to ensure full integrity has been restored to component. Once the crack has been repaired, it would be prudent to monitor the repair for a period to ensure the cause of the crack had been correctly determined and that the cracking does not recur. If cracking does recur, the member should be strengthened.

3.1.3.1.6 [RPM06] Cracks Caused by Rusting

Cracks which form directly over steel reinforcement are commonly caused by corrosion of the metal. These cracks result from the bursting forces exerted by the build-up of corrosion product and can lead to spalling and complete loss of concrete cover.

When concrete damage occurs as a result of corrosion of the reinforcement, the reinforcement must be treated to prevent rusting and the surrounding concrete replaced. If the steel reinforcement is showing only moderate corrosion, the cracks should be repaired in accordance with [RPM12] Reinforcement Corrosion Repair.

Refer to *Standard Section 689 – Cementitious Patch Repair of Concrete*

3.1.3.2 Other Concrete Repairs

3.1.3.2.1 [RPM07] Alkali Aggregate Reaction (AAR) in Concrete

A reaction can occur between the reactive form of silica or silicate in the aggregate and the alkalis in the cement paste to produce a gel called ettringite which is highly expansive in the presence of moisture and exerts tensile stress. The result is map cracking or directional cracking (pre-stressed members) in the structure. Other visible signs of damage may include an aggregate pop out and discolouration.

It can take many years before AAR reaction gives rise to cracking and the cracking will decrease with time as the quantity of silica is depleted.

Figure 30: Cracks due to AAR

Repair Method

1. Identify and remove the source of water causing the chemical reaction (i.e. fix expansion joint, redirecting scuppers and etc.). This will slow the reaction and cracking.

2. Testing of concrete cores will show the presence of the gel and advice should be sought from structural engineer in deciding the extent of further possible cracking.

3.1.3.2.2 [RPM08] Damage to Concrete Protective Coating

In some cases, the concrete surface may appear sound but may be allowing excessive chloride or moisture penetration into the steel reinforcing. The surface needs to be coated to prevent the penetration of these substances, but the coating should be capable of allowing the concrete to dry out by passing water vapour through the outer pores.

Refer *Standard Section 686 – Coating of Concrete.*

Repair Method

1. Thoroughly clean the outer surface of the concrete using a high-pressure water blast.
2. Inspect the concrete surface to identify any crack wider than 0.2mm or concrete spalls requiring crack repair.
3. Complete surface preparation in accordance with [RPM01] Surface Preparation for Crack Repair.
4. Complete spall and scale repairs in accordance with [RPM09] Spalling and Scaling Repairs.
5. The surface can then be sprayed with two coats of silane, silane/ siloxane or moisture cured polyurethane to block the pores in the concrete to a depth of 2mm to 3mm. These products allow vapour passage but not droplet penetration of the coating.
6. Recoating may be required in approximately 15 years as the coating begins to fail. Cementitious fairing coats can be effective in slowing down the ingress of chlorides but are not cost effective for large areas where the thin sprayed coatings can be easily applied.

3.1.3.2.3 [RPM09] Spalling and Scaling Repairs

Spalling may commence with local weakening of concrete and lead to more extensive deterioration of the concrete structure. It is a detachment of a fragment from concrete, usually in the shape of a flake. A spall may due to the action of the weather, pressure by overstressing, expansion of the surface concrete as a result of corrosion of steel reinforcement or impact damage (Figure 31). Cracks associated with the spalls are usually wide, long, and deep enough to reach the steel reinforcement or prestressing steel.

Figure 31: Spalling concrete

Corrosion of the underlying reinforcing steel or deteriorated aggregate is the most common cause. If the spall is about 25 mm or less in depth or about 15 cm in diameter or less, it is considered to be a small spall.

Large spalls may significantly affect structural capacity. A hollow sound when the area is struck with a hammer or steel bar or when it is swept with a drag chain can indicate unsound or defective concrete. When spalling or delamination is evident, the entire concrete component should be surveyed to determine the extent of spalling and delamination before beginning repairs.

A delamination survey might involve rod sounding, hammer sounding, drag chain sounding, or ultrasonic delamination detecting. The reinforcing cover survey uses a magnetic field detector to estimate the depth of concrete over the reinforcing steel. The chloride content survey involves analysing the samples of concrete powder produced from drilling holes in the concrete.

The potential corrosion survey consists of electrical resistivity measurements using a half-cell probe. This will not be an effective procedure when the steel reinforcement contains epoxy-coated reinforcing steel or contains galvanized coated steel or if the deck surface was treated with a non conducting material.

Once the extent and severity of the spalled area has been determined the appropriate corrective action can be determined. If a concrete bridge deck is scheduled for overlay, a low slump dense concrete should be considered to improve resistance to moisture penetration.

Light scaling of concrete does not expose coarse aggregate, and the maximum depth is about 6mm. Medium scaling involves loss of surface concrete to a depth of 5mm to 10mm. Severe scaling involves loss of surface concrete to a depth of 5mm to 10mm and exposure of coarse aggregate (10mm to 20mm). Very severe scaling involves loss of coarse aggregate as well as surface concrete generally to a depth greater than 20 mm.

For any condition exceeding a light scaling, concrete repair procedures similar to those applicable to concrete patch should be applied. When removing the deteriorated concrete, care should be exercised to avoid damage to the reinforcing steel. If the scaling results from chlorides penetrating the deck wearing surface, the deck should be monitored for further deterioration.

However, if the scaling is due to poor concrete, scaling may progress downward resulting in deeper deterioration of the concrete which requires more extensive repairs.

Refer *Standard Section 687 – Repair of Concrete Cracks.*

Refer *Standard Section 689 – Cementitious Patch Repair of Concrete*

Refer *Standard Section 686 – Coating of Concrete*

Repair Method

1. Undertake delamination survey and mark out area to repaired having regard for the repair methods available and skill of available personnel. The repairable concrete area should be twice the length and width of the original spall surface area.
2. Break out marked out areas with hand held percussion equipment such as hammer drill. Check the prepared area by sounding with a hammer to confirm all defective concrete has been removed. If steel reinforcement is exposed, the concrete should be broken out to a depth of 20mm behind the steel reinforcement. With the reinforcement fully exposed (Refer Figure 33), the repair material can lock around the bar for support and strength. The fine nature of the ingredients ensures very small pore sizes and hence improved protection against moisture and chloride ingress.
3. Clean existing reinforcement if there is light corrosion or replace steel if it has lost more than 25 percent of its cross sectional area in accordance with [RPM12] Reinforcement Corrosion Repair.
4. Sawcut to 15mm depth around the perimeter of the patch areas to avoid having feathered edges which could easily break off and provide a path for the ingress of moisture .
5. The prepared concrete surfaces and any exposed steel reinforcement should be cleaned by wash down or by blowing down with oil free compressed air to ensure removal of all residual contamination. The concrete surfaces should be thoroughly pre-wetted with clean fresh water and the surface dried prior to application of repair material.
6. The repair material should have similar properties to and be well bonded to the base material. It should not shrink away from the base surface and should offer better protection than the base material against ingress of aggressive agents where the cover depth is less than desirable. For these reasons, a cementitious polymer modified repair mortar or concrete that has shrinkage-compensating agents is preferred.
7. The manufacturer's mixing recommendations should be followed. The repair mortar may appear to be too dry, however the impulse to add extra water should be resisted. These high build mortars may be applied by trowel, or by hand to ensure proper compaction around the steel and good adhesion to the base concrete.
8. The repair must be built up in layers in accordance with the manufacturer's recommendations and in certain conditions layers such as overhead situations where layers should be less than 25 mm to reduce the risk of the repair mortar detaching from the base concrete.
9. The completed repair should be cured similar to other concrete work. Moisture cure is the preferred method of curing, but the application of a curing membrane may be the more practicable for small areas. Curing should be applied for at least the first three days, which are the most critical to preventing premature cracking of the repair due to shrinkage.
10. Minimum cover of 50mm of concrete to the steel reinforcement should be provided unless the location is in a benign and moderate exposure classification for the environment in which case 20mm may be acceptable.

11. Where existing concrete does not have the minimum cover thickness the patch can be built out locally alternatively steel can be coated with a zinc rich epoxy primer (min 80% zinc).

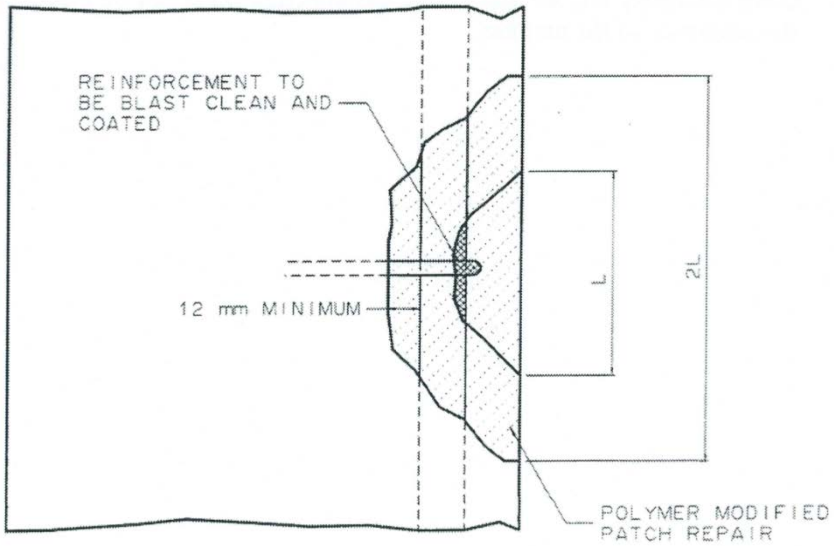


Figure 32: Basic concrete patch repair with reinforcement corrosion

3.1.3.2.4 [RPM10] Repair of Large Spalled Areas

For large areas of spalling, a suitable and economical repair method using sprayed concrete can be considered. The spalled areas can be in walls or in areas overhead such as the underside of a cast in-situ deck.

Sprayed concrete or shotcrete is used when a large area of concrete requires repair because of spalling or heavy water washes of the concrete surface fines. There are two methods of shotcreting:

- the wet method uses premixed mortar and pumps and sprays on the defect
- the dry method where the dry mixture is conveyed to the nozzle by compressed air and mixed with water at the nozzle.

The spray dry method is more reliant on the skill of the operator as the operator controls the amount of mixing water but it is quicker and more economical than the wet spray method. The high impact velocity of the spray results in compaction of the repair mortar.

If the intention is to restore the surface profile and seal the concrete surface, the existing surface should be given a high-pressure water clean prior to the shotcreting.

The mortars used are polymer modified cementitious products to ensure the bond is achieved with the base concrete and that the new concrete does not shrink away when hardened. The mortars also provide protection to the steel reinforcement that may otherwise have inadequate concrete cover.

Repair Method

1. The areas to be repaired must be prepared with deteriorated concrete removed, corroded steel fully exposed, cleaned and protected in accordance with a basic concrete patch repair in accordance with [RPM09] Spalling and Scaling Repairs.
2. The repair mortar is sprayed onto the existing concrete under pressure and is compacted on impact with the concrete surface causing some material loss due to rebounding. The repair must be built up in thin layers by the spray, and particular

attention should be paid to ensuring the proper build-up of material behind the reinforcement and elimination of voids.
3. Any smoothing or working of the surface is difficult and must be done immediately before initial set of the sprayed concrete.
4. The concrete surface will require curing for a minimum of 3 days to prevent shrinkage cracking.

Extensive breaking back of concrete or replacement of reinforcement may mean that the concrete element, such as a column, is not serviceable during the repair in which case the component may need to be to propped during the repair works.

3.1.3.2.5 [RPM11] Surface Erosion or Abrasion

Erosion is caused by abrasion or cavitation action. Abrasion action is caused by flowing liquids containing abrasive materials (i.e. debris in water).   Cavitation action is caused by fast flowing water containing tiny vapour bubbles, rather than particles of solid matter. The bubbles collapse with impact and sudden changes in direction, causing high localised pressures sufficient to abrade the concrete surface and ultimately corrode the steel.

Concrete structures or components can be subjected to impact forces at their surface in the course of normal use, resulting in abrasion.

Abrasion damage is caused by movement of solid objects or particles over the concrete surface, causing wear of the surface by rolling, rubbing and friction. The damage results in a rough friable surface with grooving, potholing or spall particularly at the edges.

The combination of an abraded surface and the permeable nature of the remaining concrete increases the risk of corrosion of the reinforcement and the abraded surface should be replaced and sealed.

Refer *Standard Section 689 – Cementitious Patch Repair of Concrete*

Refer *Standard Section 686 – Coating of Concrete*

Repair Method

1. The existing concrete surface should be high-pressure water blasted to clean it and remove any loose concrete, providing a hard, sound surface for the repair.
2. A thin polymer modified mortar fairing coat should be applied by trowel to provide a hard, impermeable surface that will resist further abrasion. The new surface improves the performance of the cover concrete in preventing moisture penetration to the steel, thereby prolonging its service life.
3. The repair mortar requires curing to prevent shrinkage cracking especially in the first three days when moist curing is essential.
4. If large walls have been water washed and require sealing then, it may be more economical to spray the fairing coat mortar than to employ hand trowelling.

3.1.3.2.6 [RPM12] Reinforcement Corrosion Repair

Corrosion of steel reinforcement is one of the most common causes of deterioration of reinforced concrete (Figure 33). Steel reinforcement in concrete can corrode in the presence of moisture and oxygen. Chloride intrusion accelerates this attack by de-passivation of the steel and lowering of the electrical resistivity of the concrete.

Figure 33: Reinforcement corrosion of concrete

The acid forming gases influence corrosion of steel reinforcement in two ways. Firstly, by reducing the pH level of the concrete (neutralisation), thereby reducing the alkalinity of the area adjacent to the reinforcement. Secondly, by acting as an acid when combined with water, once the pH is reduced by the neutralisation process (known as the carbonation in the case of carbon dioxide). In addition, the alkalinity of the environment surrounding the reinforcement and hence its passivating effect may be destroyed by water leaching the alkaline substances out of the concrete (concrete degradation).

The potential for diffusion of chloride ions into concrete and a resultant reduction in alkalinity is dependent on the quality and physical properties of concrete, particularly its permeability. Poor quality concrete can be quite permeable.

Refer *Standard Section 687 – Repair of Concrete Cracks*

Refer *Standard Section 689 – Cementitious Patch Repair of Concrete*

Refer *Standard Section 686 – Coating of Concrete*

Figure 34: Severe corrosion of reinforcement

Repair Method

1. Remove the deteriorated concrete back to sound and dense concrete to provide a minimum clearance of 20mm behind and around the rusted steel reinforcement. This clearance also provides a mechanical key for the concrete patch material.
2. Concrete should be removed along the length of visibly corroded reinforcement until at least 50mm of sound, rust free metal is exposed at each end.
3. The steel reinforcement commonly has corrosion byproducts around its whole diameter (Figure 33). Therefore, the bar is required to be fully exposed over the corroded length and at least double the length of the spall.
4. The reinforcement should be thoroughly cleaned back to bright metal and protected with a proprietary coating of zinc-rich paint.
5. With the reinforcement fully exposed (Refer Figure 33) and a depth of the bars of 12mm minimum, the repair can lock around the bar for support and strength.
6. Replace any reinforcement which has lost more than 25 percent of its cross sectional area by cutting out the corroded section and lapping new reinforcement in its place. The advice of a structural engineer should be sought in determining the requirements for lapping of the reinforcement.
7. Apply an anti-corrosive coating to prevent further rusting
8. Renew the concrete cover using suitable materials, either a resin or cementitious mortar, depending on the quantity of material required to restore the original profile.
9. Complete the concrete patch repairs in accordance with the procedure for Spalling and Scaling [RPM 10].

3.1.3.2.7 [RPM13] Repair of Shear Key Failure in U-Slab

Reinforced concrete U-slab bridges were originally constructed between 1962 and 1976. These bridges have small sections or keys of 45 MPa concrete between their tops to transfer live load from one slab to another by shear action with the aid of connection bolts between legs of the U-slabs.

When bolts become loose as a result of traffic vibration effects, the slabs tend to move relative to one another resulting in damage to the shear key.

Initially, the bolts may be only slightly loose, and a reflective crack may appear in the sprayed seal above the shear key. As shear key continues to deteriorate, the asphalt above the shear keys and the shear key itself will disintegrate.

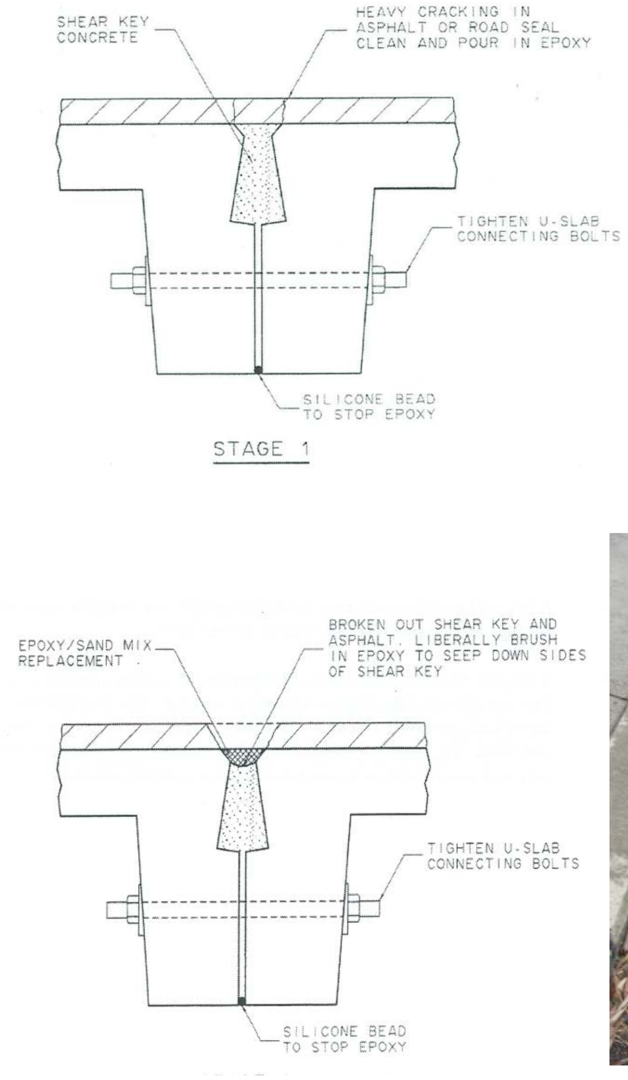


Figure 35: Shear key repair

Figure 36: Shear key failure of U-slab

Figure 37: Shear key failure of U-Slab bridge

Repair Method

1. Retighten the bolts to finger tight plus half a turn of the nut. It is important not to over-tension the bolts, to avoid springing of the legs. Furthermore excessive tightening may cause the unit to crack at either the juncion between the leg and the slab or along the centre of the top slab.
2. Clean out asphalt cracks with compressed air and seal the underside of the U-Slab with a bead of silicone in preparation for the epoxy repair of the shear key.
3. Pour a viscous epoxy along the road surface crack allowing the epoxy to seep into the key shear crack to re-establish the bond between the two surfaces. Any residual cracks in the roadway are sealed with rubberised bitumen or polymer modified bitumen. Provided the deterioration is limited, this procedure should serve as a sufficient and effective repair method.
4. However, if the shear key concrete is beginning to break up and crumble then, it should be replaced, and an epoxy mortar mix installed in its place after steps 1 & 2.
5. Remove asphalt above the shear key, epoxy brush shear keys and allow epoxy to seep down the sides.
6. An epoxy/sand mix of 45 MPa strength is placed into the shear keys to top up the missing concrete.
7. Reinstate asphalt after epoxy has hardened.
8. If cracks appear in the U-slab and moderate to heavy rust staining is observed or cracks are wider than 0.2mm and extend to the top of the slab, then u-slabs should also be overlayed with a composite reinforced concrete deck to strengthen the slabs and restore the composite action under live loads. The concrete overlay is undertaken as part of the repair maintenance. The advice of a structural engineer should be sought with the design of the new deck overlay.

NB: Light spring washers can be used to extend the time between bolt tightening maintenance is required.

3.1.3.2.8 [RPM14] Providing Additional Bearing Support

Movements of embankments or underlying soil movements can cause abutment and pier crossheads to rotate reducing the bearing area provided for the bridge superstructure. Alternatively, the bearings may have been incorrectly installed when the bridge was first constructed.

There are a number of methods for providing the additional bearing support, depending on the type of beams supported. The advice of a structural engineer should be sought for whatever method is adopted. If the beams are RSJ' s or precast ‘I’ beams then a bracket bolted to the crosshead under each beam may be the best method as the beams may be at different levels. If the beams are precast slabs or ‘U’-slabs then the appropriate treatment may be to fix a heavy steel channel section to the front of the crosshead. This treatment can effectively address multiple bearings simultaneously and may be more economical than attempting to jack the individual slabs and reinstate the support of each in turn.

With cast-in-place beams or the early precast ‘T’-beams, they were sometimes placed directly onto the crossheads or with a metal plate to serve as the sliding surface. Friction forces, especially in cases where the dowels connected the beams to the crossheads, often caused spalling of the top corner of the crossheads under the beams. Providing additional support using neoprene strips, can assist in overcoming the loss of the bearing area, particularly if the rear of the beam is badly cracked or spalled due to the high bearing and friction forces.

Alternatively if the majority of the bearing supports are sound, it may be more cost effective to jack and reposition the defective bearing correctly and repair the spall.

Repair Method

- Patch repair crossheads in accordance with [RPM09] Spalling and Scaling Repairs.
- Attach 3mm thick neoprene rubber sheet to the underside of the beams using adhesive in preparation for installation of additional support under the beam. Spans longer than 10 metres require thicker rubber sheets of 5mm to 8mm thickness. The neoprene is held in place and distributes the load preventing damage to the beams where they bear on the steel support, particularly when they rotate under live load.
- Seek the advice of a structural engineer for the design of the steel RSJ channel and its fixing.
- Review drawings and undertake a cover meter survey of the area to mark the position of holes and avoid damage to reinforcement when drilling the holes for fixings.
- Core holes through crosshead at marked location, using a jig or rig to assist with maintaining the alignment of the drill.
- Install additional steel channel or angle bracket against the crosshead to ensure firm support. The channel should be drilled on site to ensure alignment of the holes in the channel with those of the fixings installed in the crosshead.

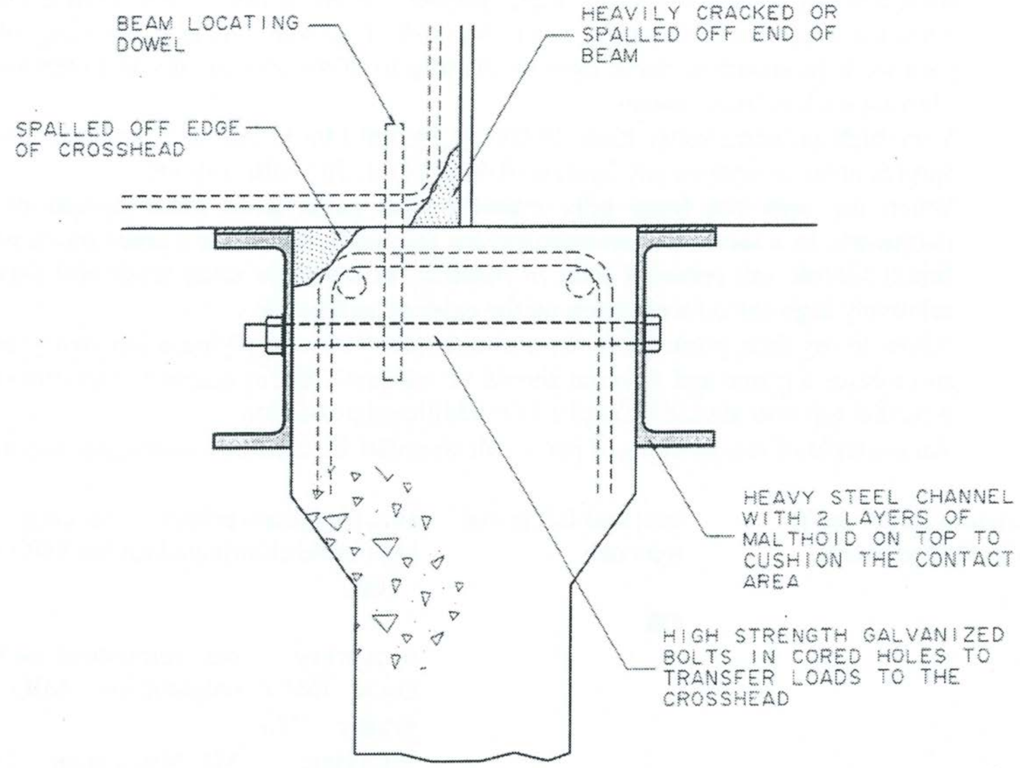


Figure 38: Providing additional bearing support

3.2 Steel Structures

3.2.1 Deterioration of Steel Structures

The vast majority of present day metal bridge structures are constructed from mild steel fastened with rivets, commercial grade bolts, high strength bolts or are welded. Bolted connections may have been designed to transfer the load by shear of the connector or by friction provided by the clamping force applied by the bolt.

There are many sources of defects in steel structures or factors that can initiate deterioration and lead to the need for repairs. The most common form of deterioration is corrosion due to inadequate corrosion protection. Once the protective coating on a steel member is lost, corrosion and loss of section can progress rapidly depending on the environmental conditions. On the one hand, corrosion rates in dry climates can be relatively slow but corrosion rates in coastal regions can be severe. Furthermore, corrosion rates of steel bridge members can be adversely affected by chemicals in the air, water, soil or accumulated debris in contact with the steel. Similarly, the life and performance of protective coatings vary significantly between regions and between parts of the structure.

When subjected to fluctuating tensile stresses steel members may fracture as a result of fatigue after a certain number of stress cycles. Fatigue performance is influenced by the presence of stress concentrations such as holes, welds, sharp deviations in lines of stress, cracks or other defects.

In addition to corrosion, deterioration with components of steel bridges includes loosening of fasteners, impact damage, failure due to overload and brittle fracture.

3.2.2 Repair of Defects in Steel Structures

3.2.2.1 Corrosion Repairs

3.2.2.1.1 Preparation for Reinstatement of Protective Coating

The durability of steel in a bridge depends on the environmental conditions of the bridge site and the quality of the protective coating. As corrosion of the steelwork advances, the section properties can be reduced, and the serviceability of the members and the structure adversely affected. The protective coating prevents corrosion and prolongs the life of the structure. The types of paint to be used vary depending on the existing paint system and whether the red lead was used in the original coating system.

Site protective coating works should be undertaken by a contractor that has accreditation to *Painting Contractor Certification Program (PCCP) for Class 3 Field Application – Atmospheric Exposure Service*.

For older steel structures the existing paint system should be checked to establish whether lead is present and any work on treatment of the surface should be in accordance *AS4361 – Guide to hazardous paint management.*

Preliminary lead testing can be undertaken with single use portable lead test kits. Further testing details are provided in *AS4361.1* for determining lead content of existing coatings, concentration, soundness or effectiveness. A paint sample containing greater than 1 percent concentration of lead is considered ‘lead paint’. Lead removal works should only be undertaken by contractor with accreditation to *PCCP for Class 5 – Removal of Hazardous Coatings.*

The lead management process generally involves the following:

- The encapsulation should be such as to collect all paint chips, the grit used in the blasting and to control the dust generated from the blasting.
- Workers should be equipped with full protective suits with breathing apparatus and a vacuum pump used to collect the lead dust particles generated by the grit blasting.
- Workers should wash down in special pits after leaving the encapsulation.
- Workers should be subjected to regular blood lead level tests to confirm their blood lead level does not exceed permissible concentrations.
- The grit can be re-used but should have the paint chips filtered from it.
- All debris should be collected and properly disposed of.

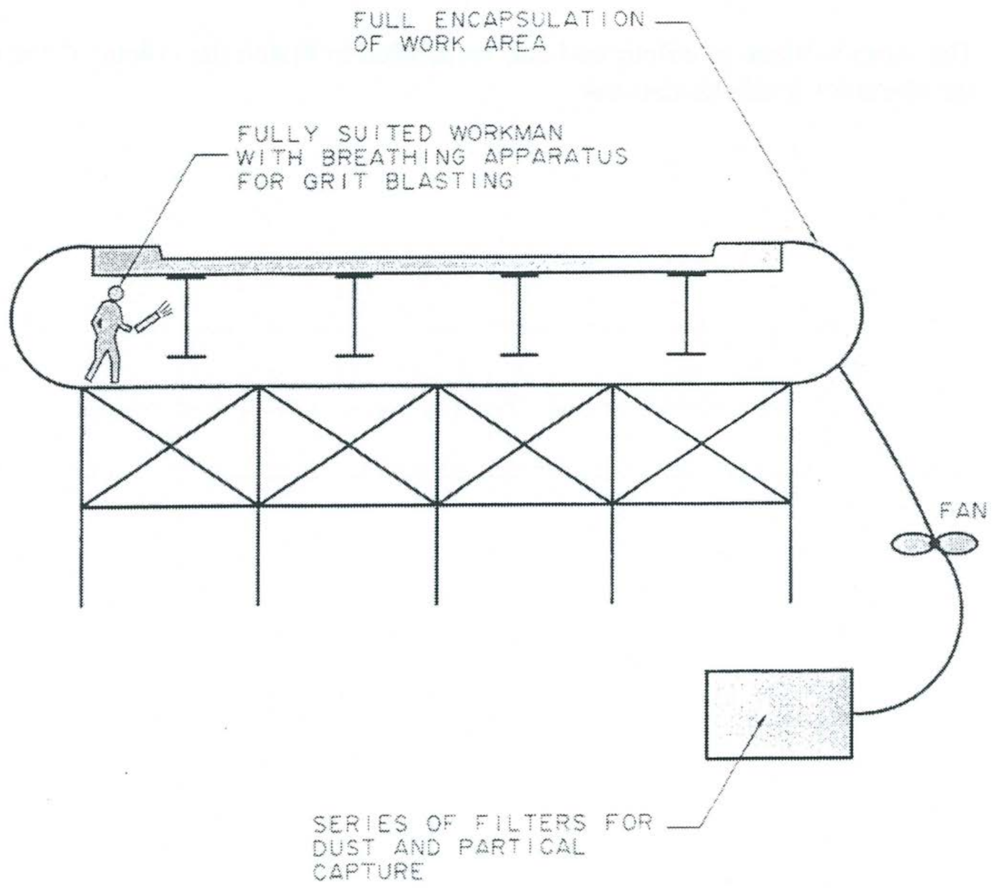


Figure 39: Surface preparation for painting

Figure 40: Surfaces damaged by spot rusting

All new steelwork should be coated in the workshop prior to delivery to the site to maximise the probability of achieving a high-quality finish. If the paint coating has been damaged in the transit, it should be spot repaired on site prior to or immediately after erection.

Rust inhibitor coatings and encapsulation paints are not recommended for bridge painting. These products rely on achievement of an entirely impervious layer for their effectiveness, and if this impervious layer is broken it permits corrosion. These products may be less costly and easier to apply, but do not provide the durability of a 2 or 3 coat paint system.

Refer *Standard Section 631 – Protective Treatment of Steelwork*

3.2.2.1.2 Methods of Application of Coatings

The method of application and the conditions under which coatings are applied have a significant effect on the quality and durability of the coating. Methods used for applying coatings to structural steelwork include the use of brushes, rollers, conventional air spray, and airless spray, although other methods (e.g. dipping) can be used.

(a) Brushing

This is the simplest method but the slowest and therefore the most expensive. Nevertheless it advantages in certain circumstances. It tends to provide better wetting of the surface and can be used in restricted spaces and results in less wastage and contamination of surroundings.

(b) Roller

This process is much quicker than brushing and is commonly used for large flat areas but relies on suitable viscosity of the paint.

(c) Air spray

With air spray, the paint is atomised at the gun nozzle by jets of compressed air, and the application rates are quicker than those for brushing or rolling, however, paint wastage by overspray is higher.

(d) Airless spray

With airless spray, the paint is atomised at the gun nozzle by very high hydraulic pressures, and the application rates are greater than for air spray and with less overspray wastage. Airless spraying tends to be the most commonly used method of applying paint coatings to structural steelwork under controlled shop conditions. Brush and roller application are more commonly used for site application though spraying methods are often used for large areas.

Weather conditions at the time of application can adversely influence the quality of the finished coating. These conditions can be more effectively controlled under shop conditions than on site.

(a) Temperature

Air temperature and steel temperature affect the solvent evaporation, brushing & spraying properties, drying & curing times and the pot life of two pack materials.

(b) Humidity

Coatings should not be applied when there is condensation present on the steel surface or the relative humidity of the atmosphere is such that it affects the application or drying of the coating. Normal practice is to measure the steel temperature with a contact thermometer and to ensure that it is maintained at least 3°C above the dew point.

3.2.2.1.3 [RPM15] Repair of Localised Spot Rusting or Corrosion

Rust spot will start appearing on the surface as the coating deteriorates. The size and the quantity of these spots spread with the time if left untreated. The rate of deterioration will depend on the environmental conditions. A steel component with spot rusting between 30 to 50% of its surface coating area can still be repaired. Generally a high-pressure water blasting and spot coating of the rusted area is sufficient. Some areas may require mechanical cleaning in addition to water blasting to achieve a suitable surface finish. A full prime coat and a top coat should then be applied to the steelwork to restore the protective coating.

The surface can be spot primed with a zinc rich inorganic primer if the cleaned surface is prepared to a class 2.5 finish or with a zinc phosphate primer if the surface preparation is to a lesser quality. Moisture-cured MIO zinc could also be applied to the lesser quality prepared surface and is advantageous if part of the coating requiring spot painting contains lead primer. Care needs to be taken to collect all the paint chips for appropriate disposal by having a drop sheet beneath.

Repair Method

1. Undertake preliminary lead test to determine whether paint contains lead. Any lead paint removal must be performed by specialist contractors with *PCCP Classification 5.*
2. Arrange plastic collection sheets and water filtering material around the work area to capture all paint flakes prior to any cleaning or removal of existing coating system.
3. For spot or localized repairs using mechanically cleaning, the use of an angular grinder or wire brush would normally be suitable for removal of rust or contaminants. Clean the surface to provide a bright metal appearance. Australian standards provide additional details of suitable tools. *AS1627.2* specifies power tool and *AS1627.7* specifies hand tool.
4. Very high-pressure water blasts 20,000 to 34,000 kPa (3,000 to 5,000 psi) can be applied on the rust-spotted areas to remove any loose or flaking paint, dirt, salts, and oils. When the area has been fully cleaned, spot prime those areas without any coatings. In a salt laden environment, the steelwork should be washed down with a

liquid soluble salt remover prior to coating, as a simple water wash tends to leave a relatively high salt concentration on the existing surface.

5. Select a coating system compatible with the existing coating and suited to the climatic conditions.
6. Use surface tolerant epoxy mastic paint. All paints must be chosen from the same manufacturer, and no paint should have exceeded the expiry date.
7. Ambient temperature at the time of coating should be greater than 15°C and at least 3°C above the dew point.
8. Follow manufacturer’s recommendations on the coating application procedure and the time between coats. Further, wet film thicknesses should be checked to ensure that they do not exceed the allowable thickness as this may cause paint to run, de-bond or craze on drying.
9. Apply to a thickness of 50 to 75µm to areas of spot repairs. Allow to dry then prime paint the entire surface before applying the finish coat.
10. Apply a top coating to a dry film thickness of 100µm.
11. In most cases, a prime and top coat should be adequate, but in aggressive environments (coastal or industrial areas) a further top coat should be applied.
12. Ensure Dry Film Thickness test records are kept for each coat of the painting system.

NB: Wire brushing does not produce an adequately clean surface for recoating. Care should be taken for worker and public protection in accordance with legislation.

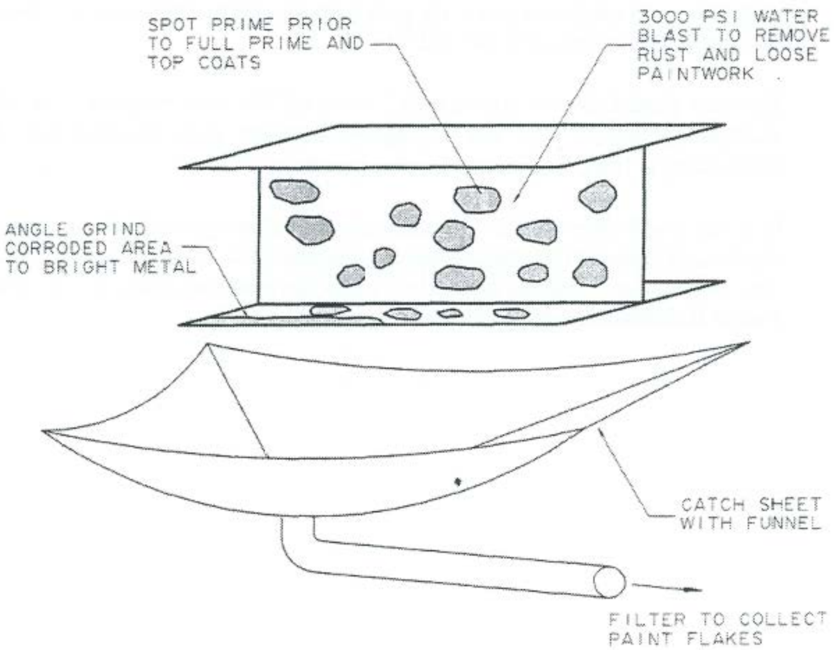


Figure 41: Spot rusting repair

3.2.2.1.4 [RPM16] Repair of Extensive Deterioration of Surface Coating

Major deterioration of the surface coating is considered to have occurred when corrosion on the structure or steel components exceeds 30% of surface area and there is heavy corrosion on flanges or edges. With a significant amount of deterioration it may be more cost effective to treat the entire steel surfaces than attempt localised repair and recoating. A total repaint will require total removal of the existing paintwork, the steel cleaned back to bright metal and the new protective coating system applied. The method of removal will require grit blasting, with full encapsulation of the work area to prevent spread of dust and to capture the paint flakes for appropriate disposal.

A painting system consisting of a priming coat and at least two top coats should be applied to the steelwork. This should provide renewed protection for the structure for 15 to 40 years depending on the environmental conditions.

Repair Method

1. Undertake preliminary lead test to determine whether the existing paint contains lead. Any lead paint removal should be performed by specialist painting contractors. Care should be taken to ensure worker and public protection in accordance with legislation.
2. Setup scaffolding and work platforms for access to the steelwork and encapsulate the work area.
3. Provide suitable work suits, breathing apparatus and wash down areas for workers, as well as vacuum extraction and filtering facilities to collect the paint dust and flakes generated by the blasting process. *AS4361.1* provides details of testing and containment requirements.
4. With the encapsulation in place, the paintwork should be abrasive blast cleaned to *Class 2.5* as described in *AS1627.4*. Areas with heavy layers of rusting or animal droppings may initially require removal by chipping.
5. Ambient temperature at the time of coating should be greater than 15°C and at least 3°C above the dew point.
6. Use rapid-cure high-build 2-coat system: rapid cure zinc-rich phosphate epoxy primer (75µm DFT)
7. If there is a time restriction, then use a two-coat system comprising two-pack organic zinc-rich epoxy primer (75µm DFT) and a rapid cure epoxy MIO, top coat (200µm DFT).
8. If there is no time constraint, then use a 2-pack organic zinc-rich epoxy primer (75µm DFT) and a 2-pack epoxy MIO (200µm DFT).
9. Follow manufacturer's recommendations on the coating application procedures and the time between coats.
10. Ensure Dry Film Thickness test records are kept each coat of the painting system.

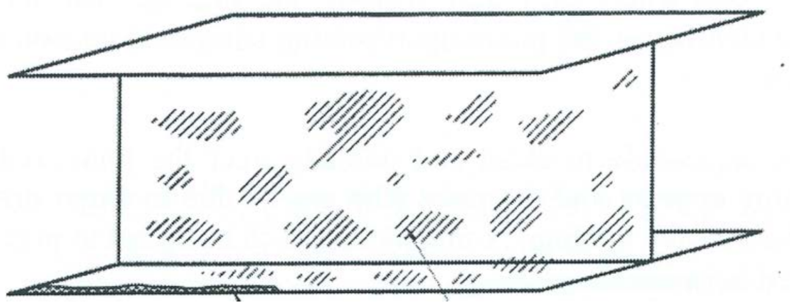


Figure 42: Corrosion over 30% of surface area

Figure 43: Typical encapsulation

3.2.2.2 Fatigue Cracking

3.2.2.2.1 Introduction

Fatigue cracking typically initiates at points of stress concentration where the stresses are predominantly live load stresses due to traffic load on the bridge and hence fluctuate and can result in a large number of stress cycles. If the stresses and number of cycles is sufficient, fatigue cracks can be initiated by microscopic defects in a connection and then propagate. The microscopic defects that initiate the crack, such as porosity, slag inclusions and undercut are almost invariably present in the fabricated steelwork. The rate of propagation is then dependent on the frequency of stress fluctuations and the level of the stress

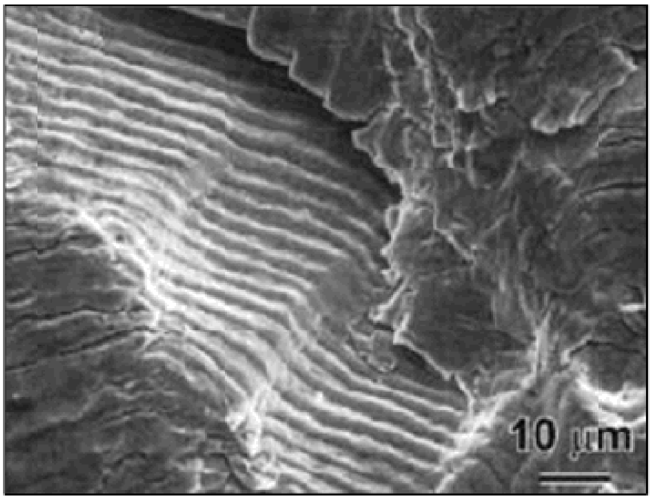


Figure 44: Microscopy of fatigue crack

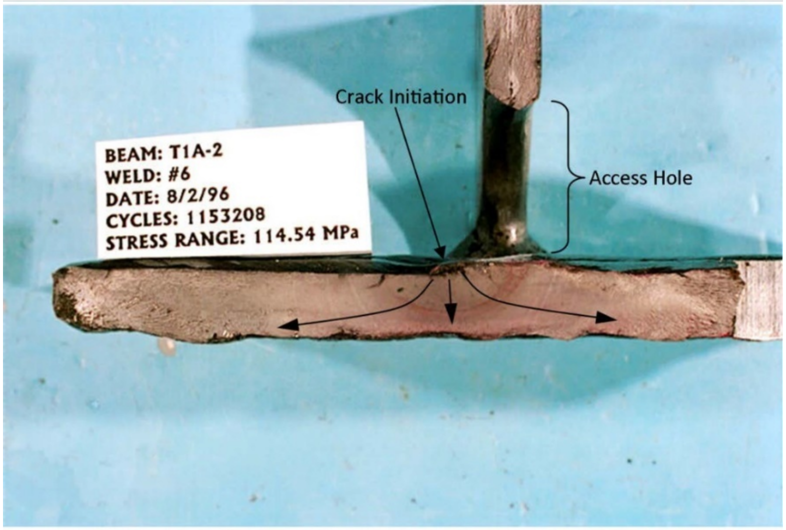


Figure 45: Typical fatigue crack across a repaired flange butt weld (FHWA-IF-13-020)

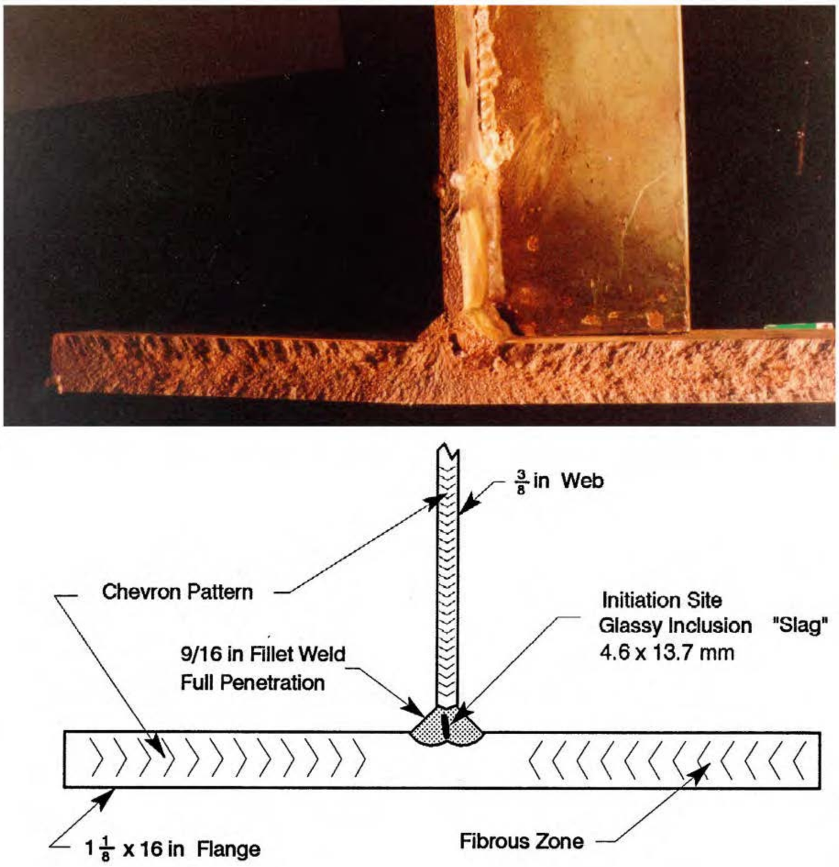


Figure 46: Girder flange fracture (FHWA-IF-13-020)

When the crack initiates it is virtually impossible to detect. As it propagates, it can be picked up by appropriate non-destructive testing and when the crack is long enough it can be picked up by the naked eye.

When cracks cycle open and closed, the crack surfaces tend to rub against each other creating a fine steel powder that easily oxidizes when exposed to the environment. The accumulation of oxidized material often leads to rust staining or discoloration which can facilitate identification. Provided the location of a potential crack is known, there are other more rigorous methods of Non-Destructive Testing (NDT) that can be used for crack detection. The most common methods for NDT are magnetic particle testing and dye penetrant.

When using dye penetrant, the area is cleaned and degreased to remove surface contaminants, a wire brush is used to remove heavy corrosion, but avoiding grinding as is tends to smear out the crack. A liquid dye (commonly red in colour) is then sprayed onto the surface, and this dye seeps into the cracks. After a specified time (~60-90 seconds), the dye is wiped away from the surface. A white developer is then sprayed over the same area where the dye was applied. Any dye within a crack is drawn out by the white developer, clearly showing the crack as seen in Figure 47.

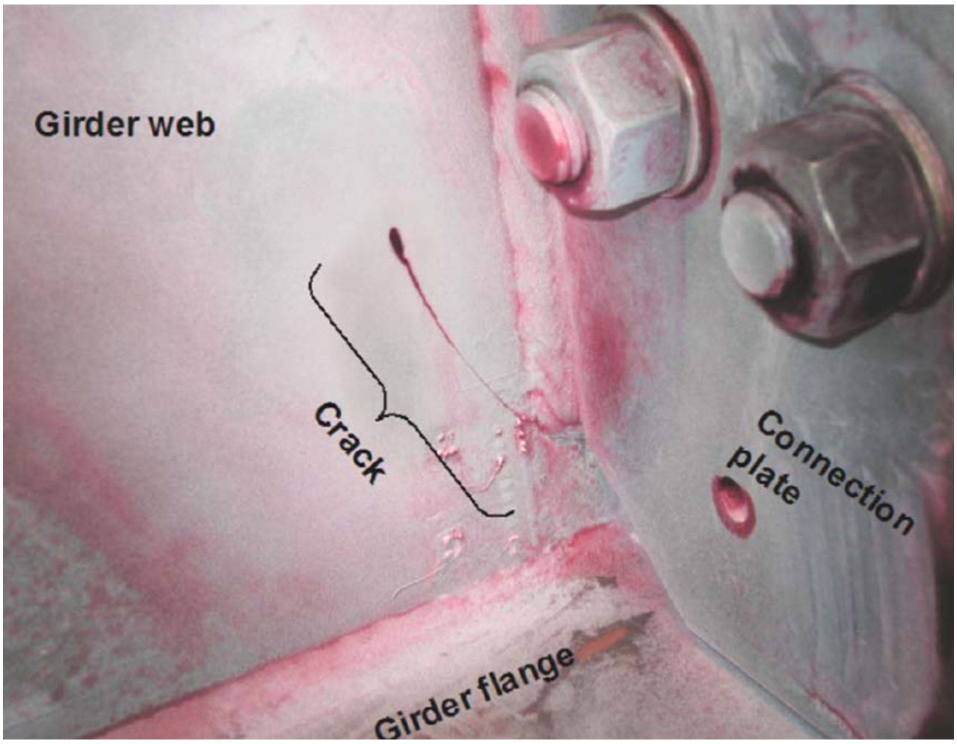


Figure 47: Crack exposed with red-dye penetration (FHWA-IF-13-020*)*

It is not practical to cover the entire structure with non-destructive testing, so the most practical method for detecting cracks is visual inspection. A practiced eye is vital to the identification of a fatigue crack. It is necessary to know exactly where to look and exactly what form the crack is likely to take. Problems are often encountered in tight corners with distinguishing between imperfections in the paint coating and fatigue cracking.

3.2.2.2.2 [RPM17] Treating of Fatigue Cracking

The earlier fatigue cracks are detected and remedial action is taken the better. A crack that has been allowed to propagate might pose a threat to the integrity of the structure or require more extensive repairs than would have been the case if it were identified earlier. If a defect is suspected to be a fatigue crack, the advice of a structural engineer should be sought to confirm whether it is likely to be a fatigue crack and advise on options to address the causes and remedial action.

Depending on the seriousness of the crack, it may be necessary to impose a reduced load limit or temporarily close the bridge to traffic. However, even if the defect is confirmed as a fatigue crack, it commonly does not mean that urgent action is required. Commonly, the response to the fatigue cracking might involve the following:

- Inspect the complete structure for other fatigue cracking, paying particular attention to details similar to the cracked detail

- Determine whether the structure is coated with lead paint, in which case any further work should be modified accordingly.
- Removal of paint in the vicinity of the crack and conduct non-destructive testing (NDT) such as magnetic particle inspection (MPI).
- Monitor the length of the crack over a period. The frequency of crack length measurements will depend on the seriousness of the crack and will require the advice of a structural engineer.
- Decide whether the crack should be repaired and, if so, the detail to be adopted for the repair.
- The appropriate treatment will normally involve both repairing the crack, using a 'V' shape preparation and modifying the fatigue-prone detail to eliminate the stress concentration and prevent a recurrence of the cracking.
- The weld should be in accordance with an approved weld procedure which suits material grade, type and weld type specified. This is very important for older structures made of wrought iron or cast iron.
- Apply the same treatment to other similar details on the bridge.
- All surfaces should then be spot primed and top coated to reinstate the protective coating in the vicinity of the repair against corrosion.

In instances where the crack is growing rapidly, a hole drilled at the tip of the crack can temporarily arrest its progress. However, contrary to the popularly held belief, it is rarely a long-term solution and can even hamper the implementation of an appropriate long-term solution or the section loss due to the hole may further degrade the strength of the component. The advice of a structural engineer should be sought before attempting to drill a hole at the tip of the crack.

3.2.2.3 Brittle Fracture

3.2.2.3.1 Introduction

Ductility is the material property that permits it to stretch, without fracture, after it has yielded. Modern steel structures are usually ductile, but under certain conditions can become liable to brittle fracture. However, the risk of this type of fracture is low.

When a weld is applied to a structure, there is an area of the parent metal, immediately adjacent to the weld and to which the weld metal is fused, that is affected by the weld. This area is called the heat affected zone (HAZ). The rate at which this zone cools following placement of the weld affects its hardness and hence its ductility. If there is insufficient heat in the weld or appropriate preheat is not applied prior to the welding the HAZ can be brittle. Even the contraction of the weld on cooling may be suficient to crack the HAZ or it may crack some time later.

3.2.2.3.2 [RPM18] Treating of Brittle Fracture

Brittle fracture within the parent metal tends to occur suddenly and without warning. Where brittle fracture of the HAZ adjacent to a weld is encountered, the following procedure should be followed:

- Immetiately seek the advice of a structural engineer as to whether the brittle fracture poses a threat to the safety of the structure
- Source a weld procedure for the weld repair
- Remove paint and conduct NDT to determine the extent of the brittle fracture
- Remove the faulty weld for a full length of the crack and 50mm beyond
- Reinstate the weld using an appropriate weld procedure

- Reinstate the protective treatment
- Examine all other similar details on the structure for signs of brittle fracture
- Monitor the repaired weld for signs of further brittle fracture

3.2.2.4 Other Structural Defects

3.2.2.4.1 Introduction

Other types of deterioration include;

- Impact damage
- Deformation or fracture due to overload
- Local damage due to seized bearings
- Inadequate provision for expansion and contraction
- Deformations may cause members designed for tension to be subjected to compressive loads. Substructure settlement may lead to distortion of members.
- Rolling flaws are relatively common in steel. They can show up as delaminations, cracks, blisters, pits or inclusions.

3.2.2.4.2 [RPM19] Repair of Defective Members

In general, the advice of a structural engineer should be soought in first understanding the cause of the defect and then deciding the appropriate procedure for repairing defective members.

If a bridge system is not redundant and cannot develop alternative load paths under the loss of member integrity, then fracture of a particular member could lead to the partial or total collapse of the structure. Such a member is called a Fracture Critical Member (FCM).

Significant damage to a FCM requires urgent actions such as lane closure of one or more lanes, restricting the bridge for cars only, or complete closure of the bridge until repairs are made.

Most modern bridges can develop alternative load paths. If a member with a crack is not fracture critical, the consequences of a defect are less severe and it may be acceptable to keep the bridge in service for a period. Even if it is unlikely to lead to collapse, any fracture is undesirable, and an assessment must be performed by a structural engineer to confirm the continuing serviceability of the structure. If the assessment indicates that the potential for collapse is unacceptably high, it may be necessary to close lanes, impose a load limit on the bridge, or to close the bridge completely until repairs are implemented.

The following outlines the approach to replacement of defective members.

1. Inspect structure identify plates or sections requiring replacement.
2. Identify the grade of steel and type of steel and appropriate welding procedure for the material. It is important to note the age of the structure as older structures can be made of wrought iron or cast iron which use different welding procedures when compared to mild steel.
3. Seek the advice of a structural engineer before attempting a repair to assess whether plate or section carries significant load.
4. Seek the advice of a structural engineer on whether propping is required to provide alternate paths for the component or relief components added before the plate or section can be removed and replaced or reducing the stress or load in the member during removal by stopping or detouring traffic.

5. Friction grip bolts should be used to replace any rivets removed after grinding off their heads to replace the members.

Refer *Standard Section 631 – Protective Treatment of Steelwork*

Refer *Standard Section 630 – Fabrication of Steelwork* .

3.2.2.5 Defective Fasteners

3.2.2.5.1 [RPM20] Rivet or Bolt Replacement

Rivets are generally found in only older structures. Rivets can be damaged by corrosion, movement of plates and tension strains from the members at joints. For their installation, rivets are placed into the holes and rounded over to form the head while they are still hot and malleable. On cooling, they shrink thereby clamping the members together firmly, and any connectors being installed to replace damaged rivets should have a similar gripping action.

Bolts and nuts missing or suffering severely corroded should be removed and replaced with new bolts.

Refer *Standard Section 630 – Fabrication of Steelwork*

Repair Method

1. Identify missing or defective rivets or bolts.
2. Remove any defective rivets or bolts by cutting or drilling out.
3. If they are misaligned, ream existing holes to permit insertion of a new bolt.
4. Replace rivets with high strength grade 8.8 friction grip bolts. Huck bolts can be used as replacements as they produce similar gripping action to rivets.
5. Bolts and rivets should be replaced with high strength bolts unless specified otherwise.

3.2.2.6 Localised Repair of Weak Concrete Deck

Riveted wrought iron girder bridges sometimes have steel buckle plates between the top flanges, supporting a weak concrete overlay. These deck overlays commonly leak causing corrosion of the buckled plates and top flanges of the girders. Furthermore, the beams are commonly not designed for current road traffic loadings.

3.2.2.6.1 [RPM 21] Repair Method for Small Areas of Weak Concrete

1. The defective areas on the existing deck should be removed, and the top surface of all girders given a high-pressure water blast (~20 Mpa or ~3,000 psi) to clean off any corrosion or flaked paint.
2. Shear connectors should be fixed to the top flange of the girders to provide composite action between them and the new reinforced concrete deck and thereby increase the strength of the superstructure along with the repair.
3. The areas on the steel plate where paint has flaked off should be spot primed to provide 50-75 microns of dry film thickness. This thickness can generally achieved with a single coat of hand brushed primer.
4. A new reinforced concrete deck should then be cast, and moist cured to complete the repair.
5. Defective paintwork on the girders and underside of the buckle plates should be repaired.

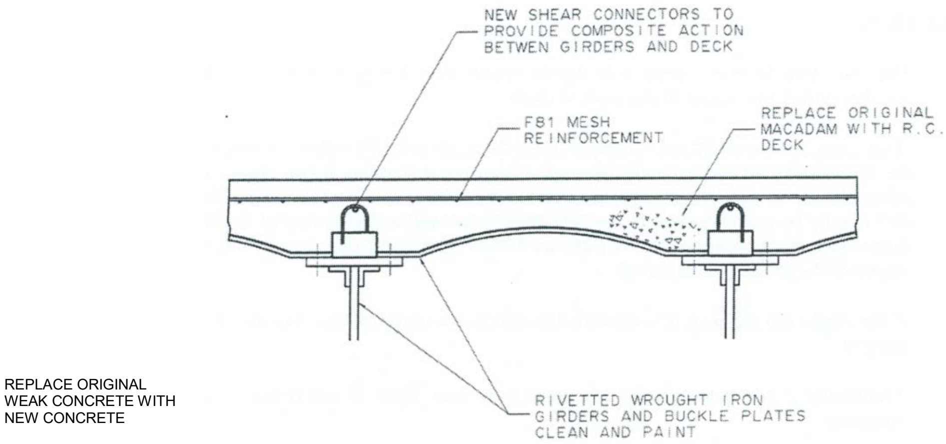


Figure 48: Repair of weak concrete deck

3.3 Timber Structures

3.3.1 Deterioration of Timber Structures

The types of attack on timber leading to deterioration can be classified into two main groups, biological attack, and non-biological attack. Fungi, termites, and marine borers are the main sources of biological attack. Non-biological factors that lead to deterioration are corrosion of fasteners, shrinkage and splitting and fire damage. Increased vulnerability to deterioration arises in areas where there is sapwood in the timber component and where moisture is trapped eg under flashing or at the end of the deck system especially where it is in contact with soil.

The most common deterioration of timber stringers is rot of the outer sapwood covering and splitting and pipe rot of the central core. Loss of the outer sapwood reduces the stringer size but more importantly it can lead to loosening of the bolted connections of the decking or plank spikes. The sapwood around bolted connections should be removed, and a hardwood timber block used to bolt against. Bolts should be galvanized and coated for ease of retightening. Locknuts or heavy steel spring washers should be used to prevent loosening of the nuts due to vibration under traffic and keep the bolt in tension at all times.

Minor splitting can be 'star' splitting radiating from the core due to drying out of the timber and is not normally a concern. Of more concern is splitting along the grain at mid-span due to overstress from heavy loads. Heavy splitting may also initiate from the bearing cutouts and can run the full length of the stringer if left unchecked. The heavy splitting can be contained by heavy steel banding of 50 x 3 mm section, but if this is not possible, then anti-split bolts can be used.

Pipe rot within the stringer heartwood is caused by microscopic fungus and reduces the strength of the member in both bending at mid-span and shear at the end supports. The deflection of the weakened stringer may be quite large under live load when there is excessive pipe rot.

Failure of the stringer may occur due to cracking through or splintering of the outer shell of good wood. Replacement or relieving of the load on the stringer with an RSJ is the most common repair method. Care should be taken with the positioning of the RSJ support point on the crosshead if it is midway between piles to ensure the crosshead is not overloaded.

If the stringer is heavily split or there is pipe rotting at the end, crushing at the end support can occur, and the stringer should be replaced or the load on it relieved. A limited extension to the life of the stringer can be achieved by steel banding or anti-split bolts

Timber cross-decking is commonly connected to spiking planks but in some instances the cross-decking is spiked directly into the top of the timber stringers where it can cause splitting and accumulation of dirt and moisture. As the spikes work loose due to traffic vibration, they are sometimes re-driven into the stringer or replaced with longer spikes that can lead to increased spike rot damage to the stringers. The pipe rot accelerates with the rot eventually eating out the top of the stringers. Replacement of the stringer or the complete deck system may then be required.

Rotted out knot holes can also be a concern especially with the high-stress area such as at mid- span or at the support point and can accelerate deterioration of the stringer.

3.3.2 Causes of Deterioration in Timber

3.3.2.1 Fire Damage

Thinner decking and sheeting can be susceptible to the bushfire hazards under sustained exposure to the fire. It is unlikely that a bridge will catch fire and incur severe damage if the bridge has been properly cleaned and maintained. Most fire damage occurs after the bushfire has passed, due to lack of attention and removal debris and fire residues from around the bridge.

Large timber sections such as girders do not ignite readily as they require a sustained temperature of about 250ºC -300ºC to ignite the wood. In larger sections, a layer of char is formed on the surface of the wood which acts as insulation and inhibits burning to approximately 0.6mm per minute.

3.3.2.2 Fungal Attack

‘White rot’ or ‘Brown Rot’ fungi are the primary cause of internal deterioration of timber bridge members. ‘Soft rot’ fungi start decaying the timber when it is in contact with the ground.

Fungi germination begins to develop a source of infestation from which the fungi can grow. Fungi do not grow unless there is an adequate supply of food (desirable wood cells), the provision of air or oxygen, suitable temperature and a continuous supply of moisture. Many fungi require moisture content above 30%, and it is unlikely that fungi germinate in moisture content below 20%. Wood that completely dry or saturated does not decay due to fungi attack either. Under favourable conditions, fungi germinate at an accelerated rate once established. If the moisture conditions change, it can cause cracking and water trap pockets, thereby encouraging fungi growth and attack.

3.3.2.3 Termite Attack

There are a large number of different termites spread across Australia. Termites, or white ants, can cause extensive and severe damage to timber if left unchecked. Once they are well inside the wood, additional colonies can form and quickly spread through a structure. They often travel up a pile inside a split and will cover their runway whether there path is in the split or on the outside of the timber.

The majority of termite damage to timber bridges occurs from subterranean termites (especially Coptotermes acinaciform), which require contact with the soil or some other constant source of moisture. Usually subterranean termite attack starts from the nest, but the infestation may spread well above ground level, either inside the wood or via mud-walled shelter tubes called galleries that are essential for termites to grow. These galleries are built on the outside of bridge members and provide shelter from sunlight, a humid atmosphere, and a source of moisture the termites require to survive.

Checking for termites should be part of Level 1 - Inspections and any infestations treated immediately to prevent more costly repairs. The inspection and treatment process is outlined in [M22] Checking Timber Elements and Treating Termite Activity

3.3.2.4 Marine Organism Attack

There are two primary groups of borers or marine organsims.

Molluscan Borers-Shipworms: One of the families of shipworms and is the family of Teredinidae, which includes Teredo spp and Banksia spp. They are commonly known in Australia as teredo or “shipworm”. Teredo spp is a wormlike borer with a grey body that produces a shell-like material to line its burrow. Initially, Teredo spp begin excavation with a 0.5-3 mm diameter hole. The borer can extend its tunnel along the grain. The length of this type of marine borer varies from 150mm to 1.8m and it can have a diameter of up to 25mm. The length of the tunnels depends on the extent of the attack. When the attack is extensive, the tunnels may be crowded, and their length and diameter limited. The white shell-like material lining the tunnels can be identified in the shavings when the wood is bored with a drill during inspection. Teredine borers destroy timber at all levels from the mud line to high water level, but the greatest intensity of attack seems to occur in the zone between 300 mm above and 600 mm below tide level.

Crustacean Borers: Gribbles Limnoria lignorum is one species of Limnoria spp which are also known by the common names “gribbles” and “sea lice”. Gribbles resemble woodlice and have a length between 3mm and 6mm. Their width ranges from one-third to one-half of their length. Gribbles can swim throughout their lives, and they can leave or be dislocated from the wood being attacked and return to the tunnel at another location. They commonly attack in coastal regions, making shallow burrows on the surface of the wood. If the attack is severe, only a thin layer of wood may be found in the burrows. The action of the waves and tidal currents washes away these thin layers exposing new surfaces for the dribbles to attack producing a wasted appearance or “hourglass effect”. For wood piles, the damage caused by gribbles is typically greatest in the tidal zone.

3.3.2.5 Shrinkage and Splitting

Bridges are usually constructed from green timber that gradually dries taking the moisture content below its fibre saturation point until it is in equilibrium with the surrounding atmosphere. Shrinkage occurs when the wood dries below its fibre saturation point. The wood does not shrink equally in all directions. Shrinkage is greatest in the direction perpendicular to the grain. Shrinkage parallel to the grain is small.

The relatively large cross sections used in timber bridges lose their moisture through their exterior surfaces and shrink while the interior of the member remains above the fibre saturation point. Tensile stresses develop perpendicular to the grain, and when these exceed the tensile strength of the wood, a check or split develops which deepens as the moisture content continues to fall. More serious splitting occurs at the ends of the member as the timber dries more rapidly through the ends of the member than through the sides. Shrinkage also causes splitting where the timber is restrained by a bolted steel plate or another type of fastening. This splitting can be avoided if the timber is allowed to shrink freely by the use of slotted holes. When it shrinks, the timber tends to lose contact with steel washers or plates in a connection, so the connection is no longer tight.

3.3.2.6 Weathering

Weathering is the combined effect of wetting, drying and exposure to UV radiation and should not be confused with decay. Weathering occurs slowly (between 6mm to 13mm per 100 years).

Regular inspections and maintenance can reduce the effect of weathering on timber. Reduction in the weathering is achieved by protecting the timber from the weather using preservative paints or physical barriers such as protective capping, shielding or flashing.

3.3.2.7 Corrosion of Fasteners

Corrosion of steel fasteners can lead to strength reductions in two ways. Firstly, the corrosion reduces the effective size of the steel fastener. Secondly, a chemical reaction involving iron salts from the rusting process can reduce the strength of the surrounding wood (this is not a fungal decay). Additional information is available in Bootle (1983).

3.3.3 **Repair of Defects in Timber Bridges**

3.3.3.1 Rotting and Splitting

3.3.3.1.1 [RPM22] Repair of Rotting and Splitting of Timber Piles

Splitting of timber piles can be caused by rot, aligned bolt holes, point loading from the crossheads and bolted connections or a poorly detailed crosshead connection. The splits should be contained to prevent further deterioration of the piles (Figure 49).

Figure 49: Splitting repair of a timber pile

Repair Method

1. Heavy 50mm x 3mm steel bands should be used around the piles to limit development of the splitting (Figure 49).
2. All loose softwood on the surface should be removed in the vicinity of the bands so that they remain tight. The bands should be regularly checked and retightened if necessary.
3. If the split pile is at an abutment, it may not be physically possible to place a band around the pile in which case 20mm diameter anti-split bolts should be installed across the split. If more than one bolt is used to contain splitting, the bolts should be offset around the circumference so they do not cause further splitting parallel to the grain along the line of the bolts.
4. If the crossheads are in sections and poorly spliced (i.e., they simply butt together at the pile) the load applied to the pile by the crosshead may cause splitting. In such situations, the crossheads should be properly spliced to transfer the load evenly to the pile. A steel plate across the butted ends should be installed before banding the split (Figure 50 and Figure 51).

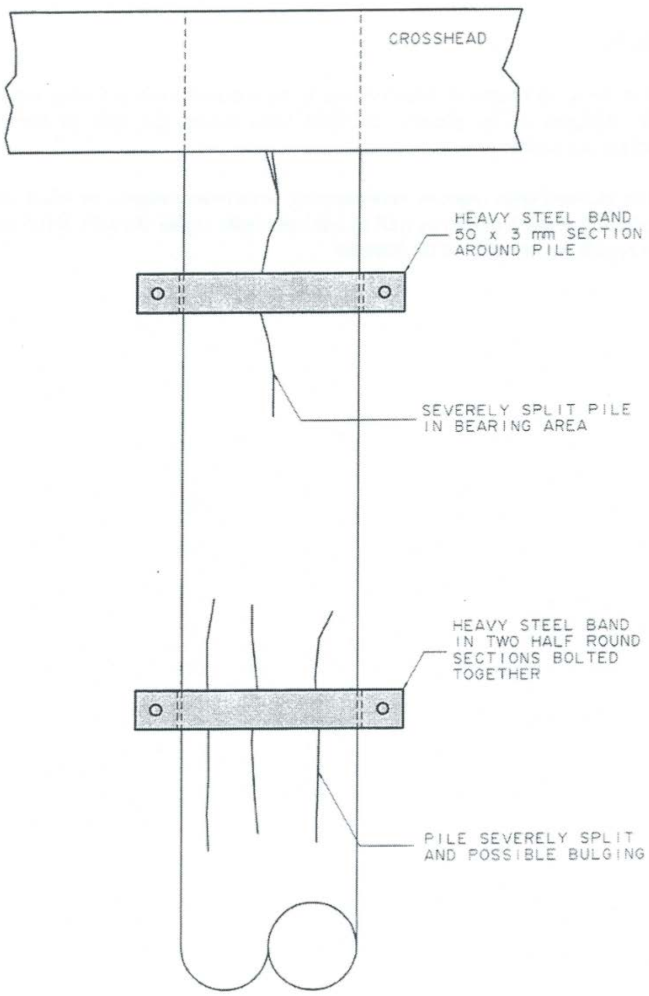


Figure 50: Banding split timber pile

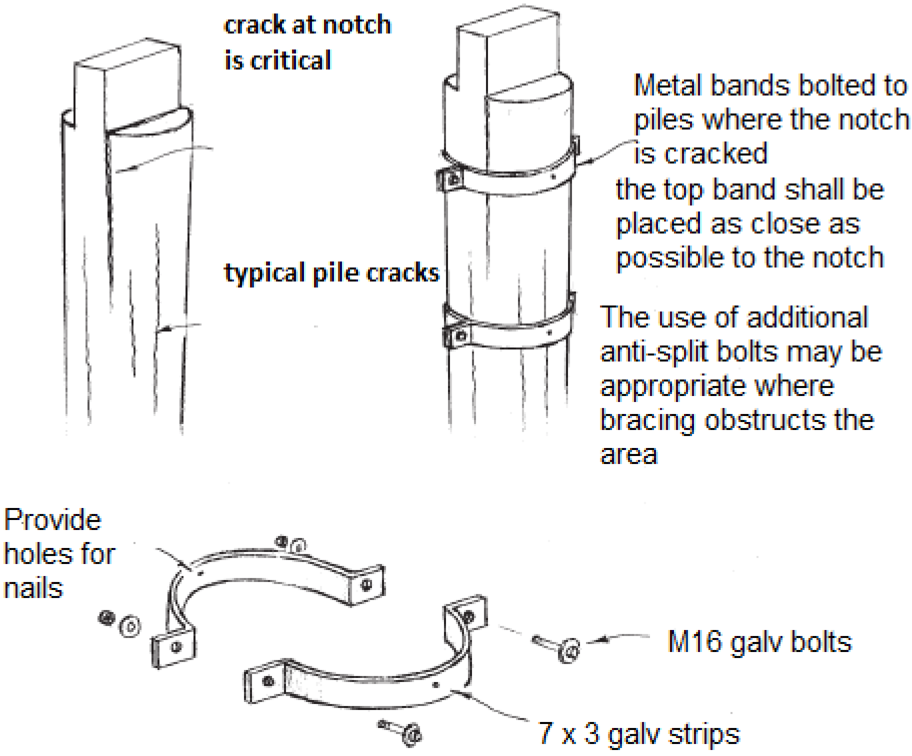


Figure 51: Pile banding details *(Main Roads Queensland (2005))*

3.3.3.1.2 [RPM23] Repair of Severely Split Timber Stringer

Timber stringers suffer structural splitting due to overloading. The splits can be vertical, horizontal, or at an incline usually from the notched area of the bearing support. This last split is the most critical as it can lead to a failure of the stringer, in shear, at the support if not repaired.

Repair Method

1. Horizontal and vertical splits can be repaired and contained by heavy steel banding around the stringers or by placing anti-split bolts across the split (Figure 53).
2. The inclined split requires strengthening with timber planks or small steel channel splints (top and bottom), as well as anti-split bolts across the split at 0.5 metre centres to restore the integrity of the stringer(Figure 52).

Figure 52: Split in corbel requiring anti-split bolt near the end

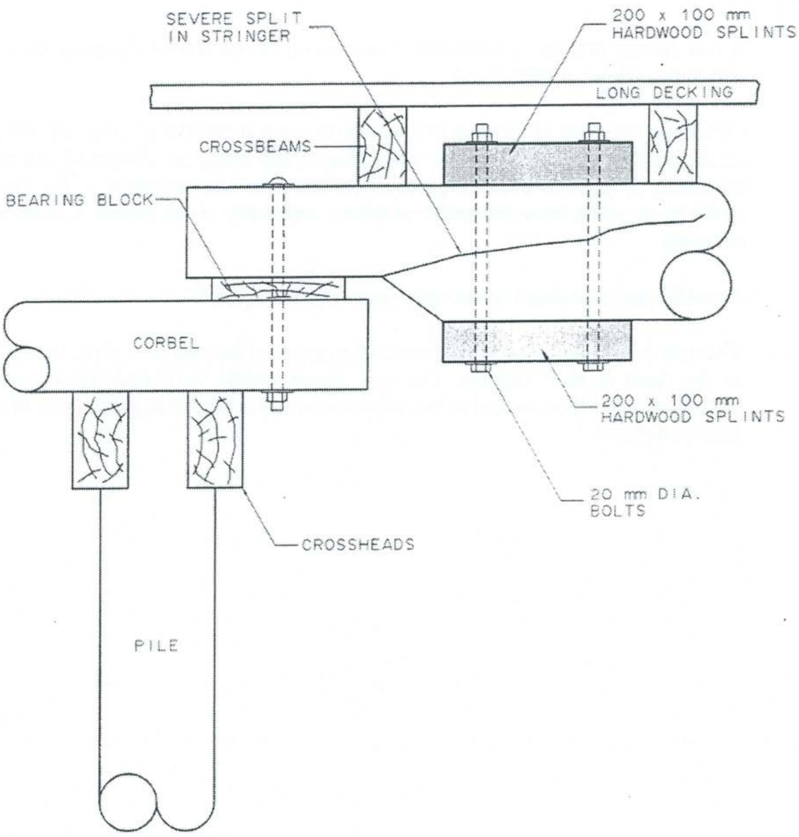


Figure 53: Diagram showing repair of split timber stringer

3.3.3.1.3 [RPM24] Repairing Splitting Timber Stringer

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

Repair Method

1. 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.
2. 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.
3. An additional crosshead or other strengthening may be required.
4. 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.

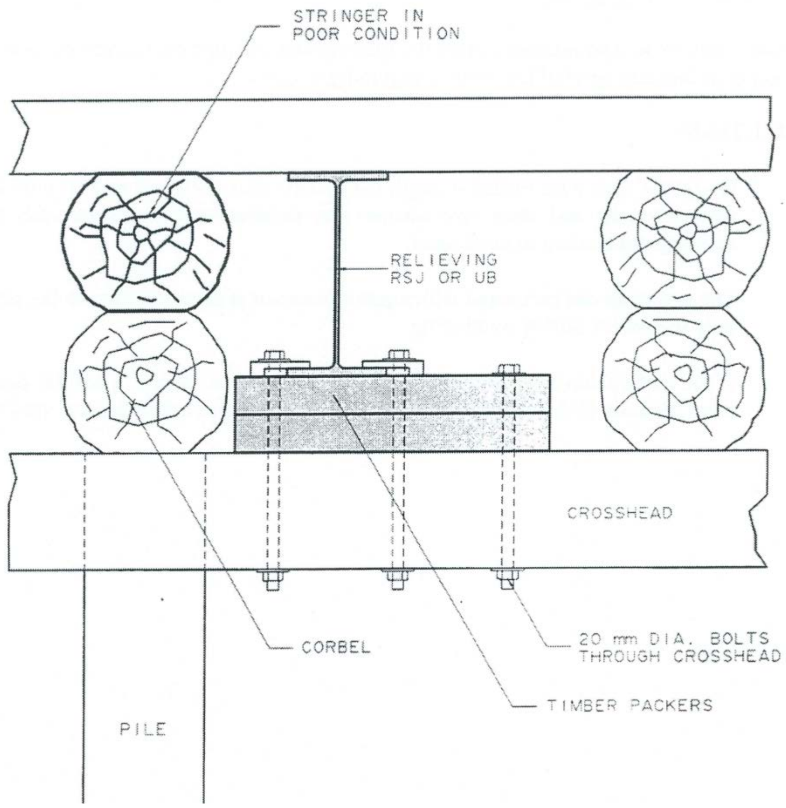


Figure 54: Relieving timber stringer

3.3.3.1.4 [RPM25] Repairing Split and Rotted Corbels

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.

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

Repair Method

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.

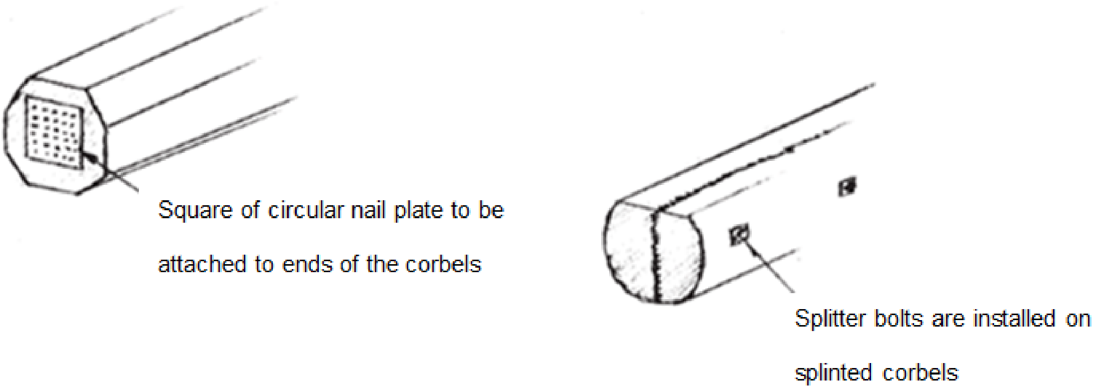


Figure 55: Repairing timber corbels (Main Roads Queensland (2005))

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.

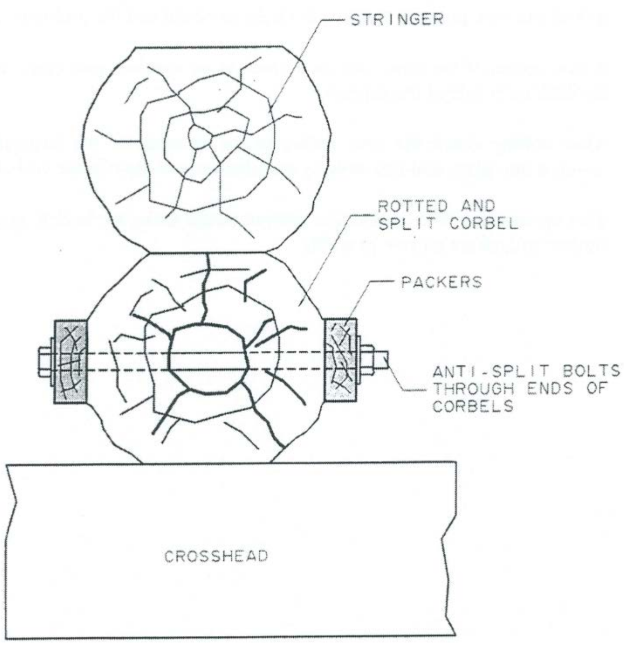


Figure 56: Repair of split and rotted corbels

3.3.3.1.5 [RPM26] Replacing Severely Split Spiking Planks

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

Repair Method

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

3.3.3.2 Weathering Repairs

3.3.3.2.1 [RPM27] Replacing Timber Crosshead/ Cap Wales/ Half Caps

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.

A defective crosshead can be replaced 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.

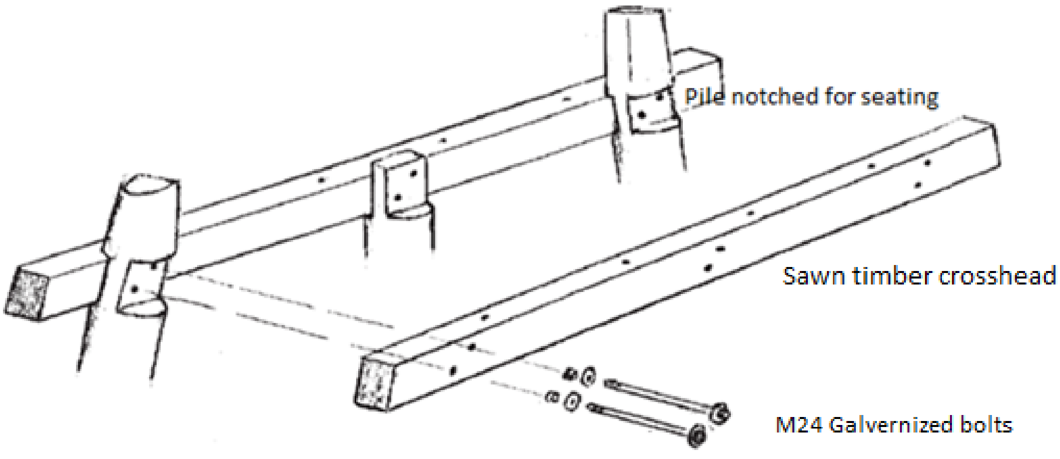


Figure 57: General details of crosshead *(Main Roads Queensland (2005))*

Repair Method

1. Inspect the crosshead to identify damage due to weathering and treat the crosshead by repairing or replacing it.
2. Recoat with a suitable waterproofing agent as necessary after brush coating a diffusing preservative over all repairs.
3. The pile attachment bolts should also be checked for tightness to prevent differential movement between crosshead and pile. Tighten or replace bolts as necessary.
4. If the crosshead has signs of severe splitting, edge rot or end rot it should be replaced.
5. Prop the girders to relieve loads on the crosshead. The advice of a struictural 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.
6. The girders beams should then be raised slightly to allow bolting to be released and the defective crosshead removed.
7. 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.
8. The props are then removed transferring the support of the girders back to the crosshead.

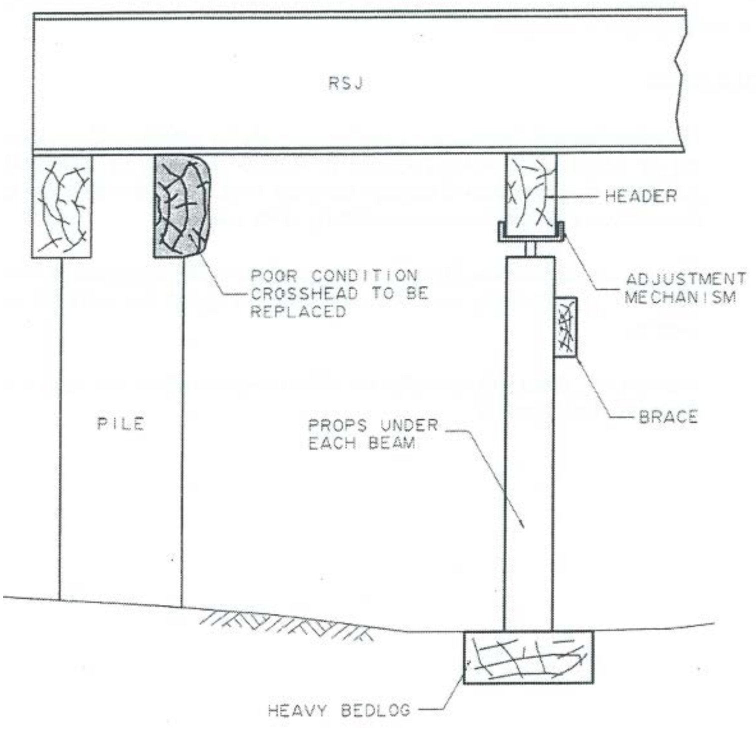


Figure 58: Replacing Timber Crosshead

3.3.3.2.2 [RPM28] Repairing Timber Deck

Deterioration of timber decks commonly results from poor drainage and general weathering. They 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.

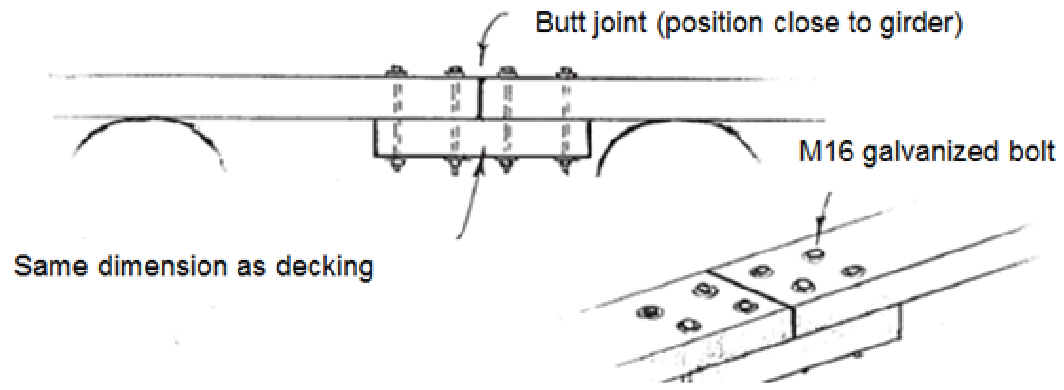


Figure 59: Splice detail *(Main Roads Queensland (2005))*

Repair Method

1. Remove wearing surface and any running planks over the defective area.
2. Release bolts and lift kerbs, where required.
3. Check the decking planks for defects.
4. 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.
5. 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.
6. If deck planks are badly rotted, they should be replaced.
7. Existing gaps between planks should be noted and maintained as these gaps provide air circulation and allow timber to dry out after rain.
8. Cut out defective planks and remove bolts, cut off where required.
9. 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.
10. Replace & reinstate bolt-on kerbs as required.
11. Reinstate wearing surface.

3.3.3.2.3 [RPM29] Repairing Timber Kerbs

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.

Repair Method

1. If the timber kerbs are loose but in good condition, then the bolts should be retightened and additional bolts installed as required.
2. If the kerbs are badly decayed, then they should be replaced.
3. The deck drainage adjacent to the replaced kerbs should be inspected, cleaned, rectified as required.

3.3.3.2.4 [RPM30] Replacing Timber Corbels

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

Repair Method

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 installed to fix them to the corbels.
5. This operation is best undertaken with the bridge closed to traffic.

3.3.3.2.5 [RPM31] Installation of Flashing

Flashing can be used to provide protection from water accumulation and weathering. However, flashing is effective only if it prevents access of water to the member (Refer Figure 59 and 60) and the timber underneath remains dry at all times. Usually, the flashing will be on the top and horizontal surfaces with a fall so that water is directed away from the sides of the member being protected.

Flashing should be installed so that it is easily removed for inspection and retreatment of the member. Installation of flashing should only be attempted during a warm weather after the wood has been allowed to dry.

Figure 60: Flashing on pile top (*RTA Timber Bridge Manual 2008*)

Figure 61: Flashing over timber member (*RTA Timber Bridge Manual 2008*)

Repair Method

1. Inspect and measure existing timber member.
2. Clean existing timber by sanding or using solvents and apply appropriate diffusive preservative.
3. Cut and bend galvanised metal sheet 1.5mm to 2mm thick to suit the members dimensions and to provide a cover over member while retaining clearance for air circulation and avoiding condensation on the timber.
4. Alternatively the flashing should be tight fit against timber and sealed with a thick layer of grease or gel type preservative to eliminate access for moisture.
5. The flashing should have a fall so that water does not collect on the flashing and flows away from the timber member.
6. Drill holes through the galvanised sheet and affix flashing with nails.
7. Seal around nails and any gaps with silicone sealant or epoxy to prevent water and moisture ingress.

3.4 Masonry Structures

3.4.1 Deterioration of Masonry

Masonry is constructed from discrete blocks with mortar between them and has virtually no tensile strength. The blocks are either natural stone or manufactured from materials and formed into bricks or blocks. The mortar most commonly used in the past was a lime mortar that is softer than cement mortar and is therefore more effective in distributing evenly across the joint.

The deterioration of masonry can be very slow but can be accelerated in the event of inadequate maintenance or increased traffic load. Common causes of deterioration include the following:

- The material of the masonry units is not durable

- repointing has not been carried out as required
- Inappropriate material has been used for the repair or cleaning of the masonry.
- changes to the loading or the environment (e.g. increase traffic loading).

Deterioration of mortar is the most common cause of the deterioration of masonry structures and water is a common contributing factor.

3.4.1.1 Moisture Saturation

Exposure to water increases the vulnerability of the masonry to influences that accelerate deterioration. Percolation of water through the masonry can cause fine particles to be washed out of the mortar thereby increasing the porosity and creating conditions favourable to growth of fungi and vegetation.

3.4.1.2 Freeze-Thaw Cycling

Repeated exposure to the freeze-thaw cycling or wet-dry cycling can cause fracture and spalling of masonry units and mortar loss from joints.

3.4.1.3 Salt Attack

Passage and deposition of salts can cause softening, crumbling, flaking, blistering and laminar spall of mortar and masonry units. The potentially damaging salts can come from groundwater, polluted rainwater, contaminated runoff or air borne pollutants from traffic fumes.

3.4.1.4 Sulphate Attack

Sulphate attack can weaken the mortar and cause it to become flaky and crumbly. In addition, sulphates can attack bricks and stone that possess chemicals that react with the sulphates.

3.4.1.5 Leaching of Mortar

Calcium hydroxide and calcium carbonate can be leached out of the mortar by exposure to water. This leaching leads to porosity, staining and a whitish deposit on the masonry surface. Severe leaching weakens the mortar so that it is more easily washed out of the joint or abraded by wind and rain and it is more susceptible to damage due to freeze-thaw.

3.4.1.6 Vegetation and Other Forms of Biological Attack

Small living organisms such as bacteria, fungi or algae can accumulate on masonry surfaces, particularly when they are damp.

Vegetation growth can cause significant damage to the mortar and reduce evaporation and thereby accelerate deterioration (Figure 62). Smaller organisms such as bacteria, fungi, algae can develop between stones or bricks and cause carbonation in stones, bricks or the mortar joints. Certain bacteria produce harmful acids like sulphuric acid by drawing on sulphur in the soil. These processes can further accelerate the decay of the masonry.

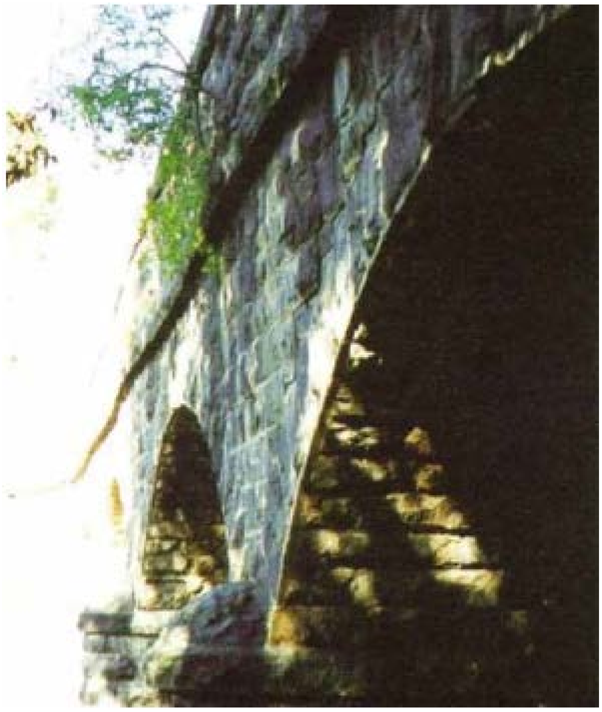


Figure 62: Vegetation growth and damaging wall

3.4.1.7 Repair with Incompatible Material

The use, for repairs, of strong or hard mortar can cause spalling on the faces and edges of masonry units. In addition, the use of hard bricks or blocks for repairs can cause damage to adjacent elements of the original structure and the use of impermeable repair material can exacerbate saturation and redirect moisture to other components thereby accelerating their deterioration.

3.4.1.8 Spalling from Impact

Accidental impact can result in cracking, spalling and dislodgement of masonry units. Depending upon the extent of damage the structural integrity of the masonry may be impaired.

Spalling due to other causes such as fretting, sulphate attack, and unsound materials can be identified as part of the inspection regime and treated before the structural integrity is threatened.

3.4.1.9 Biological Attack

Fill material over the arch ring retained between the spandrel walls or behind abutments, retaining walls and wing walls can contain enough water and nutrients to support vegetation growth. Lichen or ivy can attach itself to the masonry and cause chemical attack of the surface of the masonry. Roots and stems growing into crevices or joints can exert a bursting force that causes joints to open and dislodge blocks.

3.4.2 **Repair of Defects in Masonry Structures**

The most common causes of deterioration of mortar are weathering, migration of water, impact damage and foundation movement. Typically, the deterioration is slow and can be identified with a timely and effective inspection programme and the deterioration treated.

3.4.2.1 [RPM32] Repointing Stonework and Replacing Stonework

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.

Fretting is caused by moisture percolating through the masonry over repeated cycles of wetting and drying. The moisture breaks down the lime mortar in the joints and can cause loss of the bonding agents and spalling of the masonry units. The water can come from either the footings and backfill, it can be transferred by capillary action or can seep through the fill.

Gases or solids in the water can chemically attack the masonry by reacting with the cementitious material between the blocks leading to mortar loss.

Bluestone blocks can be found to have substantial honeycombing and can crack or split when overloaded. Blocks and bricks can completely break free and be washed away over time.

Sandstone masonry walls commonly suffer abrasion due to water and the wind, especially where the sandstone is soft.

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.

Repair Method

- The strength and elastic properties of any repair material should be matched to those of the existing material. Traditional mixes were commonly a 1:3 lime/sand mix. Mortar can be analysed in a testing laboratory to determine the formulation.
- The existing mortar should be scraped back to the stone surface to remove any soft, loose and crumbling material and the area blown clean with compressed air.
- If there is efflorescence it should be washed off with high pressure water blast to permit identification of areas of mortar loss.
- Badly cracked, split or severely deteriorated blocks should be broken out and the void created should be cleaned prior to placing the new stones.
- Pre-wet masonry surfaces thoroughly, so they do not absorb water out of the repair mortar.
- The new stones should be placed into position on a stiff 6:1:1/4 sand/cement/lime mortar layer which is allowed to partially set. If aesthetics are not important, the voids can be boxed and a concrete block cast to within 50 mm of the masonry block above, and allowed to set.
- The mortar should be placed by hand were the depth is shallow. Where the mortar loss is deeper than 20 mm it should be replaced with a low pressure injection of 6:1:1/4 sand/cement/lime mix to reach the rear of the stones, and backfilled to depth of 10 mm from the front face of the stone.
- The final repointing mix should be coloured to provide a similar colour to the existing mortar. Trial mixes can be prepared to check for colour match. The mix should be trowelled into any gaps and finished off at the face or to match the existing mortar (Figure 63).
- All excess mortar should be cleaned off.
- 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 to prevent

drying out of the mortar. When an individual brick or block is replaced, formwork is not usually necessary. Temporary timber wedging can be used.

- If a whole sandstone wall requires remedial treatment and aesthetics are not a concern, the wall can be rendered or have sprayed mortar applied to provide a more durable surface. The render or sprayed mortar should be moist cured for at least 3 days to avoid shrinkage cracking.
- Repair of a deteriorated arch may require formwork.

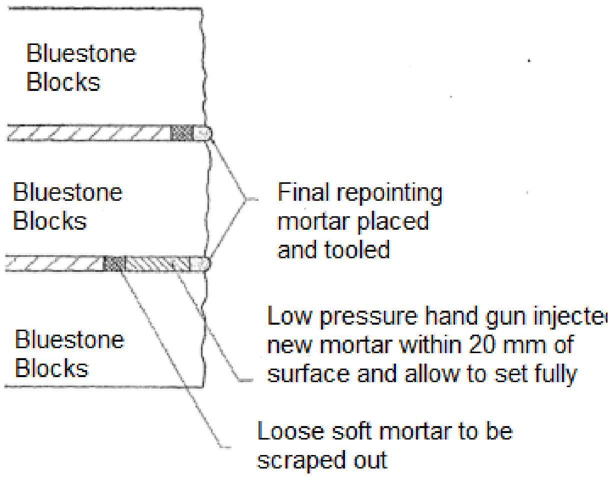


Figure 63: Repairing damaged mortar

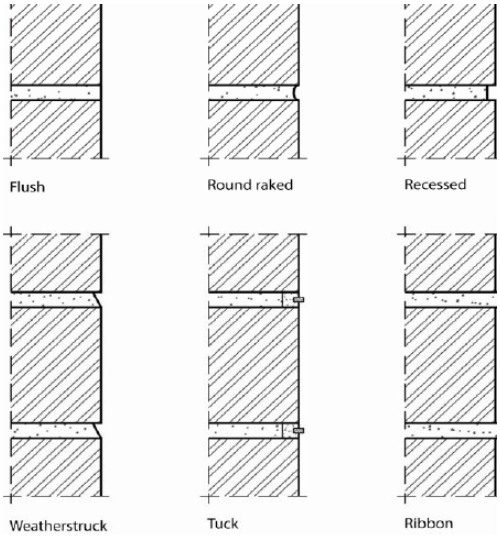


Figure 64: Different finishes for repointing (*Heritage Council of Victoria, 2007*)

The contractor engaged to undertake the work should have appropriate skills and experience with repair of masonry structures. VicRoads does not have a list of prequalified contractors, however Heritage Victoria retains a list of contractors suitable for Stone Masonry work on its web site.

Figure 65: Missing bricks (*JHR 2012*)

3.4.2.2 [RPM33] Splitting or Cracking of Blocks or Mortar

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 (ie 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.

Figure 66: Cracks at sidewall and loss of mortar between bricks

Repair Method

1. If the cracking is only moderate it may be sufficient, in the first instance, simply to monitor the crack to determine whether it is live or growing.
2. If the cracking appears inactive, then it may be sufficient to simply repair it.
3. If the crack is active and subject to moisture ingress, then the appropriate option may be to seal the crack, monitor it and defer any repairs until it is established that the crack is no longer active.
4. A crack repair involves removing the existing defective mortar, cleaning with compressed air then pressure injecting a sand/cement/lime 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 6:1mix though as a general rule the mix should be softer and more permeable than the stonework.
5. If the crack is only required to be sealed it should be cleaned, a low-pressure silicone sealant injected and the crack monitored. Monitoring the crack width may entail measuring, at intervals, the distance between two points on adjacent well-bonded stones or installing and observing a graduated metal 'tell - tale' that straddles the crack.

3.4.2.3 [RPM34] Repair of Sidewall (Spandrel Wall) Bulging

The side walls of masonry arch bridges can bulge outwards due to a combination of moist infill and compaction of the infill due to traffic loading. The bulging can cause cracking, loss of the mortar and movement of the stones relative to each other.

Repair Method

1. The most effective solution to the problem which avoids closure of the road is to install tie rods between the side walls. The advice of a structural engineer should be sought with the design of the rods and their attachment to the sidewalls.
2. This treatment requires scaffolding for access and the coring of holes through the walls and infill.
3. Plastic sheaths enclosing galvanized rods are inserted in the holes.
4. The rods, which are fitted with large steel anchor plates at each end to distribute the tension load in the rod over the face of the wall, are then tensioned to prevent further cracking and bulging (Figures 66 and 67).
5. Where the aesthetic aspects are important, the plates should be recessed into the stones and hidden by a thin veneer of stone, epoxy bonded to the plates to match the masonry walls.
6. After tie rods have been installed, the cracked mortar can be treated in accordance with [RPM32] Repointing Stonework.

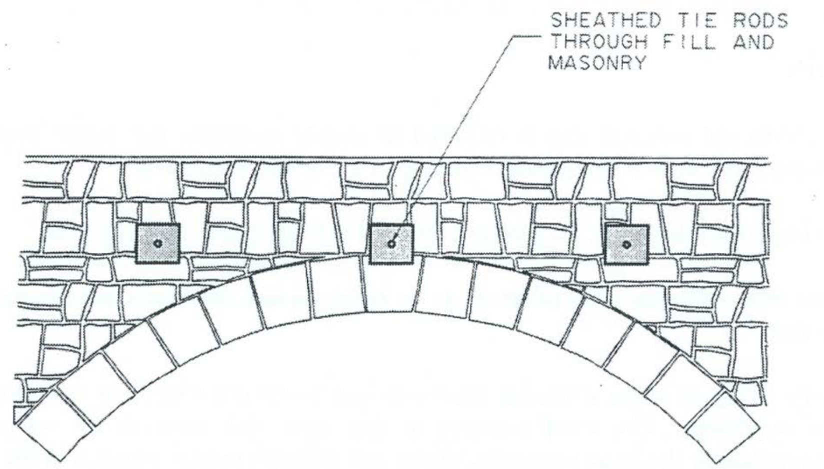


Figure 67: Repairing sidewall (spandrel wall) bulging

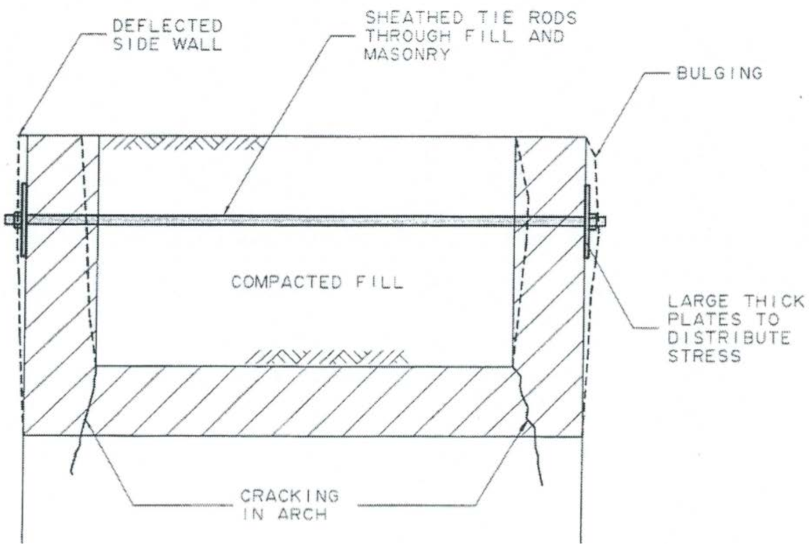


Figure 68: Detail to sidewall bulging repair

3.4.2.4 [RPM35] Stabilising Abutment or Wing Wall Movement

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.

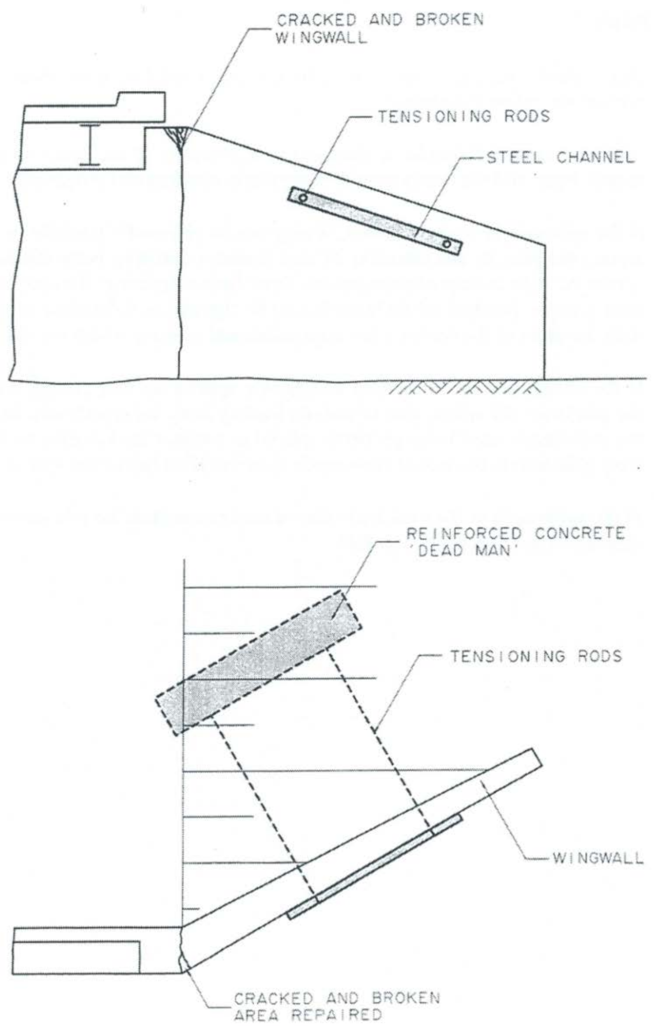


Figure 69: Repair of wingwall movement

Repair Method

Propping in front of the walls should only be regarded as a temporary measure as it is commonly not particularly effective, it is unsightly, interrupts stream flow and may be damaged by debris. A better long-term solution is to restrain the wall by means of tie rods. The advice of a structural engineer should be sought with the design of the tie rods and their terminations, including the dead man.

1. Holes are first cored through the walls and embankment.
2. Tensioning rods are inserted into holes and pushed through the embankment. These rods should be galvanized and sheathed in plastic over the length they are within the embankment fill.
3. The rods are attached to a reinforced concrete 'dead man' cast into an excavated hole some 5 metres behind the wall in the embankment.
4. After tensioning the rods, the excavation is backfilled with compacted fill and the cracks in the walls epoxy grouted.
5. Other solutions to the problem include 'soil nails' and helical ties that avoid the need to excavate for and cast the concrete 'dead man'.
6. 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.

NB: If the rotation of the wall is due to scour the wing wall foundations, this problem needs to be addressed separately, prior to the above work.

Figure 70: Wingwall cracking

3.4.2.5 [RPM36] Repair Arch Cracking

Movement due to soil pressure on the side walls (spandrel walls) can cause cracking in the arch, one stone in from the edge. If this cracking is only fine, it may only require monitoring.

If the cracking is extensive and excessive moisture is penetrating the crack, the side walls should be tied together. If the crack is associated with a wing wall movement, then the movement should be stabilized to gain a clear understanding of the cause of the problem and the appropriate remedial measures before the arch is repaired.

Repair Method

1. Identify the extent of cracking in the masonry arch and determine the cause.
2. If cause of cracking is due to sidewall movement complete the repair in accordance with [RPM34] Repairing Sidewall Bulging.
3. If the crack is associated with a wing wall movement, then that movement should first be arrested in accordance with [RPM35] Stabilising Abutment of Wing Wall Movement.
4. Once the cause of the cracking has been dealt with, mortar repairs can be completed in accordance with [RPM32] Repointing Stonework.
5. Following the remedial treatment, the arch should be monitored for a period to confirm that the cause of the cracking has been successfully addressed.

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Appendix 1: Bridge Components

The RSIM provides definitions of structural components. Some common terms are used to define the elements of each bridge. The following diagram shows primary components of a common bridge. The personnel responsible for bridge maintenance should know the basic components, their role, and their significance to help with ranking recommendations in a maintenance plan.

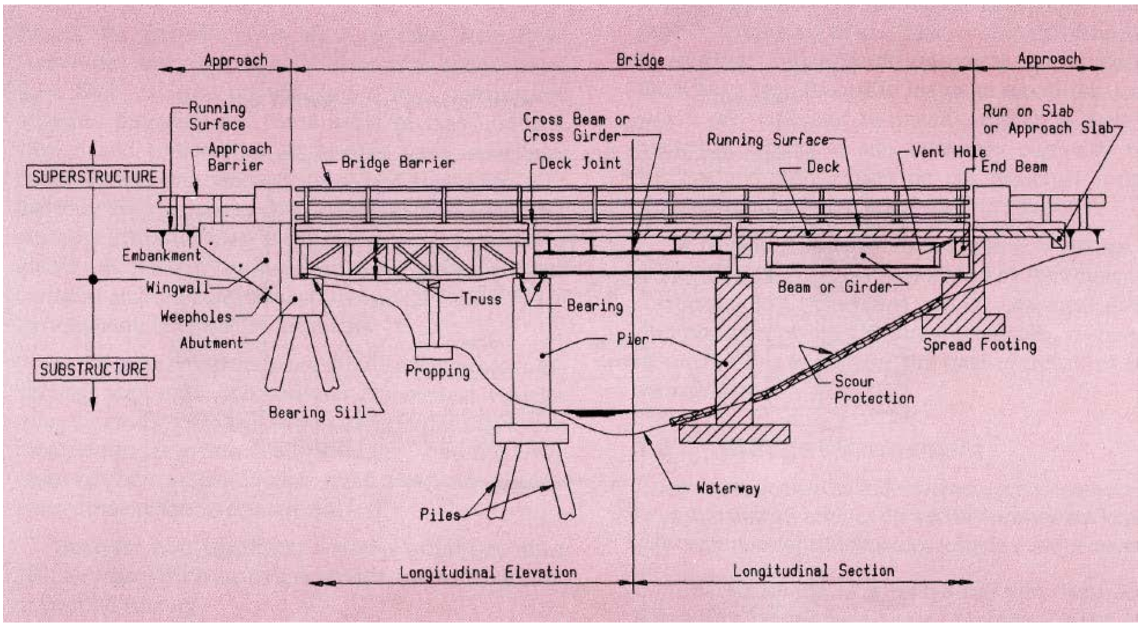

Figure 71: Bridge section and general terminology (*Source: Austroads 1991*)

Superstructure: Supports loads transmitted through the deck.

Bearings: Support the transfer loads from the superstructure to the substructure, while permitting rotation and longitudinal movement.

Substructure: Elements that transfer loads from the superstructure to the ground.

Expansion Joint: Assembly or material designed to absorb safely the expansion and contraction of the superstructure while providing continuity with the running surface of the bridge and protecting the bearings from water and debris. There are two general types of expansion joints:

i. Open joints; designed to allow water and contaminating materials to pass through the joint and onto elements beneath or are collected in drainage through to move them away from the sensitive area of the bridge structure. Butt joints, Sliding Plate Joints, and Finger Joints are the common types of open joints
ii. Closed joints; designed to be waterproof. Filled Butt Joints, Membrane Seal Joints, Neoprene Compression Seal Joints are some of the common closed joints

Deck: Supports the roadway on which traffic flows, and also distributes traffic (live loads) and dead loads. An additional purpose of the deck is to provide weather protection for primary members, bearings and the substructure and protecting them by diverting debris, salt, and stormwater. Bridge deck systems commonly encountered include:

- Reinforced concrete with separate wearing surface
- Reinforced concrete with integral wearing surface

- Prestressed concrete box beams
- Precast concrete planks
- Steel plates (Orthotropic decks) with thin wearing course overlay
- Concrete-filled grid
- Timber planks (nail-laminated, glue-laminated, stress-laminated)

Footpaths: Footpaths are provided on structures where pedestrian traffic counts warrant their use.

Kerbs: Kerbs are provided in conjunction with footpaths. Kerbs can be constructed of reinforced concrete, pre-cut granite, timber or steel plate.

Railings: Railings are placed along the extreme edges of the deck system and provide protection for traffic and pedestrians. There is a wide variety of railing materials and configurations.

Refer to the RSIM for further details of the various structure and structural elements.

Appendix 2: Durability considerations

Concrete Structures

The importance of designing and constructing concrete structures to achieve durability is crucial to minimising maintenance costs during their service life. Structures that have been designed and constructed with durability in mind can withstand the expected wear and deterioration throughout their intended life, without significant effect on their serviceability and reliability.

It is essential to follow approved construction techniques, practices, and standards to maximize the durability of concrete structures. The primary factors affecting the durability of concrete include the cement or binder content; water:cementitious material (W/C) ratio; controlled batching and mixing. Also affected by the proper placing and compaction; and proper curing starting immediately after the concrete has been finished. These factors must be adequate as described in the specifications, as they all affect concrete permeability, density, compressive strength, and durability. Clean and correctly positioned reinforcement is necessary to achieve bond strength and concrete cover. Compliance with design and construction specifications and adequate overall quality control is essential.

Concrete bridges and other concrete structures can reside in a variety of service environments, characterised by various degrees of severity of the exposed environmental condition.

- Benign environments: include inland or non-coastal locations (distance >50km from the coastline), non-industrial and temperate climate zones. Carbonation or ingress of moisture is unlikely unless the quality of concrete is poor.
- Moderately aggressive environments: include industrial zones (Industrial refers to areas that are within 3 km of industries that discharge atmospheric pollutants) or near coastal zones (1 km to 50 km from the coastline). Structures in industrial zones may be subject to carbonation or acid gases such as SO_x or NO_x, while those in near coastal zones may be exposed to air borne chlorides or moisture. Special attention should be paid to elements exposed to prevailing coastal winds.
- Aggressive or severe exposure environments: include coastal zones (within 1Km of the coast) and aggressive soils/groundwater. Coastal zones where there are strong prevailing winds or vigorous surf, can increase the salinity level in the moisture leading to chloride-induced corrosion of the reinforcing steel. Aggressive soils and groundwater include acid sulphate soils (i.e. pH < 4.0), salt-rich ground conditions (including chloride and sulphates) and areas that are subject to the emission of industrial pollutants. Particular care should be taken in these conditions in the inspection of foundations.

The service environments or zones in which coastal bridges reside can be classified as submerged, tidal, splash and atmospheric.

- The tidal zone remains wet most of the time, however it has greater access to oxygen than the submerged zone resulting in more rapid deterioration than the submerged zone once corrosion has been initiated.
- The splash zone is the most severe exposure zone because of the wetting and drying effect of wave splash and the combined effect of high surface chloride build-up to capillarity and high oxygen access.
- Atmospheric zones carry a lower risk than splash zones due to lower rates of deposition of chloride. However, surface chloride build-up can be appreciable from the deposition of seawater droplets.

Table 1: Protective Coating Material and Properties

Product Category	Classification	CO_2 Resistance	Water Vapour Transmission	Cl/H_2O Resistance	Application		Durability		Cost	
					Damp Condition	Ease	Strong UV	Wet \Dry	Recoat Interval	Ease of Recoat
Film Forming										
Polyurethane	Coating	Very High	Very Low	Very High	No	Poor	Poor	Good	Good	Poor
Epoxy Resin	Coating	Very High	Very Low	Very High	Fair	Poor	Fair	Good	Good	Poor
Epoxy Coal Tar	Coating	Very High	Very Low	Very High	No	Good	Poor	Good	Fair	Good
Chlorinated Rubber	Coating	Very High	Moderate	Very High	Yes	Good	Fair	Fair	Fair	Good
Acrylics	High Build Coating	Very High	Very Low	High	Fair	Good	Good	Poor	Poor	Good
Bituminous	Coating	High	High	High	Yes	Good	Good	Excellent	Excellent	Good
Polymer Modified Cementitious					Yes					
Non-Film Forming										
Silane Siloxane	Impregnation	Very Low	Very High	Very High	Yes	Good	Good	Very Good	Excellent	Good

Steel Structures

Steel is strong in both compression and tension. The durability of a steel structure depends on its ability to maintain serviceability in its exposed environmental conditions, primarily the resistance to corrosion of structural members and fasteners. Therefore, a steel structure exposed to a corrosive environment must be constructed to provide optimum long-term performance with a minimal level of maintenance intervention. Adequate durability requires either the use of self-protecting stainless or weathering steel or conventional carbon steel with protective coating to prevent corrosion.

Protective Coating for Steel Structures

The paint coating system should consist of a priming coat and at least one finishing coat.

- The priming coat should be an approved organic zinc-rich epoxy primer, applied to achieve a minimum dry film thickness (DFT) of 75 micrometres.
- For primers, no liquid constituents manufactured earlier than six months prior to the application should be used.
- The priming coat should be applied before discolouration occurs and on the same day as the surface preparation (abrasive blast cleaning).
- After the priming coat has been allowed to dry, it should be over-coated with a two-pack medium build epoxy micaceous iron oxide (MIO) finish
- For epoxy MIO coatings no material manufactured more than 12 months prior to application should be used on the steelwork;
- The finishing coat should be applied to a minimum dry film thickness of 200 micrometres. The total dry film thickness of the system should be 275 micrometres.

Timber Structures

Engineering properties of timber are dependent upon the type of wood and the cell wall orientation and the orientation of the applied load relative to the grain direction of the wood. Weather resistance and the elastic properties of wood differ significantly in different directions thereby classifying wood as an anisotropic material. The structure of timber is essentially a collection of longitudinally orientated cellulose cells, cemented together by lignin, a complex polymer compound that also strengthens the cell walls. Timber displays strong resistance to tension and compression along the cell direction.

Figure 72: Typical timber bridge (*RMS Clarence Town - Brig O'Johnston Bridge*)

BARK: Bark is the external layer of the wood that protects the trunk from fire and other damage and helps transport nutrients.

CAMBIUM: The thin layer, where new cells grow, is immediately inside to the bark.

SAPWOOD: This layer, generally from 10 to 50mm thick and adjacent to the cambium, constitutes the living portion of the trunk, where water and nutrient flow occurs between roots and leaves. Because it is rich in nutrients such as starch, the sapwood is very susceptible to fungal attack when it remains on structural timber.

HEARTWOOD - this is the inner region of the trunk and is composed of the dead cells remaining after the sapwood growth front has moved further out. These cells become filled with waste products that result in heartwood having a darker colour and greater durability than sapwood.

PITH - this is the centre of the heartwood zone.

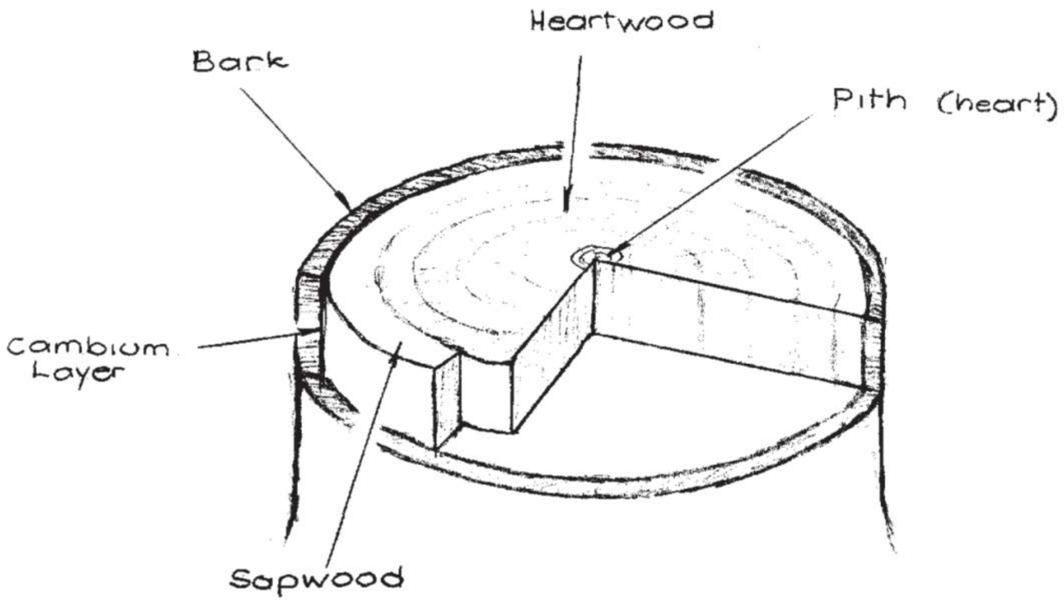

Figure 73: Section of a tree trunk (*Timber Bridge Manual - Queensland MainRoads*)

Preventative Actions of Timber Structures

Preservatives

Preservatives have been used extensively in the past with creosote being the main product used. It has been found that the inclusion of 10% tantalite oil in the CCA (hazard level 5) treatment has significantly benefited in reducing both the moisture intake and moisture loss of the timber. Thus stabilizes dimensional changes due to swelling and shrinking, especially for bridge decks with treated pine or Oregon pine.

Another treatment is Blue 7 mix fluorine, copper, and boron injection into angled holes drilled into the piles to intersect the core of the timber. Following injection, the mix diffuses into the timber slowly and protects against pipe rot. The holes are filled and plugged with retreatment approximately every 4 to 5 years.

A similar treatment is to use small rods of fluorine and boron mix (have the appearance of sticks of chalk) inserted into drilled holes in the presence of moisture. The mix diffuses into the rotted core and protects against further pipe rot. A treatment is usually undertaken every three to five years.

Preservative Protection Materials should be applied to the connections, connection holes, timber ends and possibly horizontal surfaces that are subject to moisture. This practice provides preservative protection for timber against decays associated with moisture. The end grain of deck planks and kerbings and any other element that could be subject to regular wetting should be treated with preservative and then sealed to stop the absorption of moisture.

All the piles and any other element that have direct contact with the ground should be treated internally near the ground line with a contact termiticide to intercept termites travelling down through the wood to collect moisture.

For timber that already has decay and vulnerable locations such as end grain, joints, and top surfaces, a diffusing preservative should be used.

Timber Selection for Repair

Bridge timber should be selected to satisfy minimum requirements including strength and durability outlined in relevant Australian New Zealand Standards. All replacement timber components for existing bridges should be of equal size, grade and durability class. Only hardwood should be used for repairing existing bridges. An F27 Hardwood, Group S2, and Durability Class 2 timber should be used for:

- Round timber girders (with minimum diameter 450 mm), Round timber pile, and Sawn cross girders and Beams (over 200 mm deep).

For Sawn decking (100 mm to 250 mm deep), F17 Hardwood, Group S2, Durability Class 2 should be used. For timber sheeting, pile bracing and kerbs, F11 Hardwood, Group S2, and Durability Class 2 should be used. For Timber truss components F17 Hardwood, Group S2, Durability Class 1 should be used. Australian Timber Design Standard Code (AS 1720) should be referred to for further information.

Masonry Structures

Masonry or stone is rarely used as a construction material for modern structures, except for facing or ornamentation. However, many structures in road networks were built using masonry and are still in service, owing to the general longevity of the material. Bridges, built from stone or masonry, are potentially solid and durable but rely on the original quarry material. Most deterioration can be attributed to weathering, migration of water, impact damage and foundation movements. Figure 73 illustrates common terminology used in relation to masonry bridges.

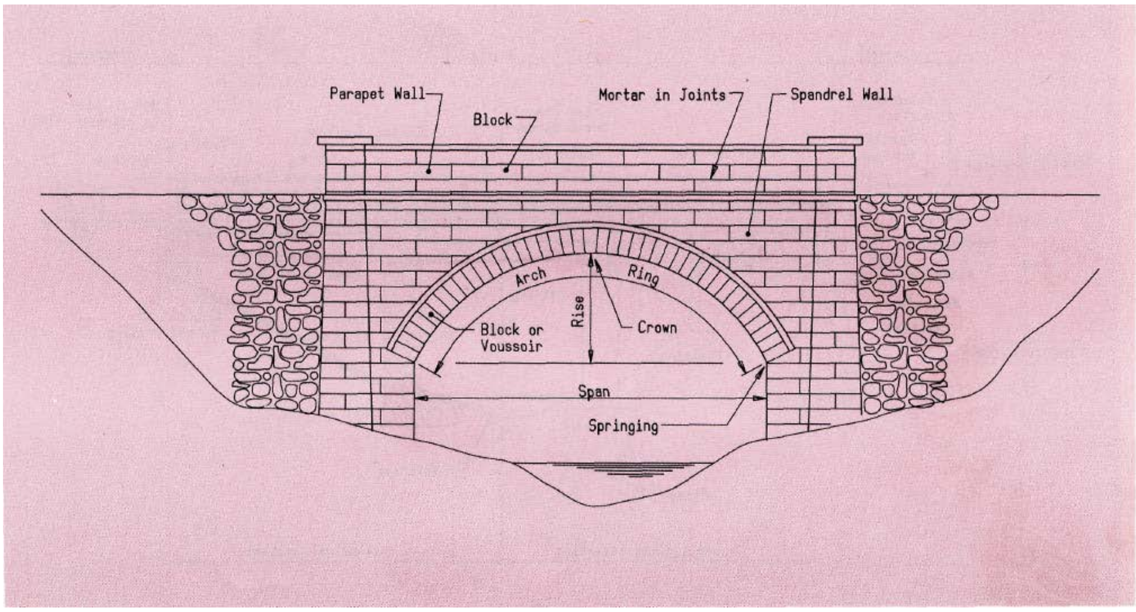

Figure 74: Special terminology for masonry bridges

Preventative Actions for Masonry Structures

Type and performance of material and structure

Many of the masonry arch bridges have been in service for hundreds of years without the need for significant repair or strengthening. Therefore, it is important to understand the performance of the material from which the bridge was built and the particular bridge form to ensure continued performance and serviceability while minimising unnecessary repair expenditure. Most of the early masonry bridges were built with stone units or a variety of bricks using lime (calcium carbonate) based mortar that can be damaged by strong cleaning materials (Figure 74). The volume of mortar per unit volume varies significantly based on the type of masonry, from, 0 in the case of some ancient arches which were built from perfectly fitted dressed stone, to 20% in the case of random rubble stones.

Also, it is vital to understand the complex structural behaviour of these bridges that were built without modern codes and the impact of changes in traffic loading.

Material Selection for Repairs

The traditional lime mortar was produced with lime: sand mix with a ratio of 1:3. The quality of this original material varies due to original limestone quality and any impurities in it or the kiln processing. Lime based mortar has advantages for maintaining old and weak masonry structures. Their relative flexibility and weakness, when set, allows them to deform plastically under load rather than cracking, imparting strength to the masonry. In contrast, cement-rich mortars have a much stronger crystalline structure but once fractured their strength is permanently lost.

However, cement rich mortar has frequently been used to undertake repairs to existing bridges that were originally constructed using the lime based mortar. This approach can result in damage to weak masonry units.

Figure 75: Porcupine Hill railway bridge (*PTV 2013*)

Consideration of the effectiveness of repairs and their likely influence on the long-term performance should be taken into consideration to minimise defects and deterioration. Particular attention is necessary when selecting stones for repairing existing bridges since the replacement stone can have significantly different properties and perform differently to the original stone. It is important to understand the original sources of stone or geological type of the stone or the properties of the bricks in selecting the repair units to ensure that they that will perform as required in an existing structure. Should the source not be available, selecting suitable matching units may require some expert advice and frequently entail consideration of a variety of alternatives. It is important to understand that the stone is natural material and may have a natural variability and may perform differently even it comes from the same source.