using coatings, such as white epoxy, that not only waterproof the railing, but also enhance its visibility by reflecting light. They also must be reapplied on a regular basis, according to the manufacturer's recommendation.

Figure 8.46: Application of Elastomeric Paint on Alkali-Silica Reactivity-Affected Barrier

Regular inspection for scaling, pop-outs and cracking should be performed. If scaling or pop- outs are found, the use of epoxies or methyl methacrylates should be used once the surface hasbeen well cleaned. Small cracks (less than 1/16 in) should be cleaned and sealed with epoxies orhigh molecular weight methacrylate, whereas larger cracks should be routed out and sealed with flexible caulk. These defects should be sealed as soon as possible to ensure that salt does not have an opportunity to corrode the rebar. If present on the structure, electrical conduits imbedded in concrete railings are exposed at the expansion joints. Slip joints in the conduit should be protected to prevent corrosion that may impair the function of the joint. Frequent inspection and maintenance of the protective coating is recommended.

In summary, preventative maintenance of concrete barriers includes:

1. Sealing the concrete
2. Inspecting for and repairing scaling, pop-outs and cracks as soon as possible.
3. Reapplying the sealant as needed.
4. Keeping the railing free of salt, dirt, and debris by regular cleaning.

8.15.2 Steel Maintenance

In Steel railing maintenance work following point has to be look for -

- Impact Damage
- Coating failure
- Corrosion
- Vegetation
- Loose Hardware

- Rail at or near expansion joints

Most steel railing is galvanized and maintenance is minimal. Small scratches in the galvanized surface present little or no problem as the zinc will corrode first, keeping the underlying steel rust-free. However, where large portions of the zinc coating have been damaged, such as gouges from snow plow blades or over width loads, it is important to repair or touch-up the damaged section. Areas of spot rust should be sanded, cleaned and recoated to maintain the finish. A zinc-rich coating will be required. A photographic example of a galvanized steel railingis presented in Figure 8.47.

Figure 8.47: Galvanized Steel Rail

Other areas of concern are where the steel is in contact with concrete or other metals. To prevent corrosion these areas should have an insulating material between the two in order to protect the steel.

A regular check of the fasteners is recommended. Any loose connections should be tightened. Finally, a regular cleaning, such as pressure washing, is recommended to keep connections free of debris. In summary, preventative maintenance of steel railing includes:

1. Touching up any minor damage with zinc-rich paint.
2. Inspecting and maintaining fastener tightness.
3. Ensuring a bond breaker is between the steel and any other material it contacts.
4. Keeping the railing free of salt, dirt, and debris by regular cleaning.

8.15.3 Aluminum Maintenance

Aluminum weathers to a dull grey appearance and is highly resistant to atmospheric corrosion. This finish provides good corrosion resistance and an almost unlimited life expectancy. However, pitting corrosion can occur on aluminum surfaces frequently in contact with a humid environment. Generally, this is only an aesthetic consequence. Accumulation of dirt and debris on surfaces can cause a reduced durability due to the extended exposure to moisture. Dirt and debris should be removed on a regular basis.

8.16 Repair and Rehabilitation of Railing Systems

Most states require that bridge railing with damage or deterioration that may prevent containment and/or redirection of errant vehicles traveling at the posted speed limit be replaced. Any replacement railing generally will be required to be upgraded to meet current standards. Often this means that the entire run of railing will be replaced.

The FHWA recommends giving consideration to the replacement of substandard bridge rails as part of any bridge rehabilitation, reconstruction, or replacement project. The addition of a continuous section of standard guardrail in front of and attached to the existing bridge railing is a very common manner of upgrading substandard bridge rail.

However, there may be limited instances where repair is acceptable. The remainder of this chapter will address some general repairs which may be taken prior to replacement.

Some critical actions that should be taken before the actual repair include:

- Upon notification of damage that leaves the railing nonfunctional, and if it cannot be repaired immediately, warn traffic of the hazard by putting out temporary warning
- devices in accordance with the Manual on Uniform Traffic Control Devices (MUTCD), such as drums, vertical panels, cones, or other devices.
- Contact your local Dig Safe utility protection well in advance of going to the site.
- Take enough signs and channelizing devices to the site to properly mark the repair zone. When your agency uses an arrow board and/or a shadow truck or Truck Mounted Attenuator, be certain there is enough equipment and personnel to handle these items.
- Set up the Temporary Traffic Control Plan for the work area to repair the railing in accordance with the MUTCD or your agency requirements.
- Ensure all workers wear equipment as provided by the Occupational Health and Safety (OHS) or local requirements, such as safety visibility vests, safety glasses, and protective-type shoes.
- Ensure all equipment and procedures conform to OHS guidance.

8.16.1 Concrete Repair

If there is minor delamination of the surface, typically caused by the corrosion of reinforcing steel, repairs can be made. In general, the process is to remove the unsound concrete; sawcut around the perimeter; and remove and patch with fast setting patch material. If there are thin areas (1-in or less), they can be patched with trowelable mortar. For widespread surface deterioration, typically caused by corrosion of the reinforcing steel and/or poor-quality concrete, the repair is more substantial. It may be possible to sawcut around the failed areas, perform a full-depth removal of the unsound areas, then recast in-kind.If the deterioration is significant, it may be more cost effective to replace entire railing.
If one or more sections of railing are broken, the procedure for concrete railing repair includes the following steps:

Concrete Rail Repair

1. Assuming that the rail will be replaced "in kind" which is a decision that should be made by

the engineer; the plans should be obtained for using constructing the new sections.

2. Mark of areas of rail to be replaced.
3. Sawcut to a depth of at least ¾ - 1 inch. Be careful not to cut through reinforcing steel.
4. Remove concrete in sections of rail to be replaced with a chipping hammer. Do not place chipping hammer on reinforcement.
5. Use sand blasting equipment to remove any rust from exposed reinforcing steel and to clean the exposed concrete surfaces. Touch up epoxy bars.
6. Replace any missing or corroded steel with new bars providing proper overlap lengths. Consult an engineer as needed. Overlap requirements may require a large area to be chipped out, or drill and epoxy anchor bars, or mechanically splice.
7. Form new sections to confirm to rail dimensions on plans.
8. Apply form release agent to forms.
9. Place concrete
10. Cure concrete for at least 72 hours
11. Finish surface with a rubbing stone to match existing rail and clean up the job site.

8.16.2 Steel Repair

Metal railing is fabricated in standard sections and most bridges are designed with one of the standard sections. It is a good idea to have an inventory of the common sections used in a state, with necessary hardware, for replacement needs. Repair and replacement of steel pipe and tubular railings should be made as follows:

Repair and Replacement of Steel Pipe and Tubular Railings

1. Collision damaged Still railings generally have to be replaced. Occasionally this type of railing can be straightened and repaired. When delays in receiving new or replacement parts are encountered, a temporary railing repair should be made to protect the public.
2. Loose anchor bolts and connections should be tightened. If corrosion is present, painting or galvanizing procedures should be followed.
3. Rust stains around the perimeter of steel rail post or anchor bolts imbedded in concrete indicate corrosion. Corroded areas should be thoroughly cleaned and painted. Railing components that have section loss should be repaired and replaced.
4. Hot-deep galvanizing is recommended for new, replacement, or existing railings. Zinc-rich paint may also be used. Painted railing will require frequent repainting when located in industrial or marine or salt laden environments. Care should be taken to touch up the protective coating after tightening the nuts on anchor bolts and other rail connections.
5. Damaged anchor bolts should be repaired or replaced as required.

8.16.3 Aluminum Repair

Aluminum railing damaged by collision should be replaced promptly. New railing sections are generally preferred because of the high degree of experience required in straightening or welding aluminum. Consideration should be given to replacement with "New Jersey" type concrete railing. Steps similar to steel repair can be taken. Do not attempt to straighten, hot dipgalvanize or use zinc-rich paint.

9.1 Preventive and Basic Maintenance of Concrete Super-structures

There are many different types of concrete superstructures, including:

- Concrete slabs (solid and voided slabs)
- Concrete frames, concrete arches
- Concrete Tee beams or T-beams (Bulb Tee, Double Tee, Quad Tee and Rib Tee)
- Prestressed concrete I-girders
- Prestressed concrete slabs and box beams/box girders (single, spread or multiple/adjacent)

Preventing concrete deterioration is much easier and more economical than repairing deteriorated concrete. This prevention begins in the design of the structure with the selectionof the proper materials, detailing, mixture proportions, concrete placement, and curing procedures. Even a well-designed concrete superstructure will generally require follow-up maintenance action. Below are some examples of design and construction considerations that improve or affect the durability of superstructures:

Precast prestressed structures

manufactured assembly line style in a large yard, the fast pace of girder production ignores some basic concepts of concrete preventivemaintenance such as concrete cover. The ends of prestressed concrete girders usually have exposed high strength steel strands which can quickly corrode. Some bridge owners require the strands to be exposed, cut and covered with mortar. Many do not require any modification. Figure 10.1 shows a precast beam in place seated on an abutment with potentially inadequate cover for strands. Although the figure shows exposed strands, this may not necessarily be a problem. For example, if the end of the girder is encased in concrete, as with an integral abutment, the strand ends are only exposed for a short period of time until the abutment is poured.

Figure 9.1: Exposed Strands on End of Precast Prestressed Concrete Girder

Precoating of girders

Applying surface protection to critical areas of the concrete girder such as its ends can extend the service life of the girder. Researchers in Wisconsinhave found the most effective way of preventing beam end corrosion was to apply a polymer resin coating to the beam ends before installing them in the field.

Drainage

design of drainage that will prohibit water from leaking onto the concrete; for example, extending drain pipes 6 inches beyond the lower face of the superstructure.

Precast box girders

This particular structure type can be problematic from a maintenance standpoint. Construction of precast prestressed concrete placed directly adjacent to one another can be troublesome to inspect and maintain. Maintenance issues for this type of superstructure include:

- Clogged drains leading to water in the voided cells of the box
- Shear key failure between adjacent box beams leading to overload and reflective cracking into the bridge deck
- Exposed strands on beam ends corroding quickly
- See topic for additional discussion on precast box girders

As an example of how details and specifications play such an important role in future bridge maintenance, there are many precast box girders that have been in service for 25 years thathave not experienced any of the problems noted above. Poured in place concrete decks over the box girders have eliminated the shear key failure issues, and recent construction specifications have called for exposed strands to be coated and covered. The primary types of maintenance for concrete are:

- Cleaning
- Surface protection
- Joint restoration
- Minor concrete repair

The approach to preventive maintenance for concrete superstructures varies from owner to owner. There are owners that clean and wash their bridges regularly, but many do not. Some bridge owners mandate a surface protection be applied to the concrete during initial construction, some never require it. However, it is generally recognized that a clean and protected concrete surface is beneficial.

In Providing maintenance to concrete superstructure, it is always to look out for a super structure that may be in distress. This could include:

- Over height Vehicular Impact Damage
- Large cracks greater than 1/8 inch in reinforced concrete
- Spall that exposed reinforcement

9.1.1 Cleaning

Cleaning of concrete superstructures is extremely important. Regular cleaning of thesuperstructure members is necessary to remove accumulation of sand, debris, bird droppings, and other harmful material by flushing with high-pressure water jet or compressed air, sweeping, or shoveling to remove build up. This is particularly critical in areas where there are likely to be chlorides in the debris or on surfaces, such as areas where salt is used for snow and ice control, and marine environments.

In addition to cleaning for concrete surfaces, ancillary elements such as drains should be cleared to allow proper drainage off the structure. An example of preventive maintenance as applied to drainage is the extension of vertical drain pipes to 6 inches beyond the lower flange of the concrete girder.

9.1.2 Concrete Super-structure Protection

Concrete super-structures are shielded from much of the traffic and weather by the bridge deck. The areas of concrete super-structures that can require protection are areas below deck joints, around deck drainage components, and on exterior girders. The noted super-structure concrete areas are exposed to spray or water flowing from the bridge deck and are thus susceptible to chloride exposure and the potential for freeze thaw damage. The most common treatment to protect the concrete from water and chlorides is to apply spray on waterproofing products. Waterproofing products fall into two general classes: pore blockers and hydrophobic (water repelling) products. Pore blockers typically used are epoxies and silanes or siloxanes. Epoxy materials are also popular to treat beam ends under joints.

While the entire super-structure can be coated with protection, the application is often directed to critical areas such as beam ends. An effective method of preventing beam end corrosion is to apply a polymer resin coating to beam ends before installing them in the field. Epoxy coating is the most commonly used polymer. An alternative treatment is to apply a penetrating sealer to the concrete end beams. Use of a Fiber Reinforced Polymer (FRP) wrap can be about equally effective, but is more costly and difficult to install than the polymer coating and is usually only used as a repair measure.

9.2 Spall and Crack Repair

Preventive and basic maintenance of concrete superstructures focuses on preventing the deterioration of reinforcing steel. Minor cracking, scaling and spalling can exacerbate the corrosion of rebar by allowing corrosive water and salt to infiltrate the concrete. Cracks or spalls large enough to affect the structural design or make the bridge unsafe for vehicular or pedestrian traffic will be covered in next Section Maintenance and Repair of Concrete Superstructures.

Minor cracking can often be repaired with sealants or by other penetrating materials such as silane, methacrylate, or epoxy. Flexible joint sealants, epoxies and cement grouts are the most common maintenance for routed cracks, which is a crack that is intentionally widened near the surface, while epoxy injection is also an option for cracks as narrow as 0.002 inches, as shown in Figure 9.2 and Figure 9.3.

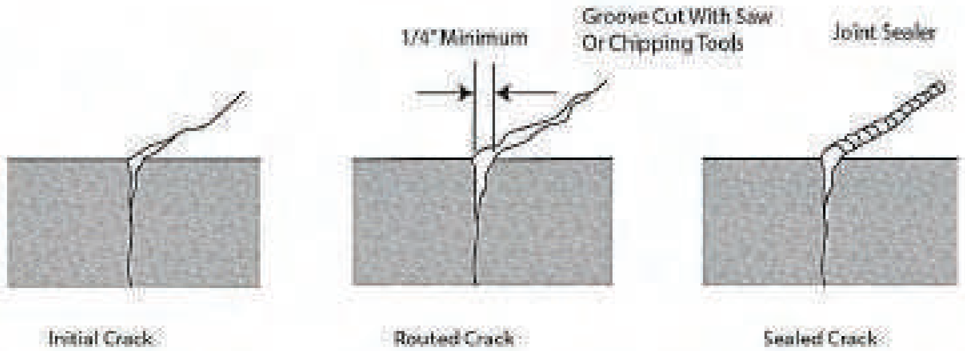


Figure 9.2: Conventional Procedure for Sealing Cracks

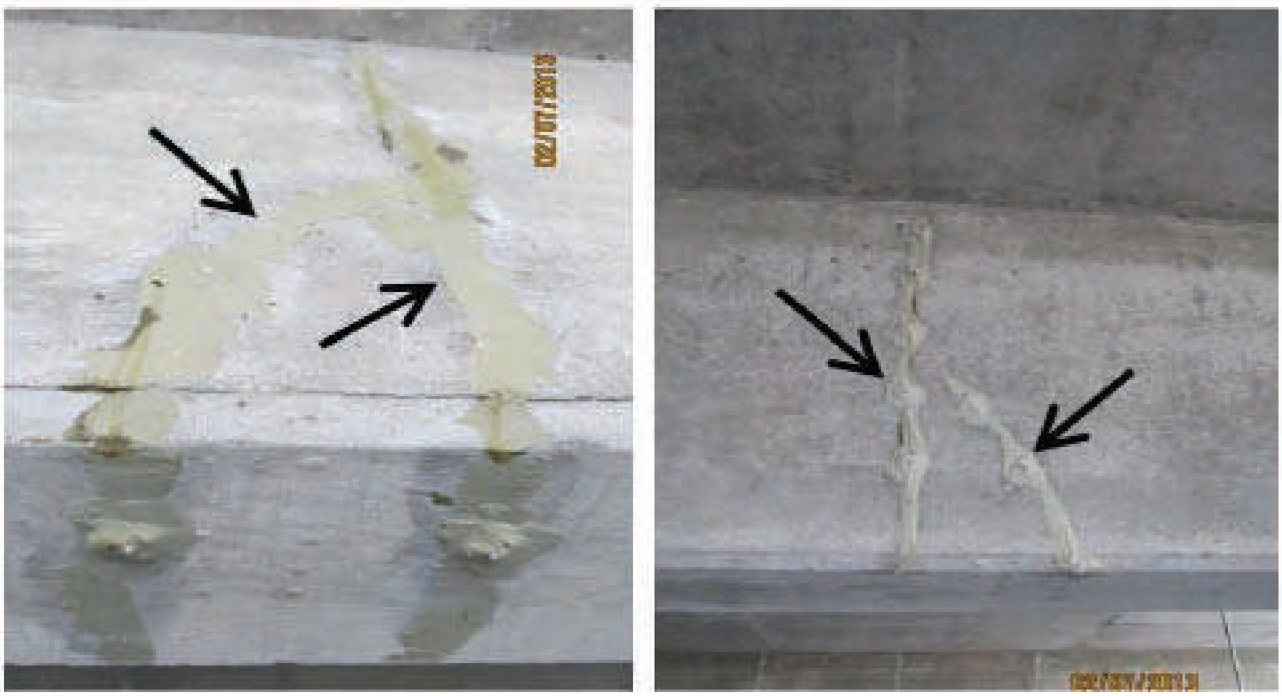


Figure 9.3: Epoxy Injected Cracks on a Superstructure

To prevent minor scaling and spalling from growing into a major repair, it is best to remove unsound concrete as soon as possible and replace with a concrete type material that willprotect the steel reinforcement while being structurally adequate. Options may include a simple mortar patch for small areas to use of shotcrete for larger areas. Deeper spalls and repairs requiring formwork and replacement concrete are discussed. In summary, preventive maintenance of concrete superstructures includes:

1. Keeping the concrete surfaces free of salt, dirt and debris by regular cleaning
2. Control and prevention of bird nesting and congregation which leads to deposits of corrosive waste
3. Inspecting for and repair of scaling, minor spalls, delaminations and cracks as soon as possible
4. Sealing the concrete to prevent chloride intrusion

9.3 Maintenance and Repair of Concrete Super-structures

In maintenance and repair work of concrete following point has to look for

- Spalls
- Cracking
- Efflorescence
- Licking water
- Soft, unsound or "punky" concrete
- Exposed reinforcing steel
- Section loss in reinforcing steel
- Exposed tensioning strands
- Damaged of broken tensioning strands

9.3.1 Concrete Super-structure Patching

Concrete super-structure elements can be repaired using a number of techniques. The selection among the repair methods is dictated by the depth and extent of the concrete deterioration or damage. Concrete superstructure repairs are often required because of corrosion of reinforcingsteel within the member, from traffic impact, or from freeze thaw damage. The repair of the concrete generally involves removing the deteriorated or damaged concrete and restoring the member with new concrete. Areas of concrete removal can be repaired in five different ways:

- Patching with trowel-applied or poured mortar
- Recasting with new concrete
- Prepacking dry aggregates and grouting
- Shotcrete
- Self-consolidating concrete

These methods of concrete removal are described in the following sections.

9.3.1.1 Patching

Patching small concrete spall areas with cementitious or resin mortars is the simplest of all concrete superstructure repair techniques. Concrete spalls between ½ and 2 inches deep canbe repaired by patching without the use of formwork. An example of patching a concrete superstructure is shown in Figure 9.4. Note that overhead shallow repairs should be avoided, particularly those that do not engage existing rebar or aren't mechanically anchored. Examples of these situations include areas over traffic, over parking, and over pedestrians.

Figure 9.4: Patching of Concrete Super-structure

Figure 9.6 shows the lower portion of a concrete superstructure ready for patching. The white blocks are cathodic protection elements. The wood forms are in place in Figure 9.6. The final repaired girder section with forms removed is shown in Figure 9.7.

Figure 9.5: Concrete Super-structure Ready for Patch

Figure 9.6: Concrete Super-structure with Wood Form

Figure 9.7: Completed Repair of Concrete Superstructure

Concrete Patch for Super-structure Members

1. Remove any loose concrete in the area to be patched.
2. Sawcut the perimeter of the removed concrete region in straight line to a depth of ¾ inch to make a clean patch line. If possible, bevel the sawcut at 45-degrees inward to lock the patch in place.
3. Clean the surface of the existing concrete using hand tools, sand blasting and compressed air.

4. Thoroughly wet the concrete surface and allow it to dry on the surface
5. Mix patch mortar in accordance with the manufacturer recommend specification for vertical or inverted patches
6. Apply a bonding agent to the existing surface, but note that all states do not require a bonding agent. Do not let the bonding agent dry before the patch materials is placed. (Follow the manufacturer instructions on bonding agent)
7. Use a trowel to firmly apply the patch material into the void created by the spall.
8. Use trowels to sculpt the member shape and texture the finish.
9. Spray applies a curing compound or wet cured for 7 days over the patched area, unless latex-modified concrete patch material is used.

The most permanent patch product for Portland cement concrete is Portland cement concrete. The closer the physical properties of the patch material are to the existing material, the better the patch will perform. Minimize the shrinkage of the patching material by limiting water to cement ratio when mixing. The inclusion of latex in a concrete or mortar will help reduce the amount of water required for workability and also reduce the permeability of the patch. Latex- modified or silica-fume concrete is recommended for vertical and inverted concrete patches due to their enhanced bond strength and cohesiveness. Other concrete additives can be used to reduce setting time and increase strength. For thin patches, the aggregate can be adjusted inthe mix design.

9.3.1.2 Recasting with Concrete

Larger concrete superstructure areas can be effectively repaired by replacing the damaged or deteriorated area. Recasting concrete requires formwork and is common for larger beam repairs. Examples of this repair are shown in Figure 9.8 (during) and Figure 9.9 (after).

Figure 9.8: Forming Repair. Pumping Concrete into the Form

Figure 9.9: Completed Form Repair

Suggested procedure are as follows:

Recasting

1. Consult an engineer to determine if there are any structural capacity concerns from removing unsound concrete to the depths and limits necessary for the repair. Place any requires temporary shoring or bracing necessary to support the structure during the repair.
2. Sawcut the perimeter edges straight to a depth of ¾ inch, remove any loose concrete in the area to be patched. Concrete should be removed 1 inch all around exposed rebar whenever possible.
3. The existing surface should be cleaned by light sand-blasting. The concrete surface should be saturated with water spray, if dry and then allowed to return to a surface dry condition. This will prevent the old concrete surface from absorbing the new concrete mix water.
4. Install the concrete formwork. The formwork should be rigid enough to prevent new concrete from sagging away from the existing concrete under the weight of new concrete. The formwork should withstand forces from concrete pumping and vibrating used to consolidate the concrete. Plywood is often used for concrete formwork. Steel forms can be used but they are heavy and not easily handled. Forms are typically attached to the member being repaired or hung from the structure and should be well constructed to prevent leakage of the patch concrete.
5. Prior to placing the concrete, the forms should be cleaned, sprayed with a form release agent and wetted to prevent absorption of the water used in the concrete.
6. Apply bonding agent (usually a cement grout) on to the concrete surface just before the installation of form work. It is very important that the bonding grout does not dry out before the repair concrete can be placed. A dry bonding grout can destroy bond of the new concrete to the existing concrete. For this reason, many owners do not allow bonding agent. The use of specially formulated polymer bonding agents may be required. If the form work can not be placed before the grout will dry.
7. Place the new concrete through holes in the top of the form work for vertical patches. If the top is not accessible. Inverted patches should be cast from above, if possible, through fill holes in the member. If inverted patches cannot be precast from above consider using the

shotcrete repair method. Concrete for recasting should easily flow and fill all the voids in the form. Typically, ⅜ inch coarse aggregates are used in the mix to improve flow and consolidation. Limit the water to cement ratio to avoid shrinkage cracking of the repair. Concrete additives may be use to provide workability without restoring to adding additional water.

8. Internally vibrate the newly placed concrete through the fill holes in the forms or by vibrating the forms from the outside. Vibration should be done along the length of the repair after shallow lifts of concrete have been placed. Good compaction is achieved by placing the concrete in small amounts and vibrating effectively as the work proceeds. An option to vibration is to use self-consolidating concrete which does not need any vibration.
9. Allow the concrete to cure.
10. Remove the form work and grind of any excess concrete or fill any voids that formed.

9.3.1.3 Prepacking Dry Aggregates and Grouting

This repair method is very similar to recasting. The surface preparation and formwork is basically the same as those for recasting concrete. The only difference is that a uniform size dry aggregate is packed in the space behind the form so that it fills the space completely. Grout is then pumped from the lowest to the highest point to fill the space between the aggregate, as shown in Figure 9.10. An advantage of prepacking dry aggregate and groutingis that the overall shrinkage of the repair is greatly reduced.

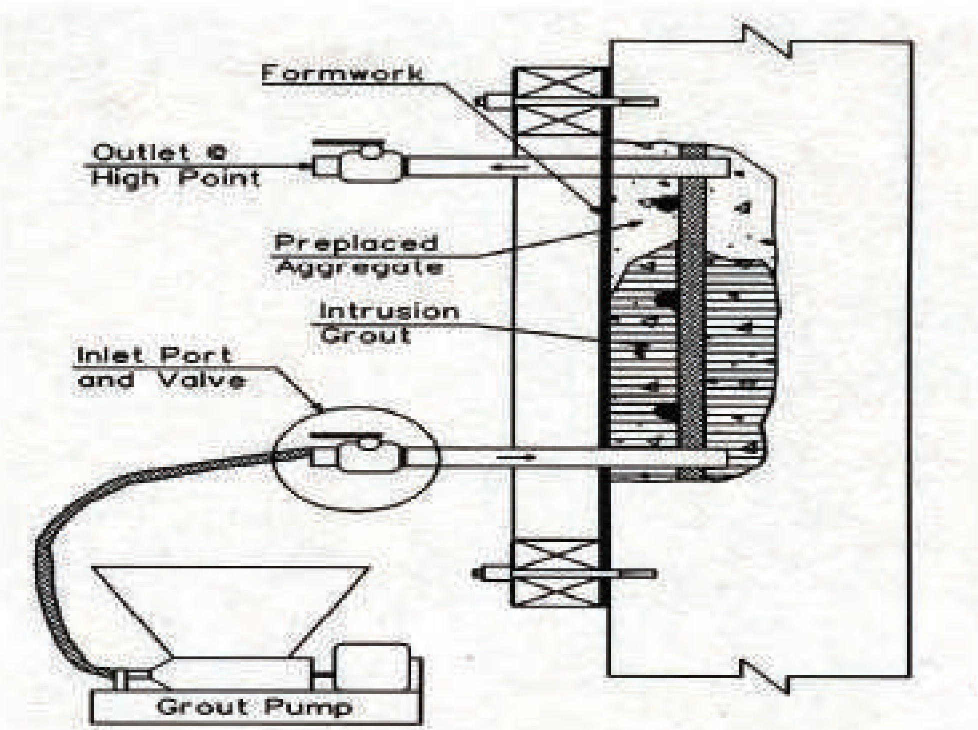


Figure 9.10: Repairing with Dry Aggregates and Grout

9.3.1.4 Shotcrete Repair Method

Shotcrete, or pneumatic applied mortar, is used to repair and restore the surface of concrete bridge elements. It is conveyed through a hose and nozzle and pneumatically projected at high velocity onto a surface. It contains the same cement, aggregate and water as concrete except that there are no coarse aggregates in the mix. Compaction is achieved by the velocity of the mixture when applied. Shotcrete repairs require a highly trained operator to obtain long lasting results. Many bridge owners require submission of operator qualifications and test panels prior to starting work. The mix has high cement content and low water/cement ratio. The addition of silica fume, fly ash and/or slag can enhance the performance of shotcrete. Steel or synthetic fibers have also been used to increase tensile strength and decrease the potential for cracking. When properly applied, the mortar is dense, durable, and has superior bonding characteristics.

Shotcrete is desirable on vertical and overhead patches because no forming is required and the pneumatically applied mortar can repair large surface areas in relatively short periods of time. The shotcrete may need to be anchored to the existing reinforcement with additional rebar, wire mesh or mechanical anchors. Shotcrete should not be used for repairs of less than 1 inch thick. A photographic example of shotcrete repair is shown in Figure 9.11, and a procedure for shotcrete repair follows.

Figure 9.11: Shotcrete Application

Shotcrete Repair

1. Preparation of the existing surface is an Important part of the repair. The edges of the repair area should be saw cut at least ¾ inch deep at a 45-degree angle into the repair area to prevent rebound of the shotcrete material. All deteriorated concrete should be removed to a minimum of 1 inch behind exposed reinforcement. All surfaces should be cleaned with high pressure water or by sand blasting.
2. For repairs 3 inches or deeper, welded wire fabric or wire mesh should be mechanically affixed to the existing concrete surface prior to the placement of the shotcrete. The wire mesh will help ensure the integrity of the repaired and limit cracking.
3. The existing surface is wetted. So, it will not absorb water from the pneumatic mortar.
4. Apply the shotcrete. A thin bond coat should be applied first with subsequent layers building up the desired thickness. When applying, place the shotcrete nozzle at 90-degree angles to

the repair surface whenever possible. Corners should be applied at a 45-degree angle to prevent rebound. Maintain a uniform flow of material and limit the layer thickness to prevent sags sloughing to occur. The natural hand gun finish is preferred for bond and durability standpoints. Scraping or cutting may be used to remove high points and materials that has exceeded the limits of the repair after the mortar has become still enough to withstand the pull of the cutting device Trowelling or other surface finishing is discouraged as it has a tendency to disturb the bond.

5. Curing is very important for the rich mixes and thin sections with pneumatic mortar. Seven days of water curing is generally advisable to promote good hydration of the cement, keep the mortar cool in hot weather, and prevent early shrinkage that may disturb the bond.

9.3.1.5 Epoxy Injection Crack Repair

Cracks that develop in concrete superstructure elements can be effectively repaired usingepoxy injection techniques. Epoxy injection techniques are well suited for cracks caused by a variety of stresses, but not cracks caused by corrosion of reinforcing steel. Epoxy repairs are typically recommended for crack widths of 0.002 inches or wider. An example of a completed repair is shown in Figure 9.12.

Figure 9.12: Completed Epoxy Crack Repair

9.3.1.6 Beam End Repair Procedure

Reinforced concrete beam ends can experience cracking and spalling near the bearings from leaking joints that cause corrosion, freeze thaw damage, or from thermal forces that develop when the bearings do not allow adequate movement. An example of beam end deterioration is shown in Figure 9.13.

Figure 9.13: Beam End Deterioration

A procedure for reinforced beam end repair follows below. It can also be applied to prestressed beams, as long as an engineer is consulted.

Reinforced Concrete Beam End Repair

1. Restrict the vehicle loads on the affected beam by directing traffic to the far side of the bridge until repairs on the beam end are complete.
2. Determine if the existing substructure can be used to jack the bridge up or if a jacking bent will need to be constructed. The jacking supports and jacking procedure should be reviewed by an engineer before any lifting begins.
3. Place jacks and raise the entire end of the bridge a quarter of an inch (figure 9.14). The lift should only be enough to take the load off and to allow a piece of sheet metal to be inserted in the beam seat as a bond breaker for the new concrete. Check with engineer if this step is necessary.
4. Sawcut the concrete edges in a stepped fashion to avoid feathered edeges and to provide bearing surfaces for the new concrete (see details in figure 9.14).
5. Remove the detrirated concrete in steps.
6. Epoxy inject any visible cracks not within the removal limits following the epoxy injection procedure in this section.
7. Place new reinforcement as needed, making sure it is properly lapped anchored, or mechanically attached to the existing steel. Bars can be welded to the existing longitudinal bars as shown in figure 9.15.
8. Clean reoair using abrasive blast cleaning.
9. Apply epoxy bonding agent to prepare the surfaces of the beam end. If agency does not allow a bonding agent, bring surface to saturated surface dry condition.
10. Place the forms for the new concrete. Place the new concrete. A non-shrink additive should be used in the new concrete.

11. After the concrete has reached sufficient strength, jack all beams simultaneously to sufficient height to allow the new bearings to be placed or to reinstall the old bearings.
12. Uniformly lower the end of the bridge check for possible distress in the repaired area.
13. Remove the jacking system.

Figure 9.14: Beam End Repair Preparation

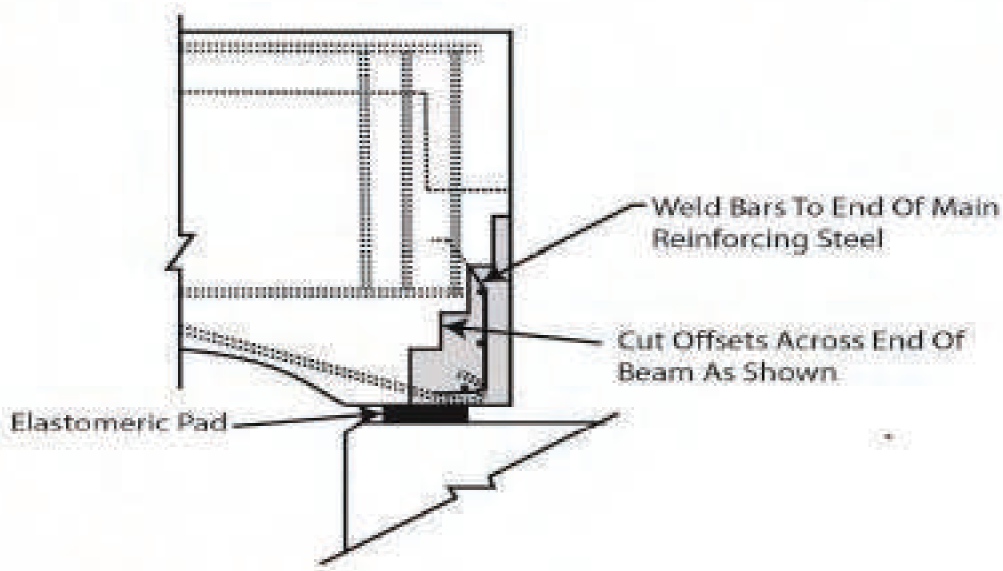


Figure 9.15: Detail of Repaired Beam End

9.3.1.7 Fiber Reinforced Polymer Repair

The flexural and shear strength of concrete superstructure members can be increased or restored by applying externally bonded fiber reinforced polymer (FRP) strips that supplement the tensile steel within the member. An example of this procedure is shown in Figure 9.16. This repair method can be highly effective in restoring strength in beams, stringers and floor beams that have lost strength due to cracking or loss of reinforcing steel caused by impact or deterioration. It has been successfully used as a preventive maintenance application for the beam ends of precast prestressed concrete girders.

The FRP strips are typically bonded to the bottom of beams in areas of high tension or the sides of beam webs in high shear areas. An engineer should determine the location, number and width of FRP strips to be placed. Once the number and placement of the FRP layers has been determined, the FRP can be applied. A suggested procedure for FRP application follows:

FRP Application

1. Remove any unsound concrete that is within the area the FRP is to be applied.
2. Cracks wider than 0.010 inches wide should be filled with epoxy resin following the epoxy injection procedure in this section.
3. The concrete surface should be throughly cleaned using abrasive hand tools or blast equipment. The surface should be blown clean with comprssed air.
4. The FRP should be cut to the size with heavy shares as specified by the engineer and in accordance with manufacturer's recommmendations.
5. Prime the clean and dry concrete surface with epoxy resin using a trowel the primed area should exceed the FRP size by epproximately one-half inch on all sidees. Allow the epoxy to become tacky.
6. Prime the surface of the FRP to be placed on the concrete.
7. Place the FRP strips on the primed concrete such that the epoxy primed sides stick together epoxy to epoxy (figure 9.16).
8. Use a rubber roller to press the FRP flat and smooth on the concrete.
9. Allow the epoxy resin to fully cure.

Figure 9.16: Applying FRP to Strengthen a Beam

9.4 Repairing Deteriorated or Damaged Reinforcing Steel

Concrete superstructure elements are typically reinforced with conventional reinforcement (rebar) or prestressing strands. The reinforcement can sustain section loss due to corrosion or can be damaged from vehicular impact. The repair techniques used to restore the reinforcing varies depending on whether the steel is stressed or not.

Conventional Rebar

When performing concrete repairs, it is important to protect the existing steel reinforcement. Incorporating the existing reinforcement into the new repair material will lengthen the service life of the repair. Steps to incorporating the existing reinforcement include:

- Locate existing reinforcing steel
- Remove unsound concrete from around reinforcing steel
- Assess damage to existing steel
- Clean
- Incorporate into repair

Locating the existing reinforcing steel is very important. If the concrete removal is started without knowing the depth of concrete cover over the steel, damage to the steel could result. There are non-destructive testing methods, such as using a pachometer, that determine cover depth.

Unsound concrete should be totally removed from the perimeter of the existing reinforcing. Concrete needs to properly bond to the reinforcing steel to resist forces. If more than one half of the diameter of the bar is exposed, the entire bar should be exposed including the underside. The underside removal could be determined based on the size of the aggregate of the repair concrete, but usually a 1-inch clear cover is needed. Concrete removal or existing corrosion may reduce the cross-sectional area of the reinforcing bar to a point where it should be totally removed and replaced. That can be determined with the aid of an engineer.

Reinforcement bar cleaning is essential for concrete bond. This includes removal of rust and chlorides from the steel to inhibit future corrosion. Ways to accomplish this for bridge superstructures include wire brushing or sand blasting. Once bars are cleaned they can be incorporated into the new repair. If supplemental reinforcement is needed to replace damaged or deteriorated bars, the new bars should be connected to existing reinforcement with proper lap lengths or mechanical connections. A lap length means the new reinforcement is placed side by side with the existing for a predetermined length decided by the bar size. Most agency specifications provide these lengths. If the patch is not large enough for a full lap length, mechanical bar splices can be used.

Prestressed Strand Splicing

Girders with significant deterioration or damage from truck impacts have been successfully repaired using the spliced strand technique. The area requiring a strand splice must be away from bearing areas and strand hold-down points. The strand to be spliced must be anchored beyond the repair area so that the re-stressing force can be attained. The length for anchorage needs to be confirmed by the engineer and is called the strand development length. The equipment for splicing strands will not easily accommodate abrupt changes in strand profile limiting the use of this technique to areas where the strands are relatively straight. The strands in prestressed concrete members have been tensioned, effectively squeezing the concrete and placing it in compression. The tendons place sufficient compression in the concrete to prevent the section from going into tension when the bridge is loaded.

Cracks in prestressed concrete and corrosion of the strands are concerns. Since the tension is high in the tendons, the loss of a significant amount of concrete can cause the remainder of the section to crush and fail. A single tendon break due to an impact or corrosion will typically only cause a minor effect, however several tendons snapping may cause a sudden failure of the member.

Special sequenced steps are needed when repairing prestressed concrete members to restore the tension that existed in the strand originally. These steps are normally determined by a structural engineer. Tension must be placed back into broken tendons as part of the repair using tendon splices. They are anchored to the ends of the damaged tendon and a threaded coupler nut between the two anchors is torqued a prescribed amount to produce the tension needed in the tendon. It is desirable to maintain the original girder cross-section to maintain headroom below and for girder appearance. The splice hardware has a much larger diameter than the strand, reducing concrete cover and increasing congestion in the repair area. It may be necessary to offset splices to reduce congestion and facilitate concrete placement. Splices generally reduce the fatigue life of the strand and the member. Often times only the slack needs to be removed from repaired broken strands, for example when only a few strands are broken due to an overweight load.

Details showing the removal and installation sequence are presented in Figure 9.18 through Figure 9.21. A prestressed strand splice procedure follows:

Prestressed Strand Splice

1. Consult an engineer to determine if there are any structural capacity concerns from removing unsound concrete to the depths and limits necessary for the repair. Place any required temporary shoring or bracing necessary to support the structure during the repair.
2. Sawcut the perimeter edges straight to a depth of ¾ inch. Remove any loose concrete in the area to be repaired. Concrete should be removed one inch all around exposed rebar whenever possible. The minimum length of concrete removal necessary in order to install all the strand splicing and tensioning devices is approximately six feet. (See figure 9.18)
3. Saw cut the brocken strand to remove any frayed or damaged length. Leave at least four inches of strand exposed to install the splice devices.
4. Install splice hardware consisting of coupler, stressing gauge and tensioning device (see figure 9.19 and figure 9.20). The arrangement these devices may be changed, if it is more convenient.
5. Torque the splice hardware to tension the strand.
6. If a significant amount of concrete is replaced, the compression must be removed from the concrete in the beam around the damaged area. This is done by placing a calibrated load on the bridge while the new concrete is place and is reaching its design strength. This step is known as preloading the member.
7. Preload member and replace the concrete using one of the techniques outlined in this section.

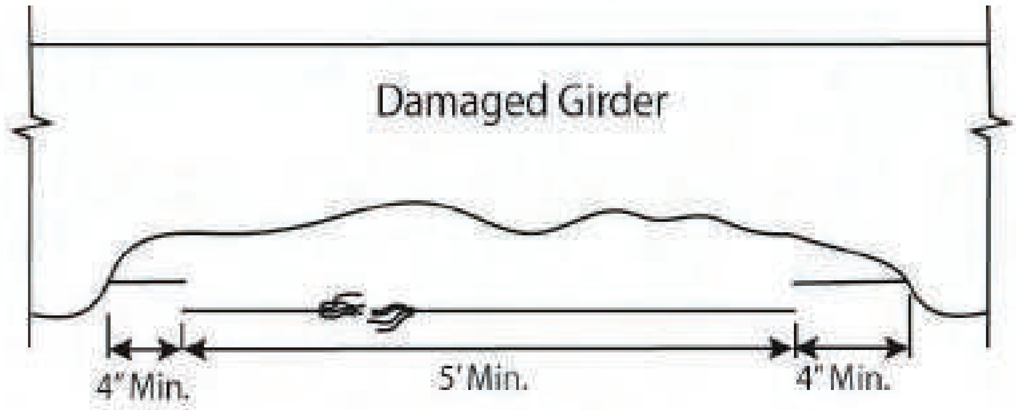


Figure 9.17: Remove Damaged Strand Length

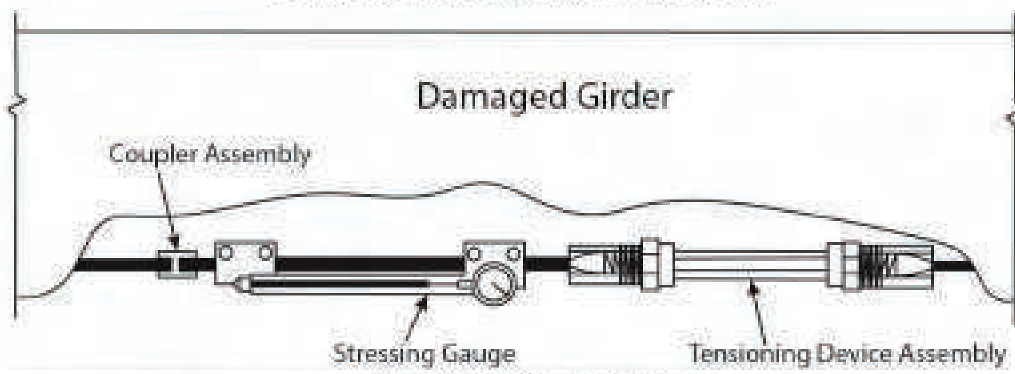


Figure 9.18: Splice Hardware

Figure 9.19: Tensioning the Splice

Figure 9.20: Completed Splice Ready for Concrete

An alternative to manually tensioning the splice is utilization of a coupling system. An example of a prestressed girder repair utilizing a coupling system is shown in Figure 9.21.

Figure 9.21: Completed Strand Coupling System in Prestressed Girder Repair

9.5 Maintenance and Repair of Adjacent Prestressed Box Beams

Prestress concrete adjacent box beams are a popular superstructure type. The beams are placed directly next to each other and may be connected with poured keyways and possibly transverse tie rods also referred to as post-tensioning. They may be constructed with or without a reinforced concrete deck cast-in-place over the beams. These beams can have issues with premature deterioration due to cracking and other maintenance issues depending on the construction details.

According to research, the predominant distress observed in these bridges is reflective cracking of the slab along the shear keys between beams and the associated degradation below the cracks. Some potential preventive maintenance options for adjacent box beam bridges include:

- Sealing the deck
- Removing the asphalt topping
- Sealing the cracks
- Washing the decks on an annual basis
- Unclog drains

Some potential repair options include

- Add a reinforced concrete deck
- Add supplemental transverse tie rods (post-tensioning)
- Replace the asphalt wearing surface with a concrete deck
- Use waterproofing membrane over the entire surface and reseal the deck

Note that these preventive maintenance or repair options are dependent upon whether the existing bridge had a poured concrete deck or not.

9.6 Preventive and Basic Maintenance of Steel Super-structures

Preventive maintenance of steel superstructures consists mainly of measures to clean to steel and protect the steel from corrosion. The preservation of steel involves protection from exposure to electrolytes, such as water or soil. When deicing salt is added to the electrolyte, there is a dramatic increase in the rate of corrosion of the structural steel.

Common protective coatings for steel superstructures are weathering steel, galvanizing, metalizing, and paint. Weathering steel is a type of steel that forms its own protective coating and theoretically does not need painting. However, there have been cases of poor performance of bridges constructed with this type of steel. Therefore, members constructed from weathering steel should be monitored for excessive corrosion and be painted if necessary. Typical painting requirements are based on whether the steel is new or is to be repainted. When performing maintenance on steel superstructure it is always good to see if anything does not look right. This includes:

- Impact damage to steel fascia girders. Generally, the girder being twisted and bent from impact.
- Severe corrosion and section loss
- Bent cross frame members indicating movement and buckling

9.6.1 Painting

Painting of steel superstructures should be performed on a regular basis with the repainting schedules based on the type of coating used, the environment, and the rate of coating deterioration. This routine maintenance prevents corrosion and section loss of the steel members. Painting operations require properly designed and approved containment systems. An example of a painting containment system is shown in Figure 9.22.

Figure 9.22: Painting Project with Approved Containment System

Less costly painting operations include:

Spot Painting

Painting of localized areas on the steel superstructures that have lost their protective coating or areas of rust and corrosion. Once steel members begin to corrode, they begin to lose strength due to material loss. It is important that areas of spot rust be touched up routinely. The loose rust must always be removed before the touch up. Importantly, if the corrosion is due to exposure from a leaking drain or joint, maintenance or repair of the source defect must be coordinated with the spot painting. It is also critical to follow the coating manufacturer's recommendations for applying the coatings (temperature, humidity, and application method) to maximize the life of the coating.

End of Beam Painting

Many agencies recommend painting / repainting superstructure steel within a distance of 1.5 times the depth of the girders from the bridge joints for extra protection. If aesthetics is a concern, the exposed areas of the fascia girders are painted for the entire girder length.

9.6.2 Weld Peening

Most modern structures use welding to connect steel plates. For the weld to be successful, the adjoining plates are brought up to a molten state as the weld material is added. Once everything cools down, there are built up stresses in the weld, as the weld material tends to shrink. This locked in tension stress is one of the reasons welds can crack. A unique idea is to apply a compressive force to the weld after the bridge is erected to counteract the tension. Imagine a hammer hitting the weld to compress it thereby relieving these built in stresses. That is the basic concept of peening.

9.7 Repair and Rehabilitation of Steel Super-structures

Modern steel bridges typically require fewer steel superstructure repairs than older structures due to their shorter time in service; use of modern corrosion resistant steels with improved toughness;

utilization of continuous superstructures with fewer deck joints or jointless bridges; absence of fatigue prone details and proper design to resist fatigue, "maintenance free" or low maintenance design and detailing of built-up members; adequate vertical and horizontal clearances reducing a potential for vehicle impact damage. Hence, the majority of the steel superstructure repairs are performed on older bridges due to the following reasons:

- Many multi-span bridges have simple span superstructures with a large number of leaking deck joints
- Failure of the aging steel coating system
- Inadequate bridge drainage infrastructure – free drop spraying or clogged old downspout system
- Stress related fatigue in superstructures designed prior to 1974 and distortion induced fatigue in superstructures designed prior to early 1980's
- Many bridges are functionally obsolete due to low vertical under clearance and are susceptible to under passing vehicle impact damage, as well as narrow horizontal clearances on some through trusses, which can also lead to impact damage Corrosion occurs from roadway and high-water debris collection on superstructuremembers, truss joints, beam seats, and around truss member penetrations through decks or sidewalks Steel superstructure repair usually involves some type of welding and/or bolting.

9.7.1 Corrosion and Section Loss

Section loss from corrosion is a common type of a steel superstructure damage that routinely requires maintenance repair. It often occurs at the girder ends under leaking deck joints and at the "pockets" of buil- up member connections, bottom flanges, and framing members that act as a shelf and trap debris.

9.7.2 Corrosion Damage at Girder Ends and Example Repair Procedure

Joint leaks over girder and stringer ends subject those areas to repeated moisture which degrades the steel coating and leads to corrosion and section loss. It typically affects the lower portion of girder ends, bearing stiffeners, and end diaphragms. See Figure 9.23 below for an example of girder end corrosion damage before (left) and after (right) sandblasting and primer application. After removing the corrosion product by sandblasting and priming, repairs can be performed.

Figure 9.23: Corrosion Damage at Girder Ends (Concrete Deck has been Removed)

A typical girder repair procedure is presented below:

Girder Repair

1. Remove the paint within the limits of repair
2. Disconnect and remove existing end diaphragm(s) as required
3. Remove girder bottom flange to bearing welds by grinding
4. Jack the stringer 1/16 inch maximum and installed temporary blocking
5. Remove deteriorated portion of the stringer to the required limits.
6. Cut a tee or full section from a matching W section.
7. Weld or bolt new tee section to replace the remove damaged portion of the stringer end or splice new full section using bolted splice connection. The choice of bolting or welding could be based on owners requirements and environmental factors.
8. If bearing stiffeners were removed as part of the process, as shown in Figure 9.25, the engineer should be consulted to address how to replace them, if replacement is needed.
9. Perform NDT (UT) testing and repair all weld flaws as required.
10. Re-Jack, remove blocking and lower the stringer onto the existing bearing
11. Field drill holes in the repaired stringer web and re-connect the existing or replacement and diaphragms using high strength bolts.
12. Re-weld the girder bottom flange to the bearing sole plate.
13. Clean and paint all steel surfaces disturbed the repair.

See Figure 9.24 and Figure 9.25 for representative examples of the above repairs.

Figure 9.24: Example of a Girder End Repair Utilizing Bolted Splice of a New Full Section

Figure 9.25: Repair in Progress using Tee – Section Cut Out Form a Matching W Section

9.7.3 Repair of Built-Up Members

Many older bridges have built up I-shaped steel girders, floor beams, and other members that are typically comprised of plates and angles riveted together. An example drawing of a built up I-shaped steel girder is presented in Figure 9.26. This type of girder often traps debris betweenthe rivets, stiffeners and on the top of beam flanges. The moisture and debris can come from leaking joints, inadequate scuppers, spray from vehicles, or bird droppings. The moisture and debris can lead to a failure of the protective coating, corrosion and ultimately section loss as shown in Figure 9.26.

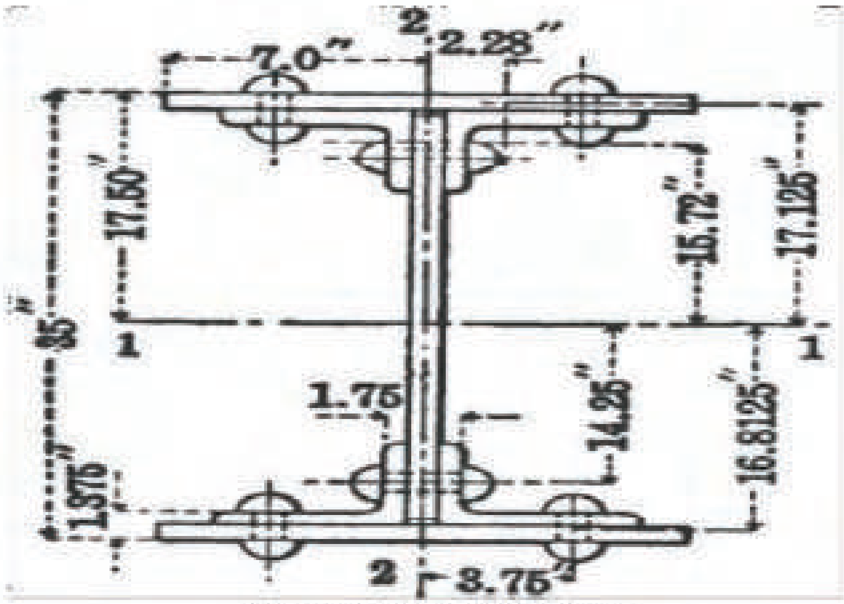


Figure 9.26: Typical Built-Up I Shape

Figure 9.27: Example of Heavy Corrosion and Section Loss

Highway overpass superstructures are particularly prone to moisture and debris accumulation carried by vehicle spray. While built up riveted members may be less forgiving, rolled members are also subject to corrosion from the same processes.

In cases where the section loss is minor and not significantly decreasing the capacity of the member, sand blasting and painting the area to arrest continued corrosion and section loss is often the chosen repair. In cases where section loss is significant and adversely affects thegirder capacity, additional cover plates or angles may be added to restore the section as shown in Figure 9.27. To assure the repair will restore the member to the desired capacity, it should be designed and detailed by an Engineer.

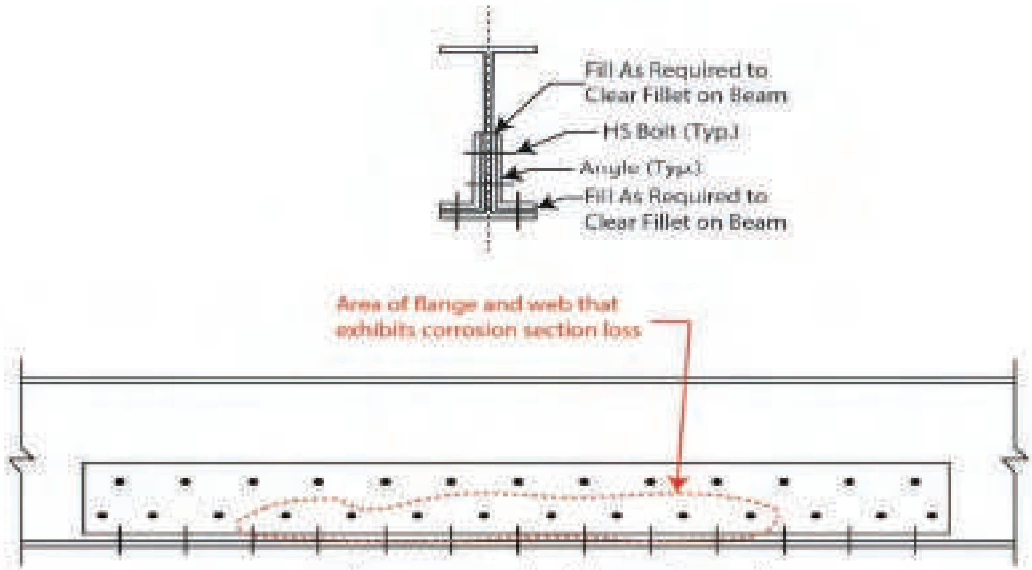


Figure 9.28: Sample Girder Repair Detail

The photographs in Figure 9.29. show a girder repair made by the OBPA MaintenancePersonnel (courtesy of the Ogdensburg Bridge and Port Authority (OBPA)).

Figure 9.29: Girder Repair. Before (left) and After (right).

Crevice Corrosion

Crevice corrosion between the cover plates and other elements of built-up members (particularly riveted members) is not uncommon. It often causes plate distortion and buckling, and sometimes even leads to rivet failure. Examples of crevice corrosion are shown in Figure 9.30, which are built up box members without top plate (left) and with top plate (right).

Figure 9.30: Built Up Box Member Corrosion

In most cases, plate replacement is required. Sometimes if the distortion is relatively minor, a power tool cleaning using a needle scaler and/or wire brush, followed by sealing and painting will slow the progression of corrosion. This type of repair is not permanent, so continued monitoring and maintenance will be necessary.

9.7.4 Repair of Truss Members

Primary Compression and Tension Truss Members

The repair of primary compression and tension truss members can be complex. It may require special access and substantial bracing. It should be properly designed by an engineer and performed by experienced agency staff, or a qualified contractor. See Figure 9.31 for replacement of truss bottom chord plate utilizing high strength thread bars and jacks for the load transfer and stability.

Figure 9.31: Repair of Bottom Chord Plate (left) Utilizing Thread Bars and Jacks (right)

Secondary Members

The repair and replacement of secondary members such as bracing is typically less complexthan that of primary members, but still requires a detailed procedure and adequate bracing to provide for overall stability of the truss during repairs. See Figure 9.32. for an example of secondary member replacement.

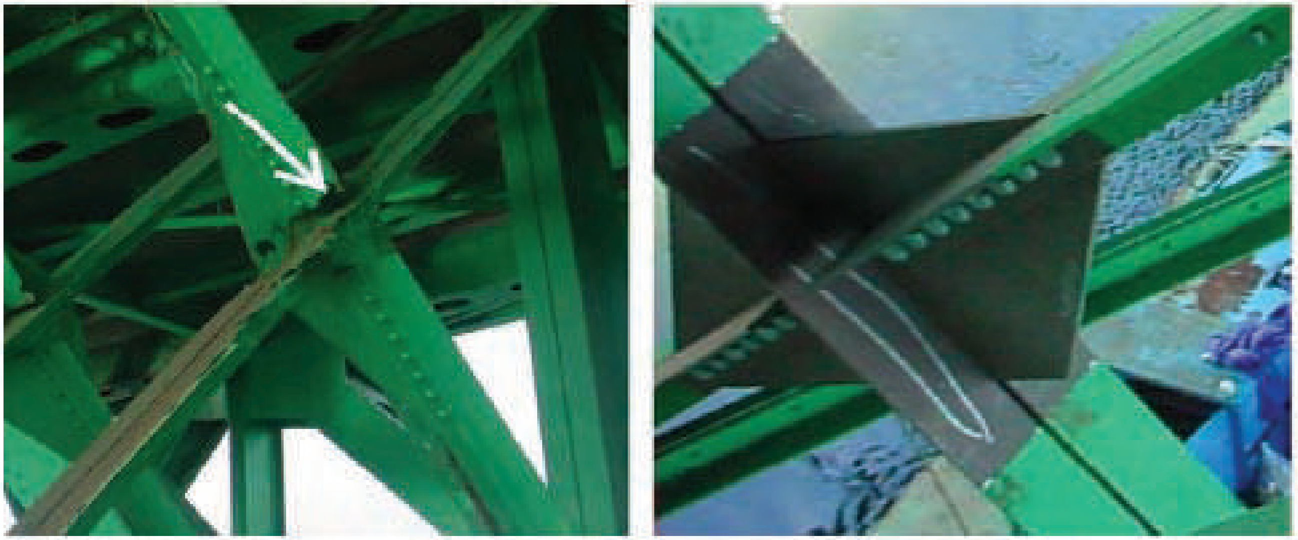


Figure 9.32: Replacement of Bracing and Connection Plate. Before (left) and After (right)

Lacing Bars and Batten Plates

Lacing bars and batten plates were commonly used in older riveted structures for the webs of I-shaped built-up members or the sides of box sections. Batten plates can be used in combinationwith the lacing bars and may be located at ends of built-up members. They can have a rectangular or U-shape to accommodate connections to other members.

Deteriorated or otherwise damaged lacing bars and batten plates can typically be safely removed and replaced in kind one at a time. See Figure 9.33 for an example of a batten plate replacement detail.

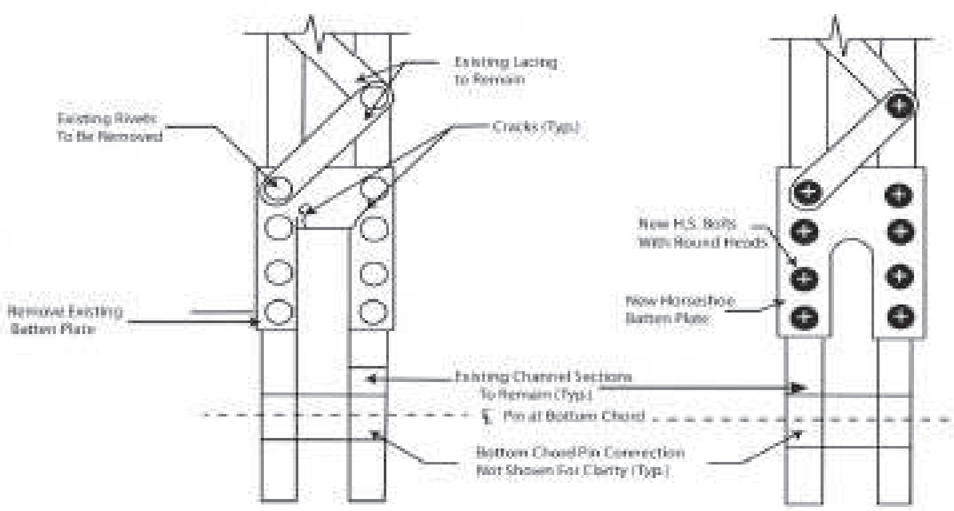


Figure 9.33: Batten Plate Replacement Detail

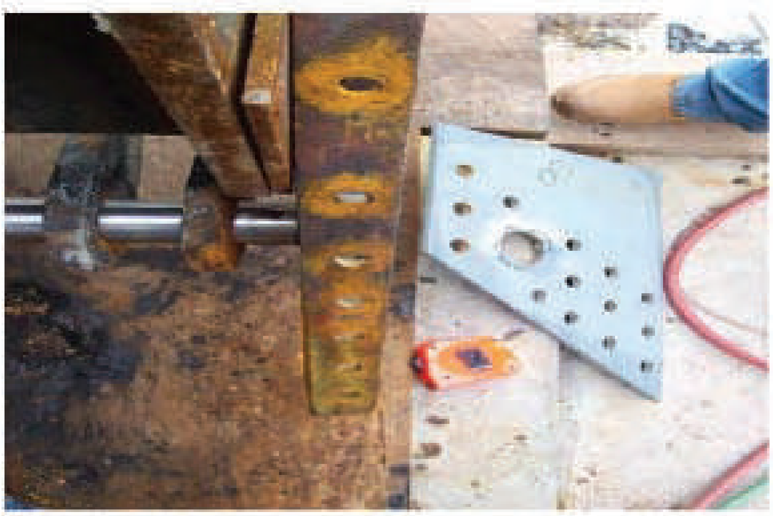
Repair of Truss Member Ends

Repair to the ends of steel truss members is a very common repair since these members are in close contact with salt and other contaminants on the bridge deck surface and because debris and moisture collect in congested end sections. This repair requires a sequence of events to properly remove, replace, and/or repair members.

After temporarily supporting the connection, deteriorated members such as the pin, eye bars and gusset plates are removed, an example of which is shown in Figure 9.34. More specifically,Figure 150 shows

(a) Pin and gusset plate replacement required due to severe corrosion and
(b) New pin installed and gusset plate ready for installation.

(a)



(b)

Figure 9.34: Corroded Truss Member End Repair

In the replacement shown in Figure 9.34, pin and gusset plate are added. The eyebars werenot replaced, but removed, repaired, and repainted.

(a)

(b)

Figure 9.35: Representative Corroded Truss Member End

In a third truss member end repair example shown in Figure 9.36, before and after photos ofthe eyebars and entire repair are shown. Specifically shown are (a) Corroded pin and eye bars, (b) Installation of new pin, eyebars cleaned and repainted (c) The repaired assembly is painted, (d) Representative location of repair (shown by arrow).

(a)

(b)

(c)

(d)

Figure 9.36: Truss Member End Repair

Repair of Primary Truss Members near Bearing

As stated earlier, the repair of primary compression and Tension truss members and their connections must be properly designed by an engineer and performed by experienced agency staff or a qualified contractor. Repairs will usually require substantial bracing and temporary supports if any parts of the primary members are being removed. These repairs can become more complex when they are in the vicinity of the bearings.

Figure 9.38 is a repair of the bottom chord near the bearing. This repair would require bracing, external support, and an engineered design. If repairs were being done on the pin or connection plate that attach the bottom chord to the diagonal member, that repair would require an even greater amount of bracing and shoring to remove the loads while the repair was being performed.

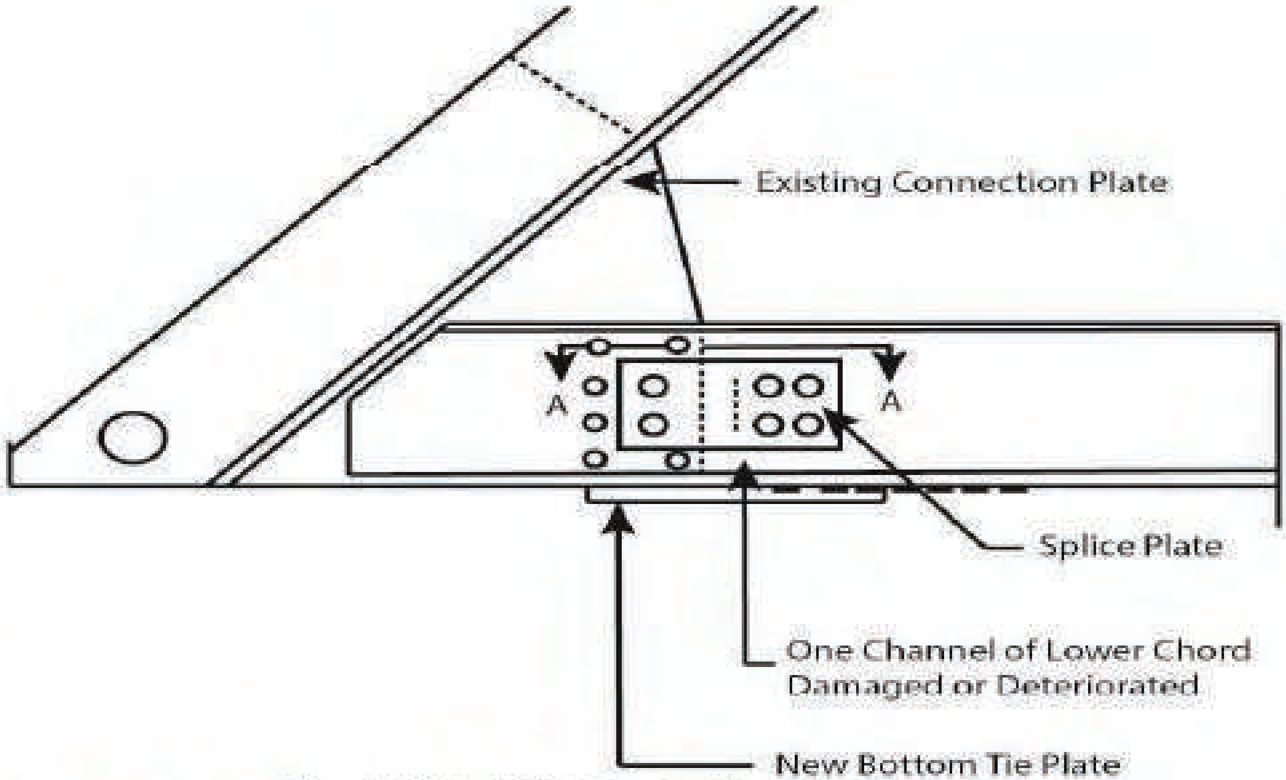


Figure 9.37: Schematic for Primary Chord Repair Near the Bearings

Bolted Splice Repair: Adding Doubler/Splice Plates

Another technique that can be used to repair corrosion loss and some types of cracks is doubleror splice plates, hereafter referred to as doubler plates or doublers. Doubler plates add materialto either increase a cross-section or provide continuity at a deteriorated or cracked cross- section. For corrosion loss, the plates simply add enough steel cross section to make up the cross-sectional loss. This technique can work as well for fatigue cracks to reduce stress range by allowing the plates to take the stress away from the cracked steel.

A consideration when using this repair for cracks is that the cracks will no longer be visible for inspection when plates are place on both sides of the repaired area. Although this repair is intended to prevent future crack growth, an engineer is needed to determine if crack propagation could be an issue and if this is the appropriate repair.

One problem with this type of repair can be maintaining the alignment of the two sides of the cracked section prior to the repair. The cracked surface may be buckled, making alignment difficult. Doubler plates should then be designed with the ability to straighten out any buckles in addition to providing added strength. The design process is identical to that used for a bolted field splice connection.

Doublers can be attached by welding or by using high-strength bolts. From a fatigue-resistance standpoint, bolted doublers are always better than welded, because a high-strength bolted connection can be considered an AASHTO Category B fatigue detail. A welded connection will most likely result in a Category E condition or worse. As a result, this manual recommends specifying only bolted doubler connections.

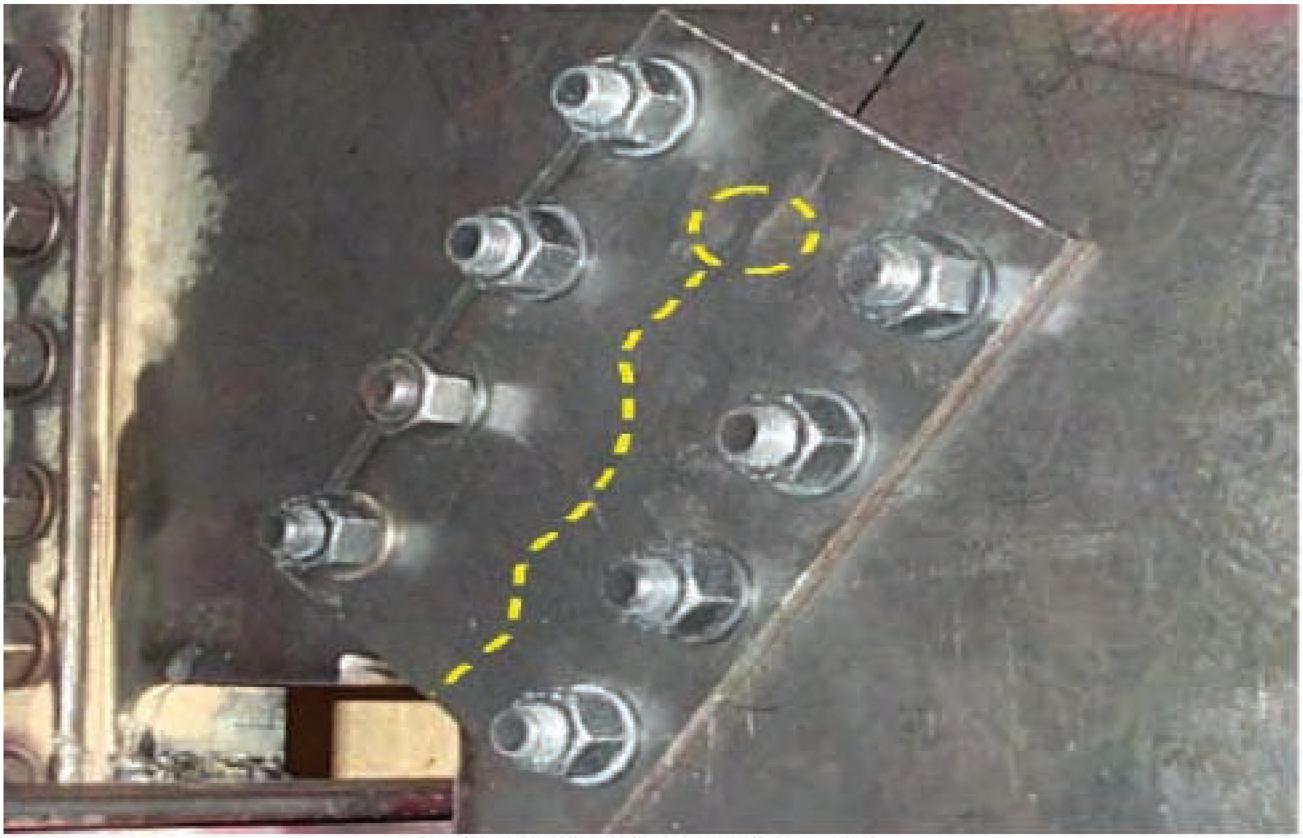


Figure 9.38: Completed Bolted Splice Repair

Bolted Doubler/Splice Plate Retrofit

1. Align both sides of the crack if there is gross deformation.
2. IF there is a crack in the steel, drill out crack, tip with a minimum 1.0-inch diameter hole to cease crack tip, which is especially important because the repaired area cannot be subsequently inspected for crack growth.
3. Determine the required cross-sectional area of the doublers depending on weather the doublers will intended to reduce stress ranges, restore a crack section or corrosion loss. An engineer is needed.
4. Fabricate the doublers with all holes drilled for bolted retrofits. In the field, clamp one of the doublers against the surface it will be attached to and use the doubler as a drilling template. Drill all holes in the cracked structure.
5. After all holes are drilled, remove the doublers and clean all contacting surfaces to remove oil, grease, dirt and cutting fluids to restore the friction surface of the slip-critical connection.
6. Reposition the doublers and fill all the holes with high-strength structural bolts. Initially snug tighten all the bolts making sure all surfaces are mated use turn-off nut method to fully tension to all the bolts after the snug tight operation, or use tension-controlled bolts. See turn-of-nut requirements published by the Research council on structural connection.
7. Prime and paint the bare surfaces. Document the location and repair procedure for inclusion in the bridge file for using future inspections.

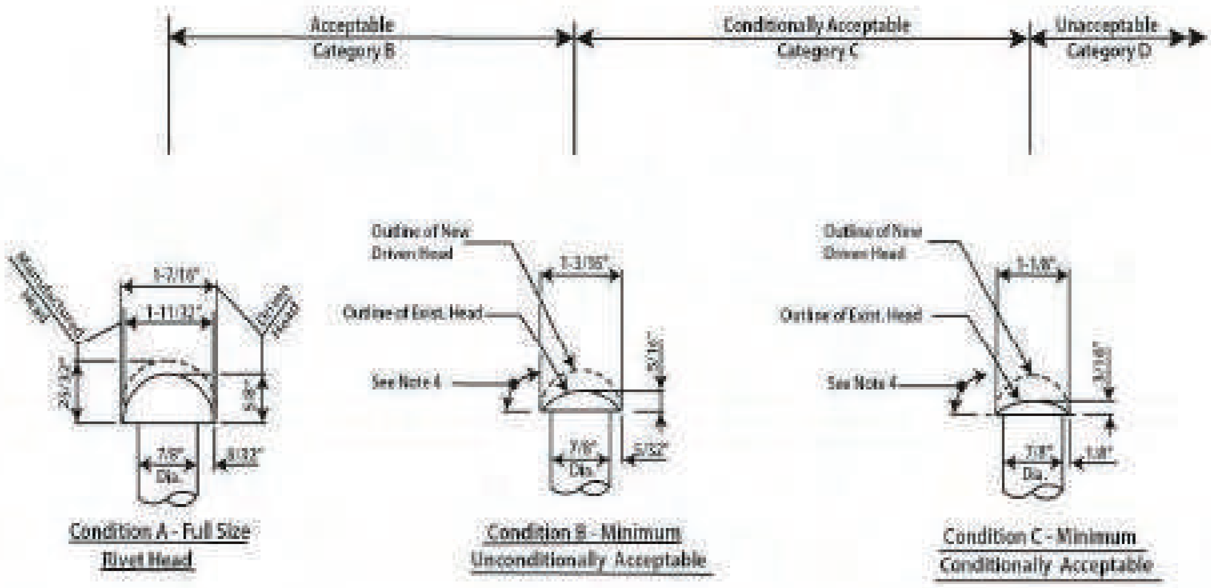
9.7.5 Rivet Replacement

Built up members and connections often exhibit corrosion of rivet heads requiring their replacement. An example of corroded rivet heads is shown in Figure 9.39.

Figure 9.39: Rivet Heads Exhibiting Various Degrees of Corrosion

Rivet acceptance and replacement criteria varies between various agencies and Bridge owners. Rivets (even at the same connection) often have various degrees of head deterioration and volume loss. The question is: how much of the rivet head metal remaining is "enough" for the rivet to perform as intended and provide for the connection capacity before it shall be removed and replaced?

Figure 9.41 is a drawing of rivet acceptance criteria for 7/8-inch diameter



Rivet Replacement Criteria for 7/8" Dia. Rivets

Rivet Replacement Notes:

1. Rivets category B with dimensions of both heads meeting or surpassing each of the minimum requirements shown for condition B may be left in place subject to conditions described in notes 4 and 5.
2. Rivets Category C not meeting the requirements of condition B, but having dimensions which meet or surpass at both heads each of the minimum requirements shown for condition C may be left in place subject to the following conditions:

There is no prying action from applied stress or crevice corrosion which tends to separate the connected parts. Rivets' heads do not have additional losses described in Note 4.

Rivets may be left in place to the extent that their number does not exceed 20% of connection rivets in any one connection or 50% of stitch rivets in any one portion of a member.

Where the above percentages are exceeded the number of rivets over the prescribed percentage shall be replaced with high strength bolts. When selecting rivets for replacement to meet the above percentage requirements, the worst rivets in any group or connection shall be selected for replacement.

3. Rivets category D not meeting the requirements of condition C a tether head shall be replaced with ASTM A325 high strength bolts of the same diameter, see Note 8 below.
4. Replacement will also be required for any rivet exhibiting additional loss in the form of pits or gouges at the edge of either head projecting beyond the shank where such loss reduces the section below the limits shown for Condition B.
5. Where crevice or interface corrosion between connected parts is present, the rivets adjacent to that area shall be replaced after cleaning between the parts regardless of the condition of the rivets.
6. Dimensions shown on these sketches for conditions B and C are minimum requirements for both driven and manufactured heads. The minimum height of head is measured to the center of the rivet. The minimum diameter applies to that direction in which it is the smallest.
7. All high strength bolt connections shall be assembled with a hardened washer under both the bolt head and nut. Where necessary washers may be clipped on one side to a point not closer than 7/8 inch of the bold diameter from the center of the washer.
8. Reading to dress up the rivet holes may be required; if after reaming the hole diameter exceeds tolerances the next larger sized bolt shall be installed.

Figure 9.40: Rivet Replacement Criteria for 7/8-inch Dia. Rivets and Notes

Rivets should be removed in a manner that will not damage the underlying connected material by using a pneumatic rivet breaker to shear the head. The shank may be driven out with a pneumatic punch or rivet breaker after shearing the head. If the rivet shanks cannot be removed by punching without damaging the base metal, the rivet shall be removed by drillingas shown in Figure 9.41.

Figure 9.41: Rivet Removal. Pneumatic Rivet Breaker (left) and Drill Removal (right)

One rivet at a time should be removed and replaced with High Strength (HS) Bolts. Thereplacement bolt should be properly tensioned prior to removal of a subsequent rivet.

Suggested Procedure are as follows:

Replacement of Rivets with HS Bolts

Rivet Removal

1. Break head of rivet with pneumatic rivet breaker, taking care not to damage the underlying metal.
2. Drive rivet shank out of hole using pneumatic punch. If punch will not remove rivet shank, drill rivet out of hole.
3. Remove only one rivet at a time and replace with HS bolt before removing other rivets unless specially authorized by the Engineer.

Area Preparation

1. Upon removal of each rivet, the base metal around the hole should be examined for surface irregularities, cracks and deterioration.
2. All oxidized materials, nicks, and burrs, steel peaks and cusps that would interfere with the sitting of the bolt head, nut and washers should be ground off.
3. Encrusted and built-up paint film around the head, nut and washers of new fastener should be removed to bare metal.

4. Where irregularities to the surface of the hole prevent normal alignment of the bolt or insertion of the bolt without damage to the thread, the hole should be reamed such the holes are perpendicular to the surface.

HS Bolt installation

1. Replace rivets with bolts of the same nominal diameter.
2. Replacement bolts should be long enough to result in minimum stick-through of 1/16 inch beyond the nuts.
3. Hardened washers should be used under both the head and nut.
4. If an irregular or beveled surface requires the use of hardened beveled washers under a bolt head or nut, the beveled washer should be used under the element which is not turned. A hardened standard washer shall be use under the turned element.

9.7.6 Fatigue Crack Repairs

Fatigue damage is a structural damage to a steel member or its component resulting from cyclic loading leading to the initiation and propagation of cracks. Fatigue damage typically occurs at stress levels that are significantly lower than the base material yield stress. Current design criteria and details have evolved to reduce the probability of both load-induced and distortion-induced fatigue damage. However, welded steel structures that were fabricated before early 1980's often used fatigue prone details which are more likely to exhibit load- induced and distortion-induced fatigue cracking that requires a remedy or repair.

An example of a fatigue crack is shown in Figure 9.43. Due to out of plane distortion where thefloor beam connects to the web, the crack most likely initiated at the lower floor beam flange to web connection.

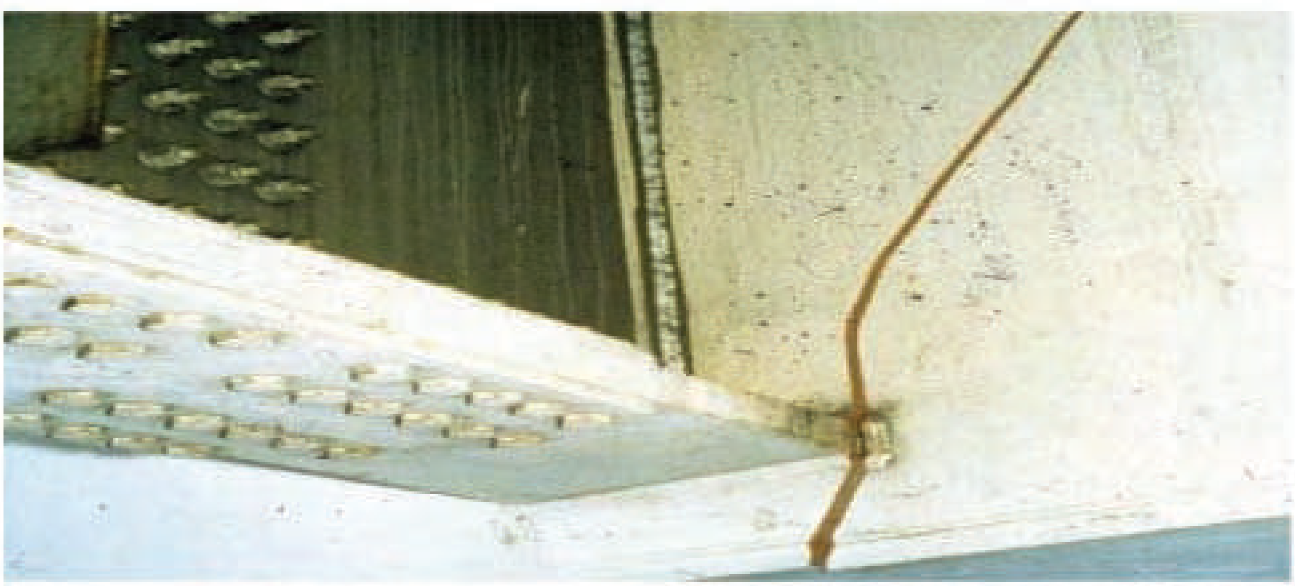


Figure 9.42: Fatigue Crack

The most common techniques that are used to remedy or repair fatigue cracking include weld grinding, arrest hole drilling, reinforcement plate strengthening and addition of a tee or double angle stiffener to flange connection. There are also other techniques as StopCrackEX bushing technology, peening, and release of connection. Weld Grinding, Arrest Hole Drilling, Stop Crack EX bushing technology, and Reinforcement Plate Strengthening are discussed in this chapter.

9.7.7 Weld Grinding

Small cracks sometimes occur at the toe of a weld. These cracks mostly are due to weld shrinkage of larger size welds. Weld toe grinding and removal of the crack containing portionsof these welds will increase the fatigue life of the weld and reduce the risk of crack propagationinto the base metal. Weld grinding can be completed using disc or burr grinding depending on the access and preference. Grinding should be performed carefully to avoid creating a notch. The repair area should be tested using Magnetic-Particle Testing (MT) or Dye Penetrant after completion of the repair to verify the crack has been entirely removed.

Identification of which weld cracks can be ground verses repaired should be made by a trained person. Nondestructive testing can help to determine the depth of the crack. If superficial, grinding would be the preferred solution.

9.7.8 Drilling Arrest Hole

Drilling a crack arrest hole at the tip of a crack is a common repair method that has been widely utilized as an economical technique for arresting fatigue cracks. An example of the holes drilled by this procedure is shown in Figure 9.44. The size of the drill hole can be calculated by an engineer taking into account the calculated stress levels, thickness of steel and yield strength. However, this is rarely done. Holes are usually drilled at diameter of ¾ inch to 1 inch.

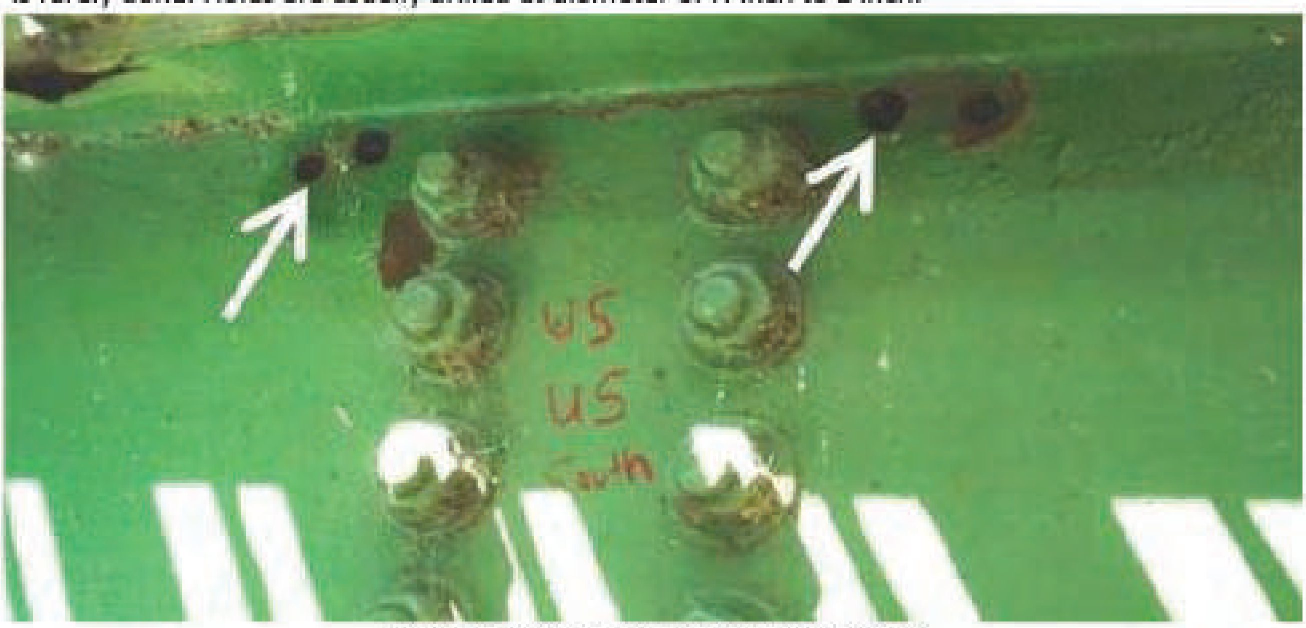


Figure 9.43: Examples of Drilled Crack Arrest Holes

The procedure must be done properly to be effective. The arrest hole should be drilled in front of the crack with the crack tip located between the hole edge and the center of the hole, as shown in Figure 160. Nondestructive testing such as dye penetrant testing or magnetic particle should be used to accurately locate the tip of the crack prior to determining the arrest hole location. The crack rarely propagates evenly thru the material thickness and often extends farther on one side of the plate than another. Therefore, dye penetrant testing on both sides of the cracked web allows a more accurate location of the crack tip. However, it may not always be practical or possible to inspect both sides due to limited access or physical constraints. After the hole is drilled additional dye penetrant testing should be used to test the hole perimeter for any cracks. After the hole has been drilled, it could be left as-is or a bolt and nut can be inserted to plug the hole and help put the area around the hole in compression. Use of weld material to plug the hole, also referred to as a plug weld, is discouraged. These types of welds can cause additional cracks to develop in the base material, especially on vibrating steel bridge superstructures.

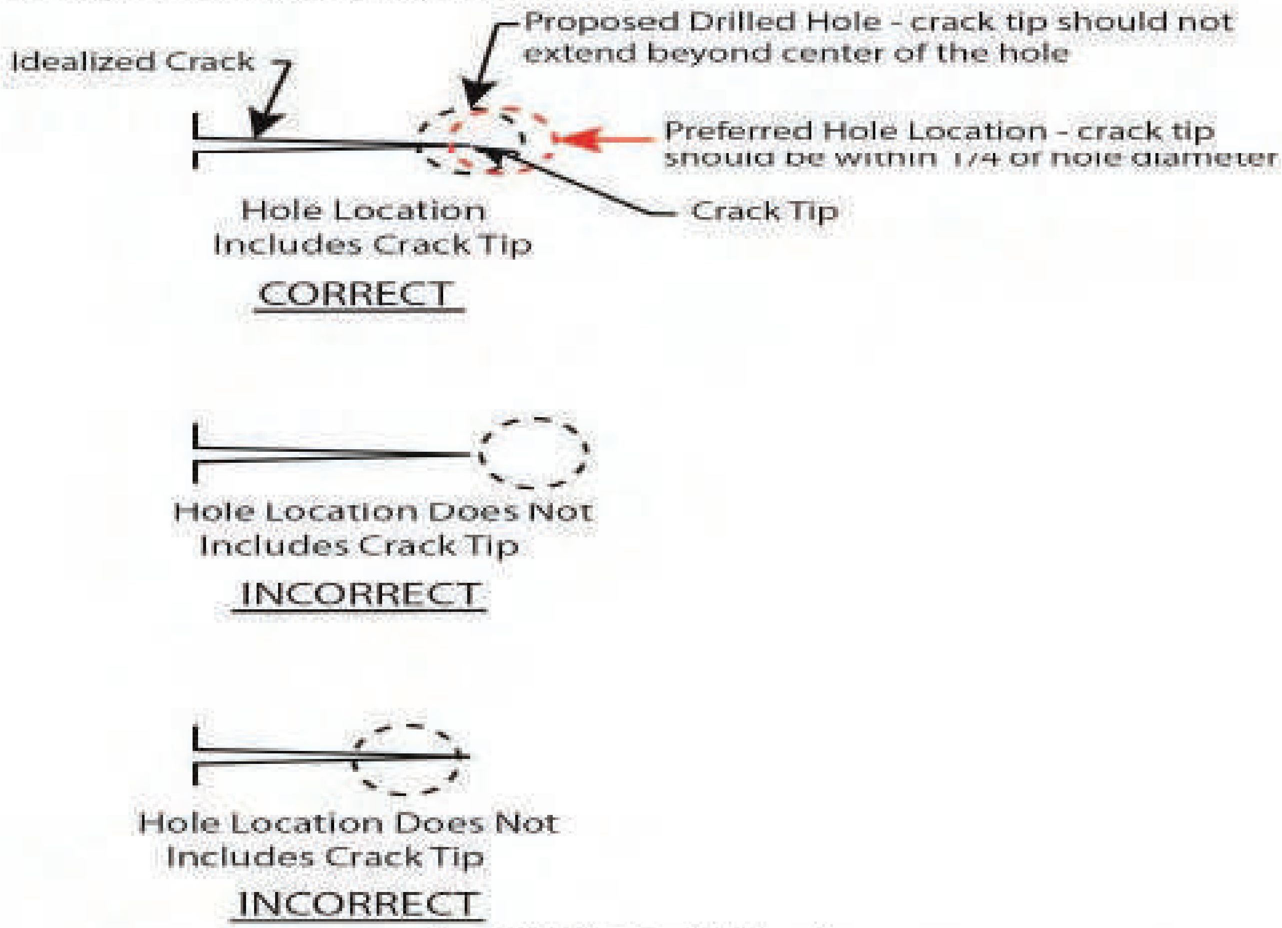


Figure 9.44: Drilled Arrest Hole Locations

9.7.9 StopCrackEX Technology

StopCrackEX Technology is used in military and aircraft industry to arrest fatigue cracks and more recently has been applied to bridge and building crack repairs. A cold-expanding bushing in the crack arrest hole creates a compressive field around the arrest hole. The additional compressive field created by the expanding bushing in the arrest hole further reduces the concentrated tensile stress field at the crack tip, mitigating crack growth. The StopCrackEX process is shown in Figure 9.45, where the gun is shown (left) and the resultant bushing and hole ahead of the crack tip is shown (right).

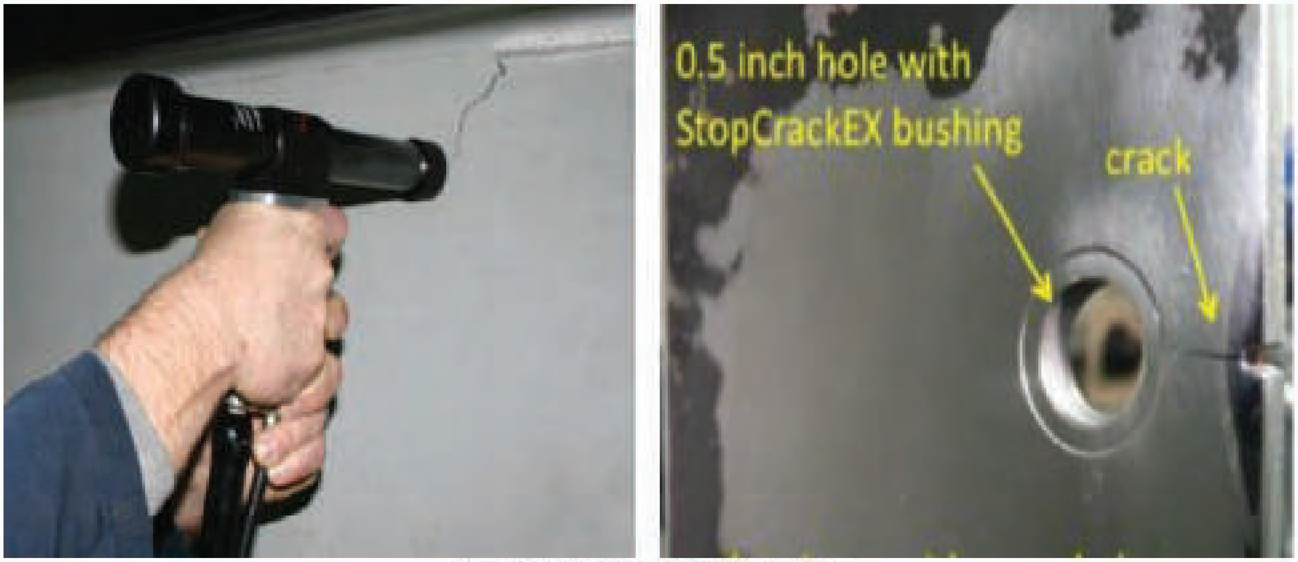


Figure 9.45: StopCrackEX Procedure

The StopCrackEx procedure utilizes the same approach as drilling the arrest holes, but requires smaller hole diameter (typically ½ inch) and is more effective due to the added benefit of localized pre-compression around the hole area.

9.7.10 Reinforcement Plate Strengthening

This repair provides strengthening by increasing the stress resisting area and reducing fatigue stress range stress. Strengthening or doubler plates can be installed on one side or both sides ofthe cracked member. Crack arrest hole should still be drilled at the toe of the crack and NDT testing is recommended prior to installation of the strengthening plate.

An example of an application for reinforcement plate repair is at a crack where a girder web hasbeen coped. The photograph below, taken from the FHWA SHRP 2 Renewal Project R19A entitled "Design Guide for Bridges for Service Life", is a good example of such repair.

Figure 9.46: Example of Reinforcement Plate Repair

9.7.11 Impact Damage

Physical impact damage due to over height or errant vehicles is common. Figure 9.47 shows an example of bridge fascia girder damage that was struck by a vehicle passing under the bridge. The bottom flange and web were bent out of plane from the impact. Additional examples of impact damage are shown in Figure 9.48 and Figure 9.49.

Figure 9.47: Bridge Fascia Girder Damage Caused by Under Passing Vehicle

Figure 9.48: Impact Damage to Fascia and First Interior Girder

Figure 9.49: Impact Damage that can be Repaired with Heat Straightening

The damaged element should be inspected for fractures. The initial inspection can be performed visually and it should be followed by NDT testing, such as Magnetic-Particle Testing (MT) or Dye

Penetrant Testing, to verify the extent of the damage. If fracture damage is present, the member should be repaired using splice plates, another engineered solution, or the steel member should be replaced in kind. If there is no fracture damage, heat or mechanicalstraightening repair can be used effectively.

Small gouges can also be removed by grinding with radius and flared back at 1:10 slope. using the procedure provided in *The* Bridge *Maintenance Manual*, PennDOT Publication No. 55, 2002.

Suggested procedure are as follows:

Small Gauge removal by Grinding (PennDOT Manual)

1. Grind impact area to bright metal to remove any regularities and surface defects. Using a sanding disc, smooth area and round over edges. Finish grinding should be done parallel to the stress to ensure the transverse grind marks are not present.
2. If the impact is within the proximity of a welded detail, the weld toes should be smoothed with die grinder to ensure that no microcracks were introduced during the impact. Using a sanding disc smooth the area and round over edges. Finish grinding should be done parallel to the stress to ensure that transverse grind marks are not present.
3. The impact should be flared that to the material edge at not less than 1 to 10 slope.
4. The area should be thoroughly inspected including any weld toes of details within the vicinity of the impact using the ultrasonic or magnetic particle testing appropriate for the detail.

9.7.12 Heat Straightening

Heat straightening is a well-known technique used to repair a deformed steel member. The method utilizes heating and cooling with a specific heating pattern and heating torch type. Areas of steel superstructure members that have been damaged can be repaired by heat straightening alone or in combination with applying external force. Repairs designated for heat straightening should be properly engineered and detailed. In addition, a detailed step-by step repair procedure that includes heating pattern, acceptable cooling method, maximum heating temperature, temperature control, limits of heating length/areas, need for and magnitude of any external force, QC/QA procedures and other governing parameters should be developed.

Properly executed and successful heat strengthening can restore a damaged superstructure element to its original condition, geometry and capacity. The FHWA Guide for Heat- Straightening of Damaged Steel Bridge Members is a good reference for heat straightening repairs. An example of a heat straightening procedure is shown in Figure 9.50.

Figure 9.50: Example of Heat Straightening Procedure

The photograph in Figure 9.51 shows a nearly completed girder repair that was made utilizing heat straightening. The heating pattern is clearly visible in the photo.

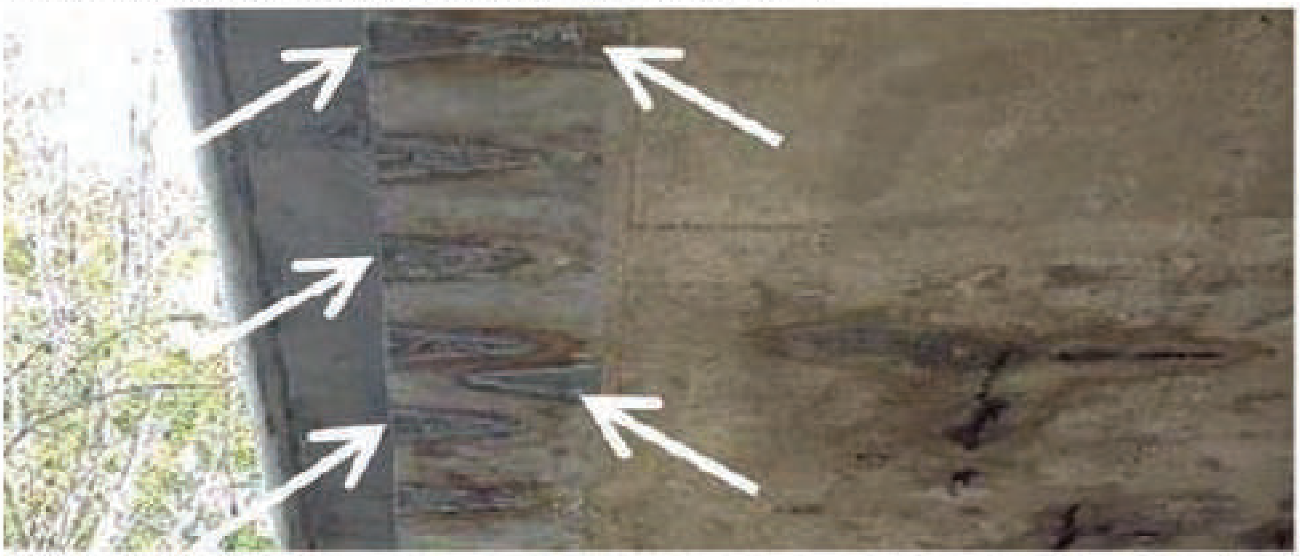


Figure 9.51: Nearly Completed Girder Repair Made Utilizing Heat Straightening

9.7.13 Mechanical Straightening

Mechanical straightening, or cold bending, forces the deformed element into the original position by means of an external force. This is not a preferred method of repair, and it shouldbe used on a limited basis for repair of minor and (most importantly) very localized damage. This type of repair has an increased risk of fracturing the damaged member when compared to heat straightening. Cold yielding also adversely affects mechanical properties of the base material. NDT testing (Magnetic Particle Test or Dye Penetrant Testing) of the repair should be done before and after mechanical straightening to verify that no cracks were created by the damage or the repair.

9.7.14 Tack Weld Removal

Tack or erection welds are widely used to temporarily hold connecting elements in place during construction. If not removed, they may develop fatigue cracks that could propagate into the base metal. Tack welds can be simply be removed by grinding followed by NDT testing. On completion of grinding, the area should be smooth, free of notches and any other surface defects that would potentially lead to development of a fatigue crack. The removal should not extend more than 1/16-inches into the base material without approval of the Engineer.

An example of a cracked tack weld that requires removal is shown in Figure 9.52.

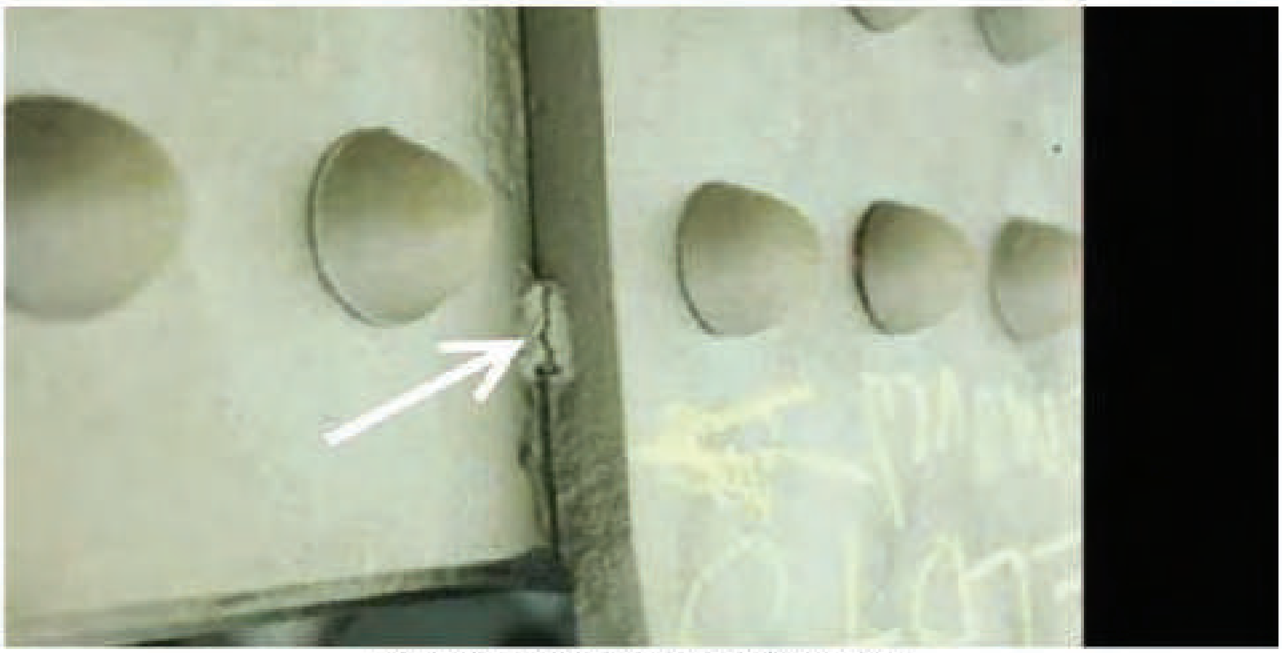


Figure 9.52: Cracked Tack Weld Requires Removal

9.8 Difference in Level due to Defect of Bearing

Function of a bearing shoe is transferring all load from a superstructure including own load of the super structure to a sub structure such as an abutment and a pier. In case the bearing shoe has some defect, a road surface will lose its flatness and causes impact to both of the superstructure and substructures. This impact will to be a cause of damages to the superstructure and substructures.

Meanwhile, rusting condition of the bearing shoe area is one of the most serious areas due to narrow space and concentration of debris and water. Effective service life of elastomeric bearings is estimated to be 15-25 years. As the material ages during its service ability period, it exhibits its severe bulging or cracking. These are signs that the elastomeric bearings need to be replaced.

Replacement with new bearing shoe should be performed strictly in accordance with the relevant technical requirements and recommendations provided by the bearing manufacturers. Installation should be performed by highly experienced staff subject to close supervision. Usually, the jack-up girder technique is utilized to allow for replacement of bearings. During replacement of the bearings, traffic may remain opened but with imposed restriction on passing speed as safety precaution. The girder shall be jacked up to around 5 mm to 10 mm, with one jack stroke. Replacement of bearing shall be implemented if existing rubber bearings already exhibited severe cracks and abnormal bulging. Old steel bearings need to be replaced especially if loose connections were found.

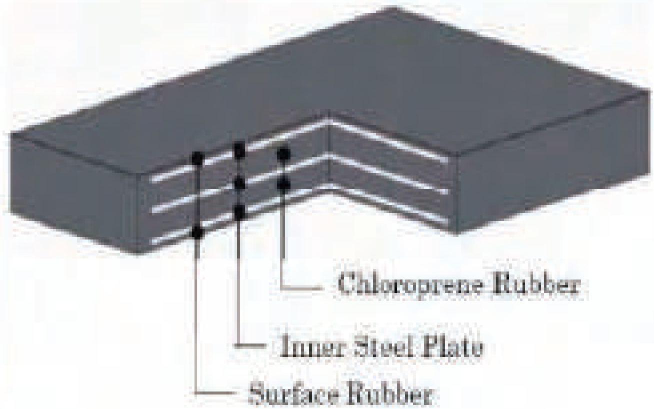


Figure 9.53: Bearing Shoe

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

Elastomeric bearing pads shall be confirmed to AASHTO M251

Property	Test Method	Unit	Specification
Hardness, Durometer	ASTM D 2240	-	60±5

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

9.8.1 Installation of jacking stages

The Contractor shall submit the shop drawings of jack up bracket staging and the working staging to be approved by the Engineer. The jack up bracket shall strong enough against reaction from jacking load. Concrete of the bracket shall be cured until concrete strength developed required strength.

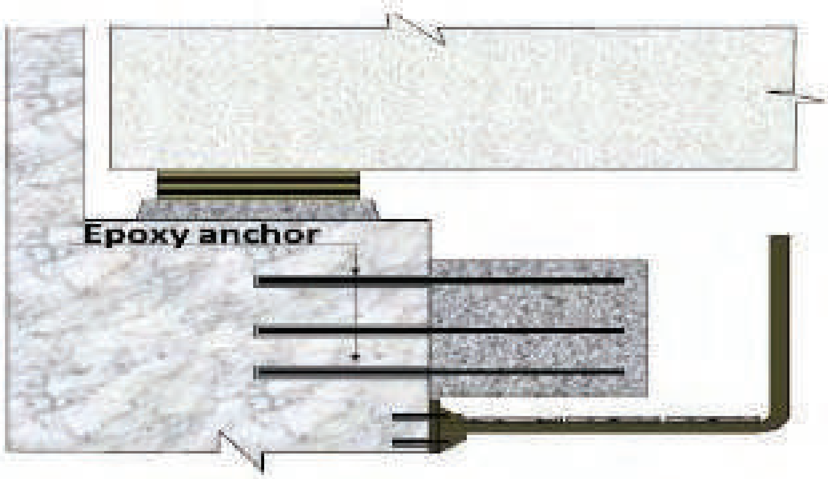


Figure 9.54: Installation of jacking stages

9.8.2 Jack up Girder

The jack capacity shall be agreed with the Engineer considering dead load and live load during the replacement work. The surface of expansion joint shall be secured to provide safety for passing traffic during jacking up process. Moreover, the height difference between surface of abutment and girder shall be kept smaller than 10 mm.

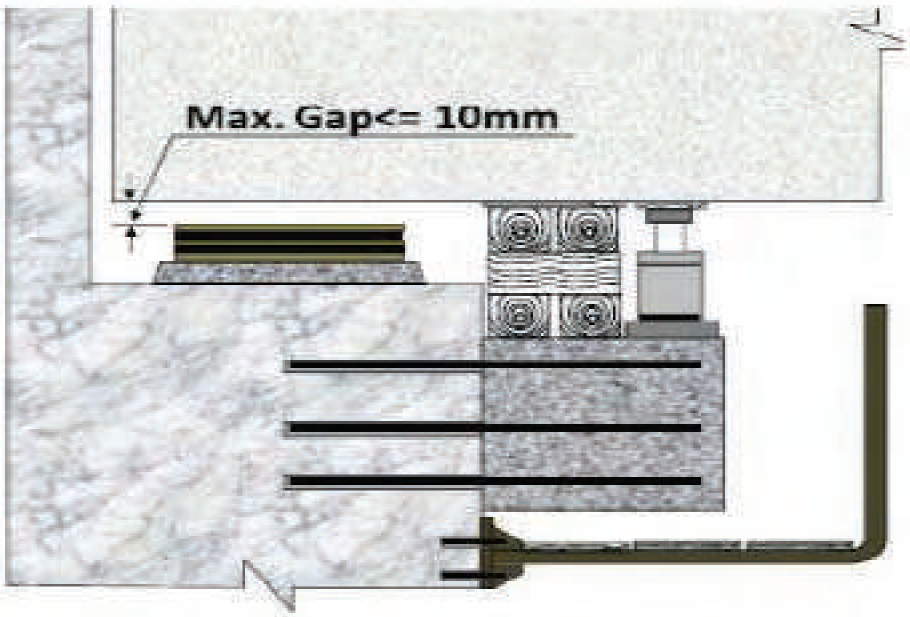


Figure 9.55: Jack up Girder

9.8.3 Casting bearing seat and set up new bearings

The Contractor shall submit shop drawings for the new bearing seat to be approved by the Engineer, prior to execution of related works including concrete chip off. After providing temporary support for the girders near the bearing locations, old bearings shall be dismantled. Position and level for the new bearings shall be set-up accordingly.

Figure 9.56: Casting bearing seat and set up new bearings

9.8.4 Jack down girder After Curing

Mortar/concrete shall be cured to achieve sufficient strength for supporting the load reactions. The Contractor shall submit test results of specimen strength in accordance with the specifications, subject to approval of the Engineer. If the test results are acceptable, jack down the girder to consequently release load reactions from the jacking device.

9.8.5 Dismantle Jacks and Temporary Supports

When the reaction is safely transferred from the jack to the new bearing, jacking device shall be dismantled. Temporary jacking bracket and staging shall be removed, epoxy anchors for bracket shall be cut at the surface of the concrete and cut end shall be applied zinc rich paint. Staging anchor bolts shall be remained with application of zinc rich paint for future's use.

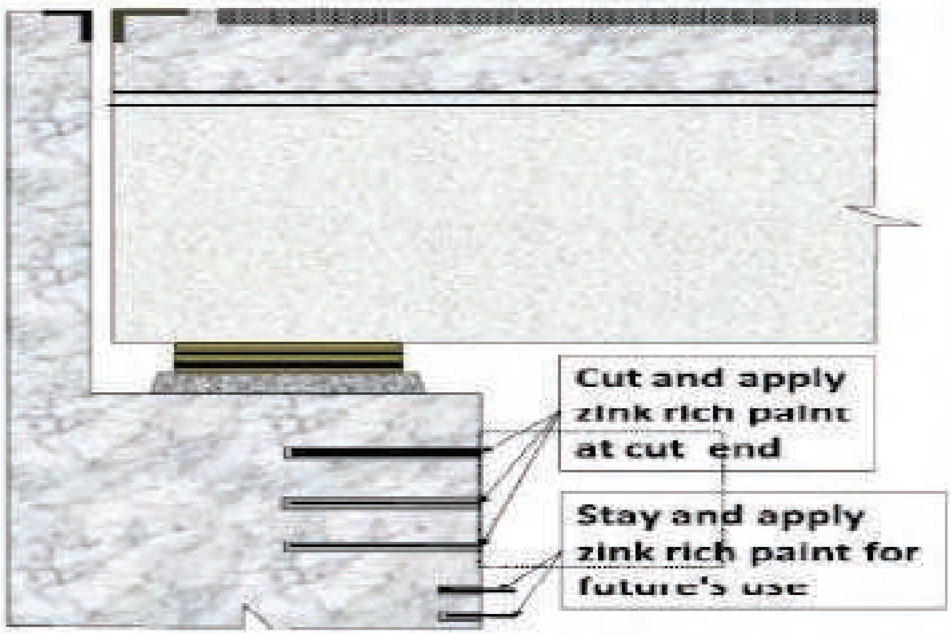


Figure 9.57: Dismantle Jacks and Temporary Supports

9.9 Water Leakage/Puddle at Expansion Joint

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

The usual gap of concrete edge is around 20 mm considering temperature here in the Bangladesh as 35 ~7C (=21 ±14C). The movement of the bridge span is 12×10-6/ ×20m×(±14) = ±3.4mm , if the span length is 20m. Otherwise, the movement by traffic load is approximately less than 5 mm. Total movement of the usual span RC deck slab is below ±10mm. With these considerations, the most suitable Maintenance measure for damaged small joint type is the installation of Buried joint with steel T-Case (Figure 9.58). However, Water leak between the steel T-Case and the gap should be avoided.

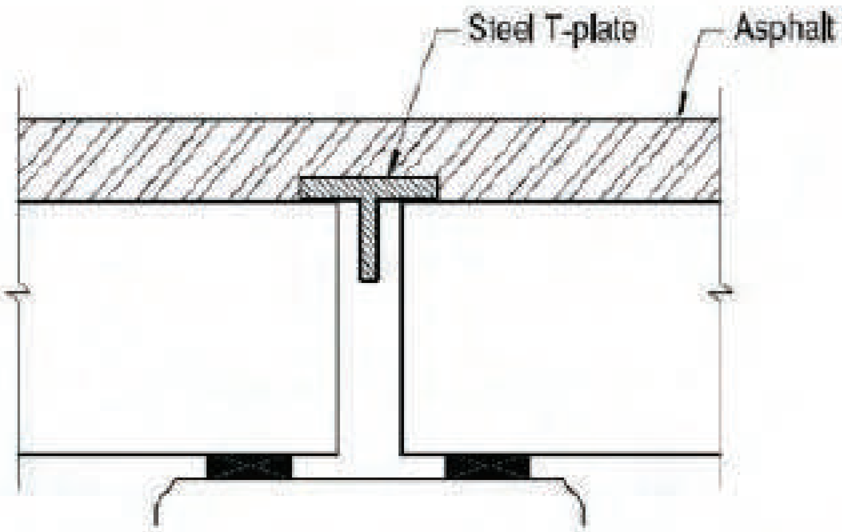


Figure 9.58: Buried joint with steel T-Case

Figure 9.59: Damaged Asphaltic plug joint after removing Sealant of Asphaltic plug joint

Buried joints with steel T-Case are mainly applied on RC deck slab bridges and steel girder bridges on fixed bearings. The former small joint such as Asphaltic plug joint is Maintenance if the following conditions are rayed as "Bäd" as per suggested condition rating criteria:

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

To improve the durability of the Buried joint, the following modified Buried joint is shown in Figure 9.60. Modification is achieved using polybutadiene Sealant on the bridge deck surface under the asphalt layer and Backup material for the gap.

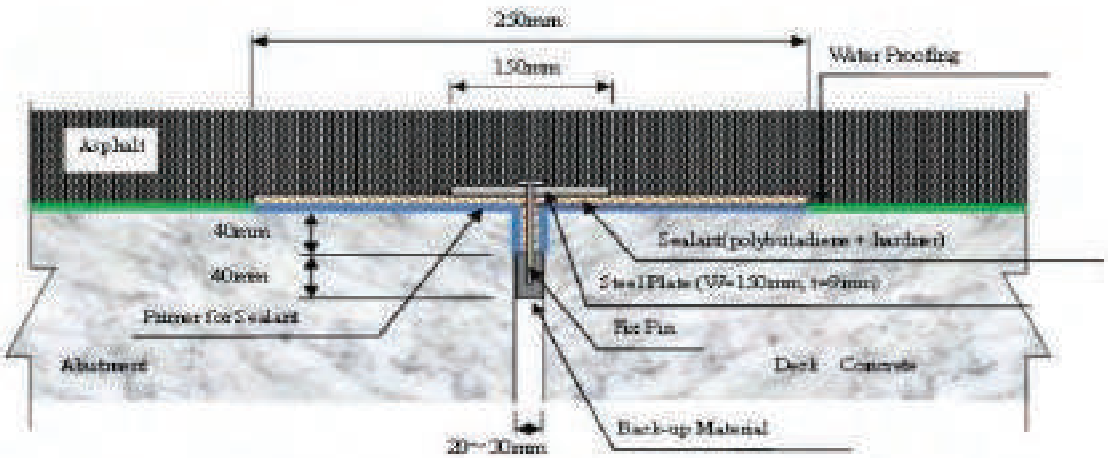


Figure 9.60: modified Buried joint with steel T-Case

Following materials should be required

1) Steel Case - Pre-fabricated **steel Case shall conform to ASTM A36 or equivalent.**

Normal asphalt - Asphalt compound shall conform to the its requirements.

2) Epoxy primer and Sealant - Polybutadiene Sealant + Hardener

3) Backup material - A compressive material used to fill the joint gap.

The Contractor shall submit shop drawings for the modified Buried joint and the Methodology Statement of the Work to the Engineer for his review and approval.

Following Procedure should be followed

Dismantle Existing Damaged Asphalt Joint Sealant The damaged sealant due to heavy traffic, aging, etc. shall be dismantled.

1) **Chipping surface concrete:** The surface of concrete at the location of the existing damaged joint shall be chipped off for purposes of installing new steel Case with fix pin.
2) **Applying of Epoxy Primer and Sealant:** The contractor shall submit shop drawing to be approved by the Engineer, prior to the installation of the steel Case.
3) **Installation of Backup material**: Backup material shall be inserted to prevent the binder leaking from the joint during the filling of the joint.
4) **Installation of Steel Case:** The contractor shall submit shop drawing to be approved by the Engineer, prior to the installation of the steel Case with fix pin.
5) **Pouring normal asphalt:** The normal asphalt shall be subjected to strict quality control especially for the temperature control requirements. Using mini asphalt cooker, normal asphalt shall be cooked until it reaches 180 Traffic operations can resume after the Asphalt temperature is cooled down to 40^{c}.

CHAPTER X: PREVENTIVE AND BASIC MAINTENANCE OF SUB-STRUCTURES

10.1 Concrete Sub-structure

Preventive Maintenance (PM) for reinforced concrete, steel, and timber substructures is an effective method of avoiding costly repairs. PM includes removing debris and pressure-washing seats, caps and other surfaces exposed to salt, maintaining coatings systems, and avoiding rot and vermin attack.

Leaking joints are commonly evidenced by discoloration of the sides of the substructure. Eventual concrete deterioration and spalling ensues. On structures with end diaphragms that extend down to the top of the cap, the water drains down the end of each cap, thereby causing significant concrete deterioration.

Protection against salt-water damage is the same as on the deck. Coatings are effective for steel or concrete if applied early and reapplied when needed. Dense concrete, such as that attained with a pozzolan additive, is also effective in resisting salt-water damage.

When performing preventive maintenance on a substructure, this is also a good time to check if the bridge may be in distress. Guidance on items to be checked for concrete substructures follows.

Typical areas of concern are shown for concrete abutments and piers in Figure 10.1 and Figure 10.2. respectively. In Concrete Sub-structure components following problem should be look for:

- Look for cracking and possible movements in the abutment walls. Check particularly the construction joint between the backwall and the breast wall.
- Look for scour or erosion around the substructure, or evidence of any movement.
- Look for loss of bearing area.
- Look for large crack, greater than ¼ inch wide.
- Look for impact damage.
- Look for efflorescence, spalling and scaling concrete.

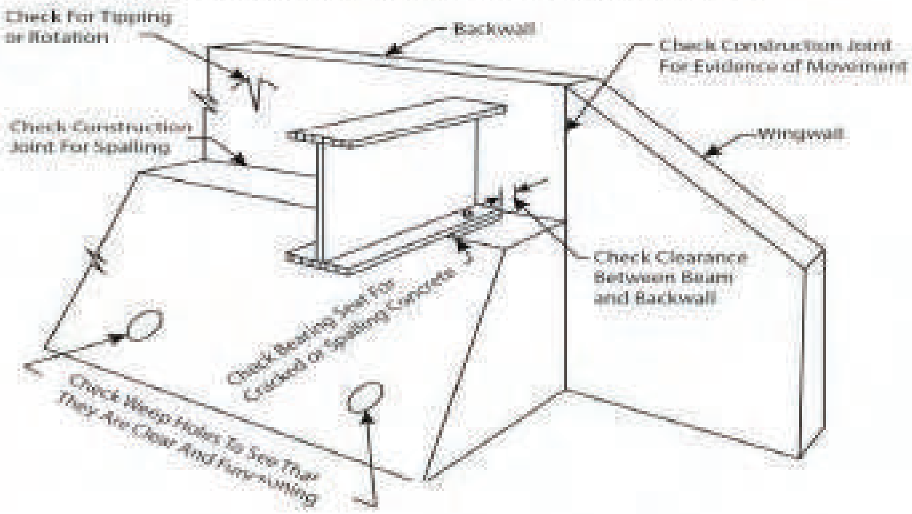


Figure 10.1: Items to Look for at Concrete Abutments

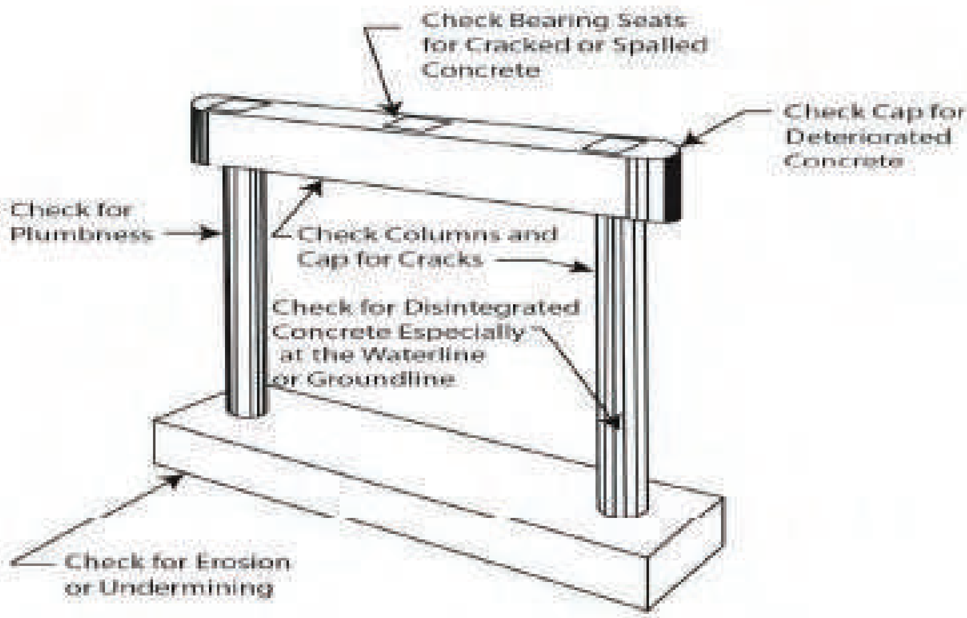


Figure 10.2: Items to Look for at Piers

10.1.1 Sealers

Concrete sealers are used to prevent chloride ions from diffusing into the concrete. Measures that prevent water from entering the concrete will also minimize chloride intrusion. However, chloride ions that already exist in the concrete, especially near the surface, will diffuse into the concrete after the sealer or coating is applied and may critically contaminate the concrete at the reinforcement level over time. Workers should be reminded that sealants and coatings contain solvents that will flash off during installation and some can be harmful in confined spaces.

There are generally two categories of sealers: penetrating sealers and surface sealers. Sealers prevent liquid water from entering the concrete, but they are generally "breathable". This means that they allow water vapor to enter and leave the concrete. This prevents moisture from being trapped inside when the concrete is sealed, thus minimizing the possibility for freeze/thaw damage of the concrete, corrosion damage, or reactive aggregate damage. This is especially important when the concrete member is in contact with earth and there is ready access of moisture into the concrete.

Vapor permeability of concrete sealers is desirable because it prevents moisture from being trapped inside the concrete element when the concrete is sealed. Acceptable sealers should be able to provide:

- Chloride screening: Sealers should be able to reduce chloride ingress into concrete by at least 90 percent after 30 weeks of ponding with saltwater.
- Penetration depth: The initial depth of penetration should be 0.125 inch, and ideally 0.25 inch, to provide for protection from wear and UV light degradation.
- Moisture vapor permeability: The minimum vapor transmission should be 80 percent after sealing of the concrete. The percentage of vapor transmission is determined by comparing the vapor loss of sealed concrete to that of an unsealed concrete over a 14- day period. The concrete used in the test should be in a saturated, surface-dry condition.
- Surface friction: The surface should exhibit acceptable frictional characteristics after it is sealed

10.1.2 Penetrating Sealers

Penetrating sealers prevent liquid water from entering the concrete; however, they are very permeable to water vapor. Silanes and siloxanes have proven to be the most effective sealers in laboratory testing. As substructure concrete is not abraded by traffic, the time between resealing is roughly twice that of concrete decks. In addition, as dry time is not critical a wider variety of sealers can be applied to substructures. Water based or 100 percent solids products should be used when sealing substructures near waterways. Non-water-based products or those not containing 100 percent solids contain volatile organics that are harmful to aquatic life and can contaminate drinking water. It is best to use water-based products near waterways.

A sealer will not penetrate properly, unless it is applied to a clean surface. Before application, any surface laitance or residual curing compounds should be removed from the concrete surface through pressure washing, sandblasting, or shotblasting. Surfaces are cleaned using pressure washing with 2,500 to 3,000 psi after removing debris. Oil, asphalt, and other surface contaminates that would interfere with the penetration of the sealer should be removed during the cleaning process. Following cleaning, any dust or loose matter should be removed with compressed air or vacuum. To provide for proper penetration, the subsurface pores must be dry to the desired depth of penetration. Newly placed concrete must be allowed to cure for a minimum of 28 days (or longer if recommended by the manufacturer) before sealing. If after curing concrete is exposed to rain, it must be allowed to dry. The drying requires a sufficient period of dry, warm weather as outlined in Table 10.1.

Table 10.1: Required Drying Time before Sealing (Days)

Ambient Temp.	Last Rain - Light	Last Rain - Moderate	Last Rain - Heavy
70 - 85 °F	0.5	1	2
50 - 70 °F	1	2	3
40 - 50 °F	2	3	5

Penetrating sealers, silanes and siloxanes, are typically applied to a prepared concrete surface at a rate of about 150 square foot per gallon. Sealers should not be applied when the temperature of the concrete surface is below 40 °F. The sealer should be applied from the low area to the high area to provide for proper saturation. Sealers may be applied by low-pressure pump (with either nozzle or spray bar) and by flood and brush techniques. Substructures can be sealed using simple equipment such as the garden sprayer on a backpack as seen in Figure 10.3.

Figure 10.3: Hand Sealing the Sub-structure

10.1.3 Surface Sealers

Surface sealers are pore-blocking materials such as boiled linseed oil (50 percent linseed oil and 50 percent mineral spirits or kerosene) or epoxy with low solid content (solids less than 50 percent). Surface sealers have an inadequate depth of penetration and quickly wear when exposed to abrasion.

Environmental exposure conditions that influence the service life of sealers applied to substructure components include UV light, moisture, and abrasive wave and ice action. Surface sealers not exposed to abrasive wave or ice action have a service life of 1 to 3 years. In the presence of abrasive wave or ice action, the service life of surface sealers may be less than 1 year. This is not a very long service life for concrete preservation, so the use of coatings as discussed before.

Some Bridge Authorities apply the protective coating to the bearing systems as well as to the sub-structure caps. When coating concrete caps, the best procedure is to extend the protective film on the abutments to a minimum of one foot below the bridge seat. On piers, the extent of the coating may depend, to some extent, on appearance.

10.1.3.1 Coatings

A coating is a one- or two-component organic liquid containing a polymer binder (such as epoxies, acrylics, methacrylates, or urethanes) applied in one or more coats to a prepared concrete surface. The primary purpose of the coating is to prevent the ingress of water into the concrete and, hence, the diffusion of chloride ions. Coatings prevent liquid water from entering the concrete, but they usually do not permit water vapor transmission. Therefore, concrete members should be dry if a coating is applied. Also, the member should not be in contact with earth with ready access of moisture into the concrete or bubbling, flaking, failure of the coating may result.

The selection of a coating material depends on individual site conditions. Polymer surface treatments cure quickly. Epoxies are abrasion resistant and have a high adhesive strength; however, they are susceptible to degradation by UV light. Acrylics are brittle and normally have low impact strength. Urethanes have high impact strength and good weathering characteristics, but low abrasion resistance. Coating materials have high solid content, usually 100 percent, and the typical thickness of coatings after drying is in the range of 0.001 to 0.003 inch. Coatings applied to existing concrete may prevent further chloride intrusion, but if chloride ions are already present in the concrete, they may still critically contaminate the concrete at the reinforcement.

The performance of any coating system is contingent upon proper surface preparation. The surface should be sandblasted to remove laitance. Before coating, the surface should be thoroughly air-blasted to remove dust and debris. The subsurface pores must be dry to minimize vapor pressure build-up on coatings. If concrete is exposed to rain, it must be allowed to dry. The drying requires a sufficient period of dry, warm weather. Coatings should be able to reduce chloride penetration into the concrete by at least 90 percent and have a minimum vapor transmission of 35 percent.

Coatings should be mixed prior to placement to ensure a uniform mix. Once the coating components have been allowed to react, the coating may be applied by brush, roller, or spray as necessary to ensure even coverage, as shown in Figure 10.4. The coating should be applied in accordance with manufacturer's recommendations which are typically between 50 °F and 90 °F. Two applications of the coating should be applied to ensure even coverage. The second coat is usually applied 24 hours after the application of the first coat, but this can vary with environmental conditions and material type.

Figure 10.4: Protective Coating Applied on the Sub-structure

If the coating is applied on horizontal surfaces, sand should be broadcast on the coating after each application and while the coating is still wet. This is to impregnate the coating and provide skid resistance on walking surfaces. Before coating, all bearings should be masked off. This is done to prevent accidental application on the bearing, which may affect its performance. The coated surface should be protected from rain and traffic spray for at least 6 hours after application.

The service life of coatings depends on the type of coating material applied and the field exposure conditions. Coated bridge components subjected to sea spray may have a shorter life than those exposed to deicer salt runoff water. For coatings on substructure components, environmental exposure conditions that influence the service life include degradation caused by ultraviolet light, moisture, and abrasive wave and ice action. Depending on the type of coating, the service life varies from 6 to 14 years for coatings subject to sea spray and 10 to 18 years for coatings subject to deicer salt runoff water. This is substantially higher than surface and penetrating sealers discussed in the prior section.

Cementitious and epoxy coatings have been applied under water to protect a concrete surface against abrasion, cover cracks, and make small repairs. These products are normally applied by hand as a thick mortar. The cementitious products often include anti-washout admixtures and accelerators. Cementitious materials are mixed above water and delivered to divers in a plastic bag. Epoxy resins applied under water must perform satisfactorily and cure under wet and low surface temperature conditions.

10.1.4 Galvanic CP System

This system is based on the principle of dissimilar metal corrosion and the relative position of specific metals in the galvanic series. No external power source is needed with this type of system and much less maintenance is required. The anode sacrifices itself to protect the reinforcing steel from corrosion. Over time the anode will be exhausted and will no longer provide protection. The basic layout is shown in Figure 10.5.

Thereby, corrosion stops, or at least is greatly minimized. CP is divided into two basic types: 1) galvanic (or sacrificial anode systems, and 2) impressed current systems. In both types of systems, the reinforcing steel functions as a cathode, hence the name cathodic protection. Such system provides protective current primarily to the areas on the steel surface that need it the most. Due to the limited power provided by this system, most of the installations have been on bridge components in marine environments or areas with high humidity where the concrete resistivity is generally much lower. Recently, galvanic systems are gaining more widespread usage, particularly for substructure applications.

Galvanic (sacrificial anode) Systems are made from a metal alloy with a more "active" voltage (more negative electrochemical potential) than the metal of the structure. The difference in potential between the two metals means that the galvanic anode corrodes, so that the anode material is consumed in preference to the structure. The loss (or sacrifice) of the anode material gives rise to the alternative name of sacrificial anode.

For this to work, there must be an electron pathway between the anode and the metal to be protected (e.g., a wire or direct contact) and an ion pathway between both the oxidizing agent (e.g., water or moist soil) and the anode, and the oxidizing agent and the metal to be protected, thus forming a closed circuit; therefore simply bolting a piece of active metal such as zinc to a less active metal, such as mild steel, in air (a poor conductor and therefore no closed circuit) will not furnish any protection.

There are three main metals used as galvanic anodes including magnesium, aluminum and zinc. They are all available as blocks, rods, plates or extruded ribbon. Magnesium has the most negative electro-potential of the three and is more suitable for areas where the electrolyte (soil or water) resistivity is higher. This is usually for buried portions of substructures. Zinc and aluminum are generally used in salt water, where the resistivity is generally lower.

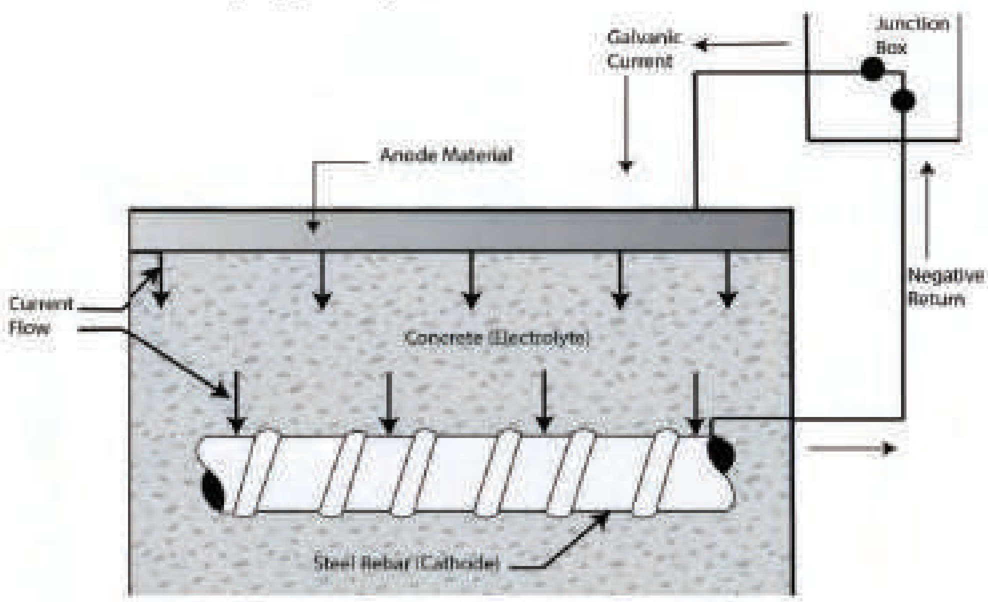


Figure 10.5: Layout of Galvanic (Sacrificial) Anode System of the Reinforcing Steel

As the anode materials used are generally more costly than iron, using this method to protect ferrous metal structures may not appear to be particularly cost effective. However, consideration should also be given to the costs incurred by closing a bridge to repair a pier column in the water or the need to shore a pier cap because of their structural integrity has been compromised by corrosion.

There is a limit to the cost effectiveness of a galvanic system. On larger structures, so many anodes may be needed that it would be more cost-effective to install impressed current cathodic protection.

Sub-structure anode systems are of two types: 1) encapsulated or embedded and 2) surface applied. The encapsulated or embedded systems use an anode, such as zinc anchored to concrete (e.g., the pier surface) and encapsulated in concrete (e.g., formed jacket or shotcrete). A schematic illustration of a zinc mesh jacket is presented in Figure 10.6. It is a two-piece snap together system.

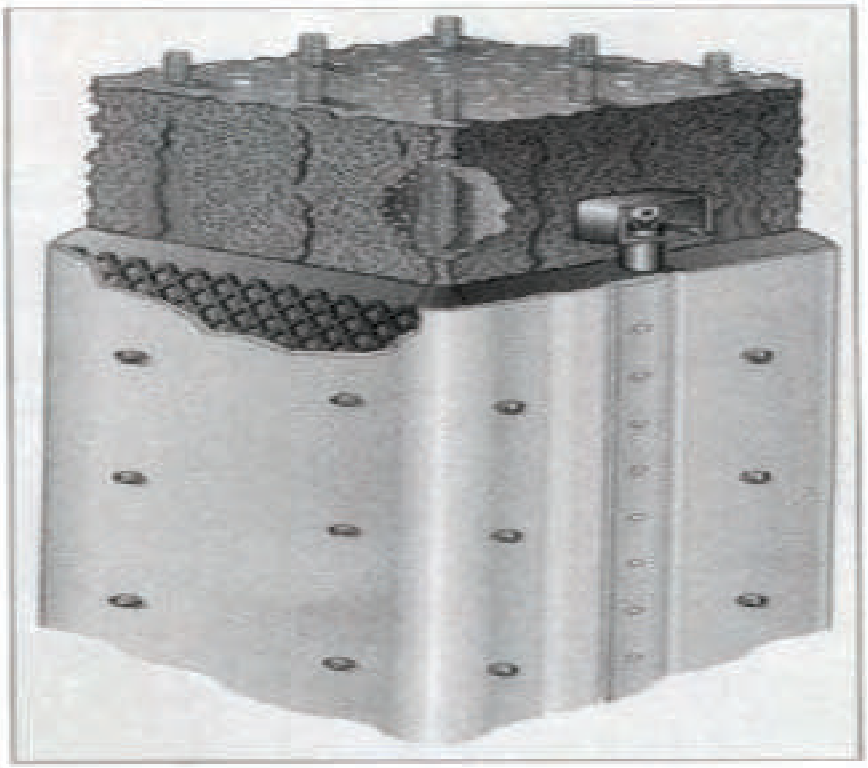


Figure 10.6: Schematic Illustration of a Zinc Mesh Jacket

The two most common galvanic anode systems for substructures in a marine environment are 1) Thermally Sprayed Zinc (TSZ) and 2) Zinc-hydrogel anode. The application of thermally sprayed zinc is the same as used in the impressed current system. Except in the case of the galvanic system, the zinc may be applied directly to cleaned steel in areas where damaged concrete has been removed and to the adjacent concrete surfaces. If structurally and aesthetically acceptable, the areas where damaged concrete was removed may be left unrepaired.

Thermally sprayed zinc for cast-in-place substructure components and zinc mesh jackets for precast ones are common means to control this corrosion and extend useful service life. For both types of systems, a submerged bulk zinc anode (SBA) is included to polarize the reinforcement below the waterline and reduce current drain from the lower portion of the thermal spray or zinc mesh. See Figure 10.7 for a schematic illustration of thermal spray Zn with a Submerged Bulk Anode (SBA) system applied to a pier and Figure 10.8 for an example of thermally sprayed zinc applied to a pier column.

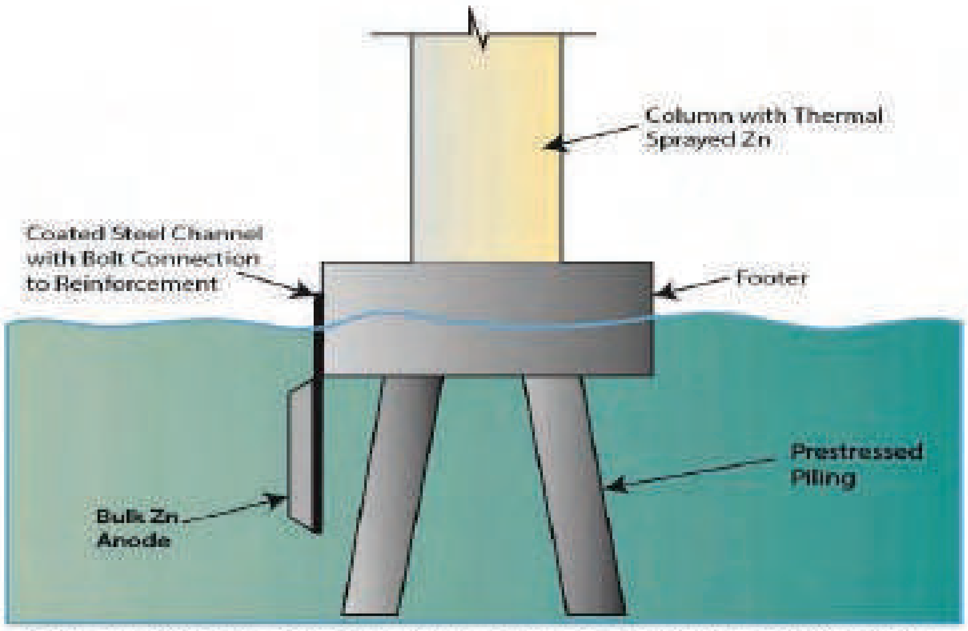


Figure 10.7: Schematic Illustration of Thermal Spray Zn/SBA System of a Sub-structure

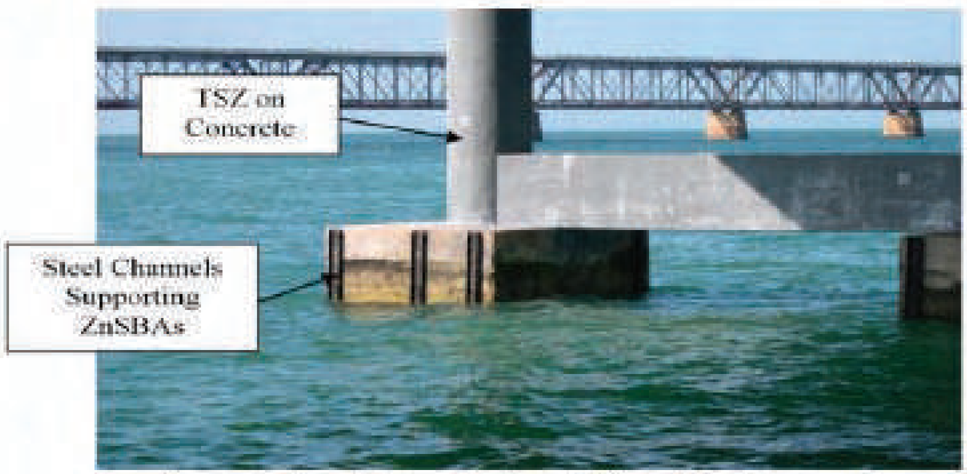


Figure 10.8: Thermally Sprayed Zinc Applied to a Pier Column

The zinc-hydrogel anode system is also a sacrificial anode system. A very thin sheet of zinc is glued to the prepared concrete surface by means of a hydrogel glue (basically the same as the material used for electrode attachment to skin in medical applications). It should be noted that the gel is a hydrophilic material and attracts moisture. Therefore, this system should not be used in areas with potential to water exposure. Otherwise, moisture will accumulate at the interface of the gel and zinc and can cause deterioration in time. The zinc sheet can be coated for aesthetics, if desired. This system is generally more effective than the thermally sprayedzinc system.

10.2 Repair and Rehabilitation of Concrete Sub-structures

Problems often found in reinforced concrete substructures include the deterioration of concrete and the corrosion of reinforcing bars. The problems that deteriorate other reinforced concrete elements are generally the same problems that create problems in the substructure. Repairs to the substructures generally can be performed using the same basic materials and techniques as used for all reinforced concrete. The repairs however, may involve supports and shoring of the superstructure and deck and unlike for deck repairs are more often done on vertical surfaces. Specific repairs involving piles and pile bents will be presented later in this chapter. As all the loading is carried by the substructure, it is critical that the substructure is maintained in a state of good repair.

Substructures deterioration initiates similar to any other reinforced concrete bridge elements. It can begin with the failure of other elements, such as moisture and contaminants falling through leaking deck joints, environmental or climatic conditions, such as substructures in a marine environment or salt spray onto piers near the shoulders of underpasses, restricted movement, as when frozen bearings create thermal forces and pressure is created on substructure elements, or impact damage. Lateral force such as large debris striking a bridge during periods of high water or an over-height vehicle hitting a beam can also create large forces on the anchor bolts which in turn are transmitted to the substructure cap, which can cause damage to the bridge seats or cracks in other parts of the substructure such as the columns. These problems can be traced back to inadequate design, improper placement of the assemblies, movement of the superstructure, or corrosion related friction between the sliding surfaces.

During the preliminary planning stage, necessary substructure repair procedures should be determined. One of the first questions to ask is whether the repair intends to only protect the element from additional damage or is it intended to improve or restore its load carrying capacity? These procedures should then be scheduled in a logical order, and they may include the following:

- Identify damage by sounding and marking the unsound concrete
- Make provisions to correct the cause of damage
- Determine whether the repairs are structural or non-structural

Structural repair of substructure elements may require the loads to be temporarily supportedby shoring while the repair is performed and the repair concrete reaches full strength. If the deterioration is caused by loads, or in case of extensive concrete deterioration, the superstructure may need to be lifted (to take the load off the substructure) prior to repair. The repair may also require raising the superstructure in order to provide workspace. Shoring and temporary supports are discussed at the end of this chapter.

10.2.1 Surface Repairs

Surface repairs are generally non-structural repairs. In most cases, rebar corrosion has caused the facing concrete to deteriorate and spall. The concrete behind the rebar remains sound and capable of carrying the loads. Surface repairs can be done without shoring and temporary supports. The work can be done while the bridge remains in service, though traffic may have to be moved away from the immediate area of the repair. The column repair shown in Figure 10.9 was performed under loading as the repairs were onlyto the superficial concrete covering the rebars. Sub-structure concrete will deteriorate from the effects of water, deicing chemicals, freeze cracking, settlement cracking, structural cracking, or impact by debris. The deterioration leadsto spalling and results in edges or portions of the cover concrete breaking off. This condition requires that repairs be made to prevent continued deterioration, specifically additional spalling as moisture continues to reach the rebar causing additional corrosion. Surface repair procedures are often used to face old rubble masonry or concrete made from large stone. Superficial substructure damage can be repaired without affecting traffic. Concrete is removed, a protective coating can be applied to the rebar, and the repair material can be placed by conventional form and pour methods or shotcrete.

Figure 10.9: Non-Structural Repair of a Column

Deterioration at the waterline is particular to abutments or piers in streams. It forms a depression or cavity in the concrete extending some distance above and below the average waterline of the stream. Deterioration at the waterline usually occurs on the upstream face or along the sides of the pier. Repairs at the waterline are very similar to the surface deterioration problem except it is necessary to control the stream flow so that the work can be kept dry. The following procedures can be used to repair deterioration of this type:

Non- Structural repair for concrete sub-structure components

1. Dewater the abutment or pier.
2. Chip away all loose concrete in poor condition
3. Chip or roughen the surface to provide a better bond between old and new concrete.
4. Clean the reinforcing bars of scale and loose rust Using abrasive blast cleaning.
5. Clean the surface in all areas where new concrete will be placed
6. Construct a form of eadequate strength
7. Apply a bonding agent to the surface (if owner allows)* and fill form with concrete.

*Not all agencies authorize the use of bonding agent

Effective bonding of the new concrete to the old is usually accomplished with a bondingmaterial and is particularly important when deep deterioration requires a large volume of concrete to be replaced. Installing rebar into the existing concrete to act as anchorage for the repair material ensures the repair material will not fall out if the repair becomes de-bonded. A grout of neat cement base can be used as an effective bonding agent. Grout can also be used when the form for the concrete is so inaccessible that an epoxy material cannot be applied effectively. The exposed area can be liberally coated with grout just prior to pouring theconcrete. Before and after photos of surface repair of a retaining wall are shown in Figure 10.10 and Figure 10.11

Figure 10.10: Preparation for Repair of Retaining Wall

Figure 10.11: Retaining Wall After Repairs

10.2.2 Structural Repairs

For more extensive repairs aimed at the rehabilitation of the substructure concrete elements, involving structural repairs, common equipment and materials utilized are listed below. The necessary equipment:

- Cribbing, jacks, shoring equipment
- Air drill
- Tie screw or equivalent bolts
- Wood spacers, walers, etc.
- Reinforcing rods or steel
- Hand tools
- Concrete removal equipment
- Anchor bolts and anchors

- Plywood sheet forming
- Cement concrete

The following steps in the rehabilitation procedure are normally required:

Concrete Structural Repair

1. Establish traffic control, if necessary.
2. Install erosion control material if original material missing or disturbed.
3. Install shoring and jack the superstructure to remove the loading on the element (always check with an engineer for shoring and jacking procedures).
4. Remove deteriorated concrete by chipping and blast cleaning.
5. Drill and set the tie screws and studs to support the framework.
6. Set reinforcing steel and forms.
7. Apply epoxy-bonding agent (if owners allows)* to the concrete surface just before placing the concrete.
8. Place the cement concrete, cure and remove the forms.
9. Place superstructure back on newly repaired element and remove shoring.
10. Remove erosion control material and clean up the site.

*Not all agencies authorize the use of bonding agents.

An example drawing for more extensive repairs aimed at the rehabilitation of the sub-structure concrete elements is shown in Figure 10.12

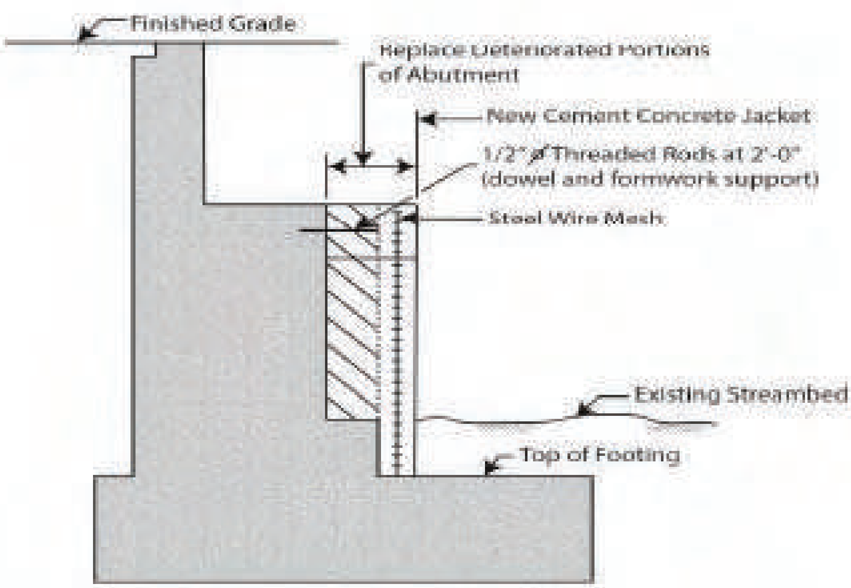


Figure 10.12: Repair of Abutment Face

Portions of an otherwise sound concrete may be broken off by frost heave, ice that forms invoids created by fill settlement adjacent to the wall, ice in the cracks, voids in the concrete, or insufficient air entrainment voids. Deterioration may occur due to deicing, salt-rich snow and ice plowed onto the substructure and retained by moisture-holding debris. Bad aggregates sometimes cause concrete failure; see Chapter 5 for further information on aggregate issues such as Alkali Silica Reactivity (ASR). The loss of portions of a substructure element can result in erosion of the fill and further damage to the wing wall and the approach.

The cause of the failure should be determined so that it may be corrected if possible and to ensure that any defects or deteriorated areas present can be removed in order to ensure an effective repair. The forming should be preplanned and the materials cut to size in advance if feasible. Any excavation required to gain sufficient working access and to facilitate the removal of defective concrete could be accomplished in advance of the repair.

10.2.3 Wingwalls and Abutment Backwalls

The wingwall repair consists of recasting the broken or deteriorated section as follows:

Wingwall Repair

1. Excavate as required to set the dowels for formwork support.
2. Remove all fractured or deteriorated concrete to sound concrete by chipping, and blast clean to remove material left after chipping.
3. Drill and set dowels. Dowels, #4 bars, are placed a minimum of 9 inches into sount concrete and set with non-shrink grout, 8 inches on center.
4. Set the dowels for formwork support and install the forms.
5. Just prior to placing the concrete, apply an epoxy-bonding agent (if owner allows)* to all existing concrete that is to come into contact with new concrete.
6. Cure concrete for a minimum of 7 days before backfilling with granular material, or until concrete has developed sufficient strength to resist the imposed lateral pressures.

*Not all agencies authorize the use of bonding agents.

An example of a wingwall repair procedure is presented in 3.

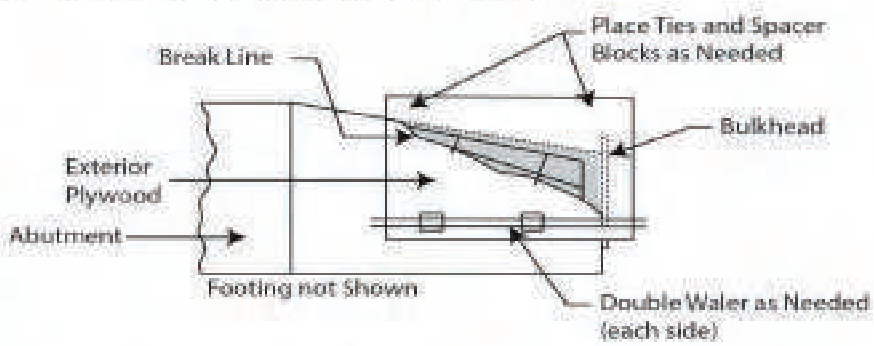


Figure 10.13: Reconstruction of Wingwall

Abutment Backwalls

Abutment backwalls can be damaged from several factors including shoving of the approach slab, wheel impact of vehicles from the joint, and salt contaminated run off from the joint. Damaged abutment backwalls may be partially or totally replaced. The following steps in the replacement procedure are normally required:

Abutment backwall Replacement

1. If a steel armored joint is used, temporarily tack weld the abutment side of the steel armored joint to the deck side of the joint assembly. Certified personnel should perform welding.
2. Cut and excavate the approach slab or pavement to allow access to the backwall.

3. Remove deteriorated concrete from the backwall and clean concrete and reinforcing bars using abrasive blast cleaning.
4. Place replacement bars by lapping them with the existing bars by drilling and grouting.
5. Place forms for concrete. Just prior to placing the concrete, apply an epoxy-bonding agent (if owner allows)* to existing concrete that is to come into contact with new concrete.
6. Place and cure concrete. ensure concrete is placed beneath existing joints.
7. Remove forms and temporary tack
8. On joints.
9. Backfill and compact subgrade under the approach slab or pavement.
10. Patch the approach slab or pavement.

*Not all agencies authorize the use of bonding agents.

10.2.4 Pier Caps

Pier caps are exposed to water and chlorides from leaking joints. Debris retains the moisture and chlorides and if not removed, subjects the cap to continuous exposure to these contaminates. Corrosion of the main longitudinal steel may cause the concrete cover to spall exposing the reinforcement to further corrosion. A horizontal crack along the face of the pier cap, 3 to 4 inches from the top, normally indicates that the top mat of rebars has expanded because of corrosion and has forced up (delaminated) the concrete. It is not uncommon to seea similar crack along the bottom of the cap.

A pier cap functions similar to a continuous beam, and repair considerations are similar. However, the method of repair and costs may be quite different depending on whether the repair can be performed in the dry or not. It may be possible to repair in the dry by scheduling for a certain time of year. Cofferdams may be possible depending on the streambed material, water depth, water velocity, and environmental requirements.

Figure 10.14: Pier Cap and Column in Need of Structural Rehabilitation

10.2.5 Spread Footings

Deterioration of concrete in spread footings can be caused by any of a number of corrosive chemicals which are often found in soils or groundwater. Geotechnical investigations should include evaluations of the presence of these types of chemicals. If they are found to be present, appropriate protective measures should be taken. A wide range of options exists including the use of special materials (or additives to standard materials), protective surface treatments and more frequent inspection and/or maintenance intervals.

Deterioration of the spread footing concrete can result in breaking off the footing projections or spalling the sides. Severe deterioration may be caused by ice and debris pounding against the upstream side of the footing, water penetration resulting in corrosion of the reinforcing steel, or poor material in the footing. The area of the footing must not be reduced, as the load of the bridge must be distributed uniformly upon the material under the footing. The repair of the footing proceeds as follows:

Footing Repair

1. Water must be kept clear of work area by means of diversion channels, cofferdams, sandbags or sheet piling is required.
2. Move the traffic to the opposite side of the bridge.
3. Install shoring and jack the superstructure to remove the loading on the element, if necessary.
4. Chip away the deteriorated concrete until sound concrete is reached. Clean away all loose concrete with air blast or other means.
5. Install reinforcing bar, anchors and rods if they are to be used.
6. Construct forms that are adequate to restore the footing dimensions to the original size. It is common to extent the footing to cover a large area and extent the sides downwards if undermining has occurred.
7. Apply an appropriate epoxy compound (if owner allows)* or a neat cement paste for bonding just prior to pouring the new concrete into the forms.
8. Mix and pour the new concrete using a strong mix with low slump. Vibrate the concrete thoroughly to ensure a dense pour and a good bond.
9. When the new concrete has been cured for at least three days, or longer if specified, remove the forms.
10. Replace loading on footing and remove jacking and shoring, if necessary.
11. Remove any cofferdam and restore the stream channel to its proper course.

*Not all agencies authorize the use of bonding agents.

Most piles require little maintenance because the material into which they are driven protects them, and subsurface damage or deterioration is not common at lower depths where oxygen concentrations are lower. Where piles are exposed, whether by design or by scour, there are potential problems. These problems include scaling and spalling of concrete piles, corrosion of metal piles or decay in timber piles and buckling in all types, if the unsupported length becomesexcessive.

It is not always safe to assume that a buried pile does not corrode. There have also been documented occurrences of corrosion of piles due to saturated soil and a high ground water-table.

10.2.6 Jacketing of Concrete Sub-structure Elements

Jackets are the most common type of pile protection or repair. They are used for protection of all types of piles: concrete, steel, and timber. The jacket can be for protection from abrasion damage, repair of section loss, or both. If the jacket were for protection only, it would consist ofa liner placed around the area to be protected with a cementitious grout or epoxy resin pumped into the annular opening between the existing concrete and the liner. If the jacket is intended to repair structural damage the liner will provide space for reinforcement and the space between the liner and old pile is filled with concrete. The liner (form) is often pre-molded fiberglass; however, it could be steel or fabric. Old drainpipes have been used as jacket liners. Figure 10.15 shows a standard concrete pile jacket with steel reinforcing cage.

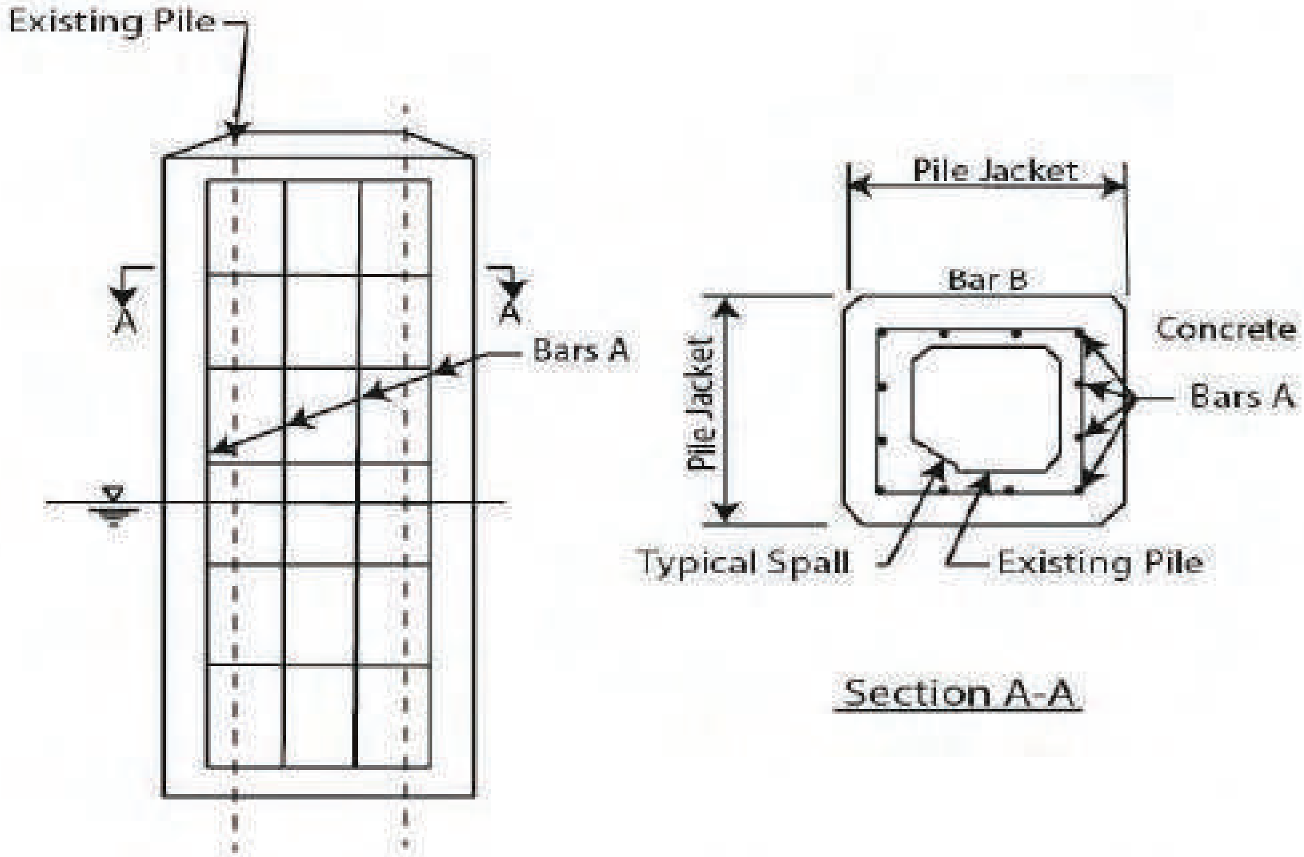


Figure 10.15: Concrete Pile Jacket with Steel Reinforcing Cage

Deteriorated reinforced concrete and prestressed concrete piles can be encased with a concrete jacket after all unsound concrete has been removed and the surface prepared as described previously. Encasement will compensate for the cross-sectional loss and strengthen the pile. Deteriorated concrete in a concrete pile should be removed until sound concrete is exposed. The reinforcing steel should then be cleaned of all rust and scale, and new concrete placed. Sufficient concrete should be removed so that new concrete is replaced to a minimum of 2 inches in depth.

Reinforcing steel cages or reinforcing wire is placed around the pile before forms are placed. The reinforcement is usually epoxy-coated for protection against corrosion. Stand-offs are placed on the reinforcement before they are drawn tight to the pile. Forms, either rigid or flexible, are then installed and sealed. Concrete is placed in the form either by tremie or dewatering the form if the concrete placement is below the waterline. After placing the concrete, the forms are either left in place permanently for further protection of the pile or removed when the concrete is cured.

Special requirements for the installation of concrete-filled pile jackets include qualified divers for underwater survey and repairs and a concrete pump for underwater placement.

Concrete-Filled Pile Jacket Installation

1. Scrap surface of the pile clean, removing deteriorated concrete or wood.
2. Sandblasting may be use to clean the exposed reinforcement in concrete piles above the water line. Splice with new reinforcement if required. Install steel mesh reinforcing cage around timber pile or concrete pile. Use spacers to keep the forming and reinforcement in proper position.
3. Place the forming jacket around piles and seal the bottom of form against pile surface.
4. Pump suitable concrete into form through opening at the top. Sulfate-resistant concrete should be used in salt-water locations.
5. Finish top portion of repaired area.

An example detail showing the installation of concrete-filled pile jackets is shown in Figure 16.

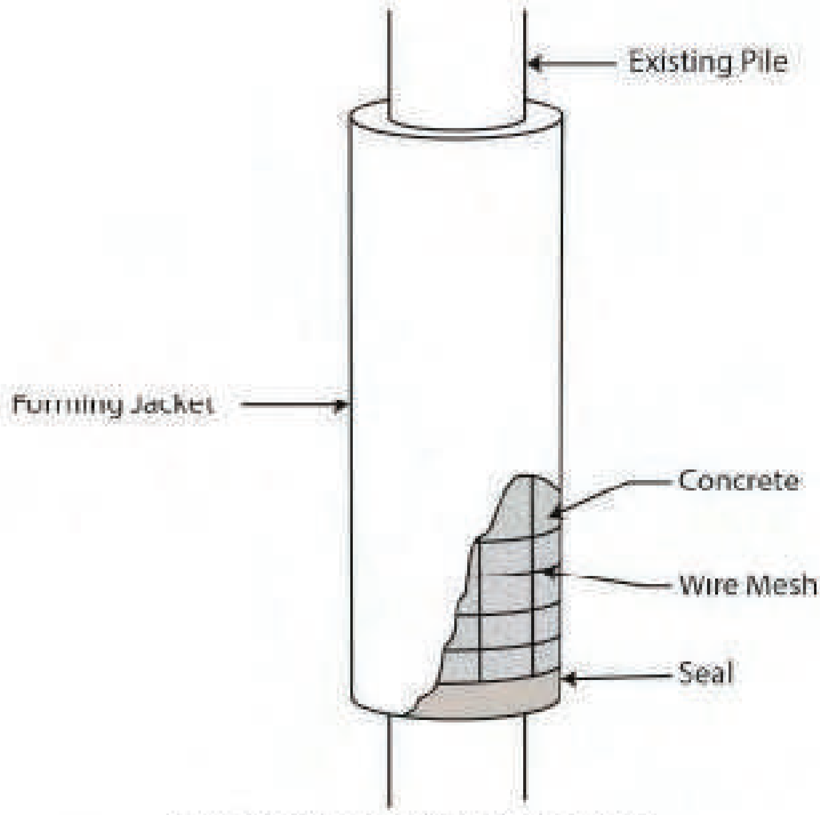
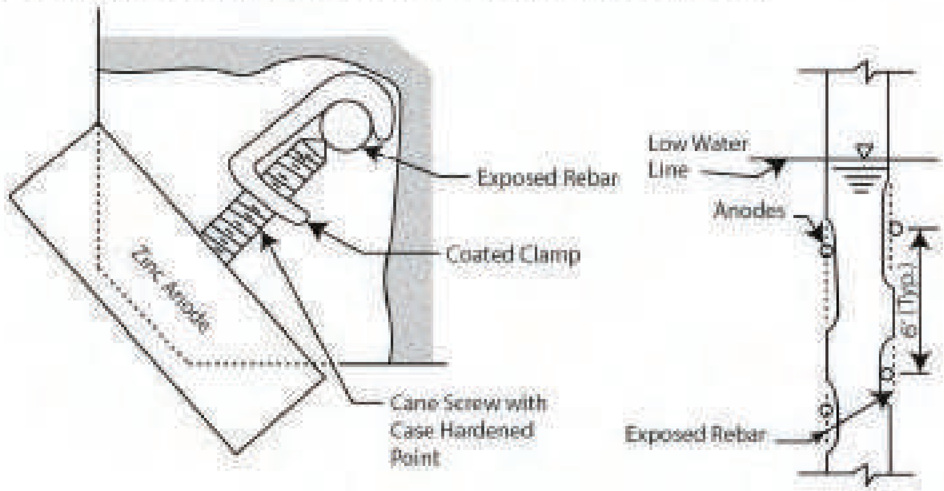


Figure 10.16: Concrete Pile Jacket Installation

Fiberglass forms can be used to construct pile jackets. The forms are light, can be easily installed, and create a watertight protective layer for the pile. Damage normally extends above and below the waterline. Deteriorated concrete is removed using high-pressure water jets. The jacket should extend approximately 2 feet beyond the damaged area at each end of the pile to account for any concrete segregation near the bottom or loose materials at the tops of the newconcrete. Welded wire fabric or a reinforcement cage is wrapped around the repair area.

Fiberglass forms have a vertical seam, so that it can be fitted around neatly, top and bottom centering devices and a bottom seal are placed. The form is secured in place with bolted ends and tightened to ensure full enclosure. If the length of the repair exceeds the length of the form, the piles may be repaired in two lifts. If the damage extends below the mudline, trenches are dug at the bottom to extend the repair into the mud zone.

Underwater, exposed reinforcing steel in concrete piles can be protected against corrosion by attaching zinc anodes to them, as shown in Figure 12.9. If the pile is repaired and jacketed, the reinforcing steel that is embedded in sound but chloride contaminated concrete has potential for corrosion. This corrosion and the subsequent concrete deterioration may be undetected because of the presence of the jacket. Attaching zinc anodes to the exposed reinforcing steel in the cavity prior to repair and jacketing can mitigate or stop the ongoing corrosion of the reinforcing steel in jacketed piles. Commercially available zinc anodes that are embedded in cementitious materials may be used for this purpose. Manufacturer recommendations should be followed.



a. Zinc Anode Rebar Attachent b. Anode Attachment Spacing

Figure 10.17: Galvanic Cathodic Protection of Concrete Piles (Underwater)

Filled shells are cast-in-place concrete piles. A metal shell is driven first, the mandrel withdrawn, and the shell is then filled with concrete. A problem that sometimes develops is corrosion of the shell due to deterioration of the concrete.

Cast-In Place Pile Repair

1. Erect temporary shoring bent to assume the load when necessary.
2. Remove rust and scale.
3. Prime and paint steel
4. Where both the shell and the concrete are damaged, remove the deteriorated portion of the shell and place a collar of sufficient strength and diameter placed around the pile.
5. Ensure the collar is extended well above and below the affected area and pressure inject a high quality, low shrinkage concrete, epoxy mortar or cementitious grout inside the collar to fill voids.
6. Compact the material so voids are completely eliminated.

10.2.7 Shotcrete for Sub-structure Surface Repairs

Shotcrete can be used in the repair of substructure concrete. Shotcrete is a concrete or mortar pneumatically projected at high velocity onto a surface. Shotcrete repair is effective for the repair of bridge beams, caps, piers, abutments, wing walls and decks. Since forms are not generally used for shotcrete, it is particularly effective on the underside of a deck for an overhead patch where there is no possibility of using a form.

The advantages of shotcrete are

- Superior bond
- Greater strength due to high density
- Low shrinkage
- Requires no formwork
- Ability to use in overhead repairs

The disadvantages of shotcrete are

- Space required for application
- Skill required for application
- Appearance and aesthetics
- High cost, particularly for small quantities

When the shotcrete method is used, no bonding agent is typically necessary. When the depth of the patch exceeds 3 inches, hook or expansion anchors should be used to secure to the existing concrete. When shotcrete patches are over traffic or public spaces, an anchorage system should be used regardless of patch depth. A typical anchorage system may consist of welded wire fabric (plain, galvanized, or epoxy coated) on 18-inch centers and 2-inch by 2-inch wire fabric hooked and wired to the anchors. This anchoring system may be repeated for every 3 inches of depth of the shotcrete applied 2-1/2 inches beyond that layer of steel, as shown in Figure 10.18. This provides an excellent anchor for the new concrete or shotcrete; if removal stopped at the plane of reinforcement, a cleavage plane is apt to develop at the interface between the old and the new concrete. Rust and other harmful a material should be removed from the reinforcing steel. Sandblasting should be used in those cracks where reinforcing steel is exposed because it cleans the concrete as well as the rust off the reinforcing steel.

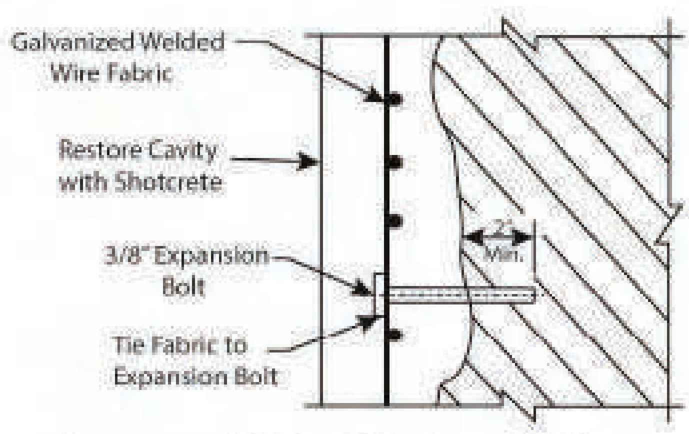


Figure 10.18: Welded Fire Fabric Anchorage for Shotcrete

Shotcrete Considerations

- Wet or Dry
- Surface Preparation
- Skilled Nozzleman
- Mix Design
- Alignment Control
- Finishing and Aesthetics
- Inclusion of Fibers

Shotcrete Surface Preparation

- Remove Loose or Unsound Material
- Transition Changes in Thickness
- Abrasive (or Hydro) Blast Surface
- Avoid Feathered Edges
- Pre-wet Surface

Shotcrete Mix Design Considerations

- Prepackaged Mix
- Cement/Aggregate (1/3-1/5)
- Low Water-Cement Ratio
- Superplasticizers (Wet Mix)
- Air-Entrainment (9-12 percent Wet Mix)
- 7-15 percent Silica Fume
- Accelerators

Shotcrete Application Considerations

- Assure Uniform Flow of Material
- Apply Thin Bond Coat First
- Maintain 90 Degree Nozzle Spray Angle
- Vary Angle Around Rebars
- Apply in Thick Layers
- Remove Rebound Ahead
- Cure to Avoid Cracking

10.2.8 Crack Repairs

Sealing cracks in substructure elements typically involves vertical or horizontal application ofthe material. However, before a method is identified for repairing a crack, it must be determined if the crack is working (i.e., active or growing) or not. If the crack is working itshould be filled with flexible material. If it is passive a bonding material such as an epoxy can be injected into the crack. It is also necessary to determine if the crack is full depth. This may be difficult if the crack is in an abutment.

Narrow cracks that a r e dormant may be effectively sealed by epoxy injection. The procedure can be applied to both horizontal and vertical surfaces, though low viscosity polymers can be applied by the gravity-feeding approach for horizontal surfaces. Cracks as narrow as 0.002 inches can be sealed and bonded by the injection of epoxy. The procedure has potential to provide structural repair (increase stiffness and strength) in addition to sealing the crack.

A footing may crack transversely due to uneven settlement of the pier or abutment. This will often be accompanied by a crack continuing up through the pier or abutment. It is advisable to seal the crack to prevent further intrusion of silt, debris, and water, which will attack the reinforcing steel. If the crack is moving it should be filled with a flexible material; otherwise, it will crack again. If the crack is not moving it can be bonded back together.

10.2.8.1 Epoxy Injection

The most effective method of repairing substructure vertical cracks is epoxy injection. Anexample of the installation ports is shown in Figure 10.19. The crack should be sealed full length(on both sides if it is a wall) before injecting the epoxy. Application of epoxy resin to seal the cracks is shown in Figure 10.20

Figure 10.19: Installation of Epoxy Injection Ports (Courtesy of MDOT)

Figure 10.20: Application of Epoxy Resin over Cracks Prior to Injecting (Courtesy of MDOT)

To get maximum penetration of the epoxy filler, the first injection is made at the bottom of the crack. Starting at the bottom and moving up in gradual increments toward the top increases thepressure needed to apply the e p o x y and should result in greater crack-filling penetration.

The injection progresses from port to port, normally starting at the lowest point, and continuinguntil epoxy is extruded from the next port. The distance between the ports should not exceed the expected penetration depth. A handgun or pressure pot can be used, but various types of machines are available that assure the proper proportioning, mixing, and temperature of the two-part epoxy and the proper injection pressure. This technique may also be used to fill isolated voids or delamination in concrete. In this case, injection pressure must not be too high.

10.3 Mechanisms that Move Sub-structures

To better understand how to repair concrete substructures, it is important to understand why the structures settle. The mechanisms that drive the movement of the substructures can be related to:

Slope failure (embankment slides): These are shear failures manifested as lateral movements of hillsides, cut slopes, or embankments. Footing or embankment loads imposing shear stressesgreater than the soil shear strength are common causes of slides. Slides usually occur during wet conditions which reduces the soil shear strength.

Bearing failures: Bearing failures are settlements or rotations of footings due to a shear failure in the underlying soil. When bearing or slope failures take place on an older structure, it usually indicates a change in subsurface conditions. This may endanger the security of nearby structures and foundations.

Consolidation: Serious settlement can result from consolidation action in cohesive soils. Settlement of bridge foundations may be caused by changes in the groundwater conditions from drawdown, the placement of additional embankments near the structure, or increases in the height of existing embankments.

Seepage: The flow of water from a point of higher elevation through the soil to a lower point is seepage. Seepage force acts on the soil through which the water is passing. Seepage results in lateral movement of retaining walls by:

- An increase in weight (and lateral pressure) of the backfill because of full or partial saturation.
- A reduction in resistance provided by the soil in front of the structure.

Water table variations: Large cyclic variations in the elevation of the water table in loose granular soils may lead to a compaction of the upper strata. Changes in the water table may also change the characteristics of the soil that supports the foundation. Changes in soil characteristics may, in turn, result in the lateral movement or the settlement of the foundation.

Frost action: Frost heave in soil is caused by the growth of ice lenses between the soil particles. Footings located above the frost line may suffer from the effects of frost heave and a loss in bearing capacity due to the subsequent softening of the soil. The vertical elements on light trestle bents may also be lifted by frost and ice actions.

Expansive soils: Some clays, when wet, absorb water and expand, placing large horizontal pressures on any wall retaining such soil. Structures founded on expansive clay may also experience vertical soil movements (reverse settlement).

Ice: Ice can cause lateral movement in two ways. Where fine-grained backfill is used in retaining structures and the water table is above the frost line, the expansion of freezing water will exert a very large force against a wall. The piers of river bridges are also subject to tremendouslateral loads when an ice jam occurs at the bridge.

Thermal forces: On structures without expansion bearings, or where the expansion bearings failto operate, thermal forces may tip the substructure units. Pavement thrust is another force thatwill have the same effect.

Drag forces: Additional embankment loads or very slow consolidation of a subsurface compressible stratum will exert vertical drag forces on the bearing piles which are driven through such material. This may cause yielding or failure of the piles.

All piles may develop weaknesses from deterioration, insect attacks, and construction defects. These weaknesses may lead to foundation settlement:

- Timber, steel, and concrete piles are subject to loss of section because of decay, rusting, and deterioration.
- Timber piles are vulnerable to marine borers and shipworms.
- Construction defects include overdriven piles, under-driven piles, and failure to fill pile shells completely with concrete or imperfect casings of a cast-in-place pile.

Settlement will probably be gradual in improperly driven piles or in piles with weak or voided concrete. Piles suffering severe loss of section due to rust, spalls, chemical action,or insect infestation may fail suddenly under heavy load.

Scour and erosion: Scour can cause extensive settlement and/or structural failure. Since water will carry off particles of soil in suspension, a considerable hole can be formed around piers or other similar structural objects. This condition results in a greater turbulence of water and an increased size of soil particles that can be displaced. Erosion of embankments due to improper drainage can also lead to approach and abutment settlements. A common occurrence is erosion loss of the toe of an embankment which is problematic because slope stability is reduced. The reduction in slope stability causes either surface failures or deeper subsurface slides.

Earth or rock embankments (stockpiles): Post-construction placement of embankments may cause instability since it will produce greater loads than were included in the original design.

10.3.1 Settlement Repairs

All foundations undergo some settlement. However, very small foundation movements have no effect. Simple span structures, and those with joints, will tolerate even moderate differential displacements with little difficulty other than minor cracking and the binding of end dams. Movements of large magnitudes, especially when differential, cause distress in nearly all structures. Tremie Concrete Scour Repair. Schematic with arrows indicating water level, one half inch diameter forming struts, welded wire mesh reinforcing, 12-gauge metal forming left in place, tremie concrete enclosement, heavy stone riprap to control future undermining. Large movements will cause deck joints to jam; slabs to crack; bearings to shift; substructures to crack, rotate, or slide; and superstructures to crack, buckle, and possibly, even to collapse. The larger the settlement to be accommodated within a given distance, the more structural damage can be anticipated.

10.3.2 Sensitivity of Bridges to Settlement

The types or settlement are categorized as:

1. **Uniform settlement**. A uniform settlement of all the foundations of a bridge will have little effect upon the structure. Small single-span bridges have experienced settlements of roughly 1 foot with no sign of appreciable distress.
2. **Differential settlement**. Differential settlement can produce serious distress in any bridge. Where the differential settlement occurs between different substructure units, the magnitude of the damage depends on the bridge type and span length. For example, a rigid frame arch type structure is so stiff any significant differential movement could produce large cracks. However, if the structure is tall and flexible and with superstructure joints over the piers it should be able to handle some settlement without severe distress in the concrete. Should a differential settlement take place beneath the footings of the same substructure, damage can vary from an opening of the vertical expansion joints between the wing wall and the abutment to severe tipping and cracking of walls or other members. Types of differential settlement include simple span and continuous span:
3. **Simple span differential settlement.** As mentioned, movements usually do not affect the strength of a simple span structure unless they are quite large. There are usually enough joints to permit the movements without major damage to the basic integrity of the structure. At most, some finger joints or bearing may require resetting, or beam supports may need shimming. However, pile bent or trestle bridges are very vulnerable since a large settlement or movement of a bent could cause the superstructure to fall off a narrow bridge seat, leading to the loss of the bridge spans.
4. **Continuous span differential settlement.** Differential movements seriously affect a continuous bridge, since such movements at supports will redistribute the loads, possibly causing large

overstresses. These bridges are very likely to be damaged if subjected displacements that are greater in magnitude or different in direction, from those considered in the original designs.

Following are the most common causes of foundation movement and are classified by the type of movement:

1. **Lateral movements** - Earth-retaining structures, such as abutments, wingwalls and retaining walls, are susceptible to lateral movements from either bending or sliding although piers sometimes also undergo such displacements. Both shallow and deep foundations are subject to lateral movement.
2. **Settlement (vertical movement)** - Any type of substructure not founded on solid rock maybe subject to settlement. Again, both shallow and deep foundations may settle. Settlement can be caused by:
    - Erosion of soil
    - Erosion of weathered or soluble rock
    - Inadequate bearing capacity of soil
3. **Rotation (tipping)** - Rotation can be considered to be the result of unsymmetrical settlements or lateral movements. It will be discussed under the movement that is typical of the various substructures.

The common causes of foundation movement leading to foundation failures are shown in Figure 10.21.

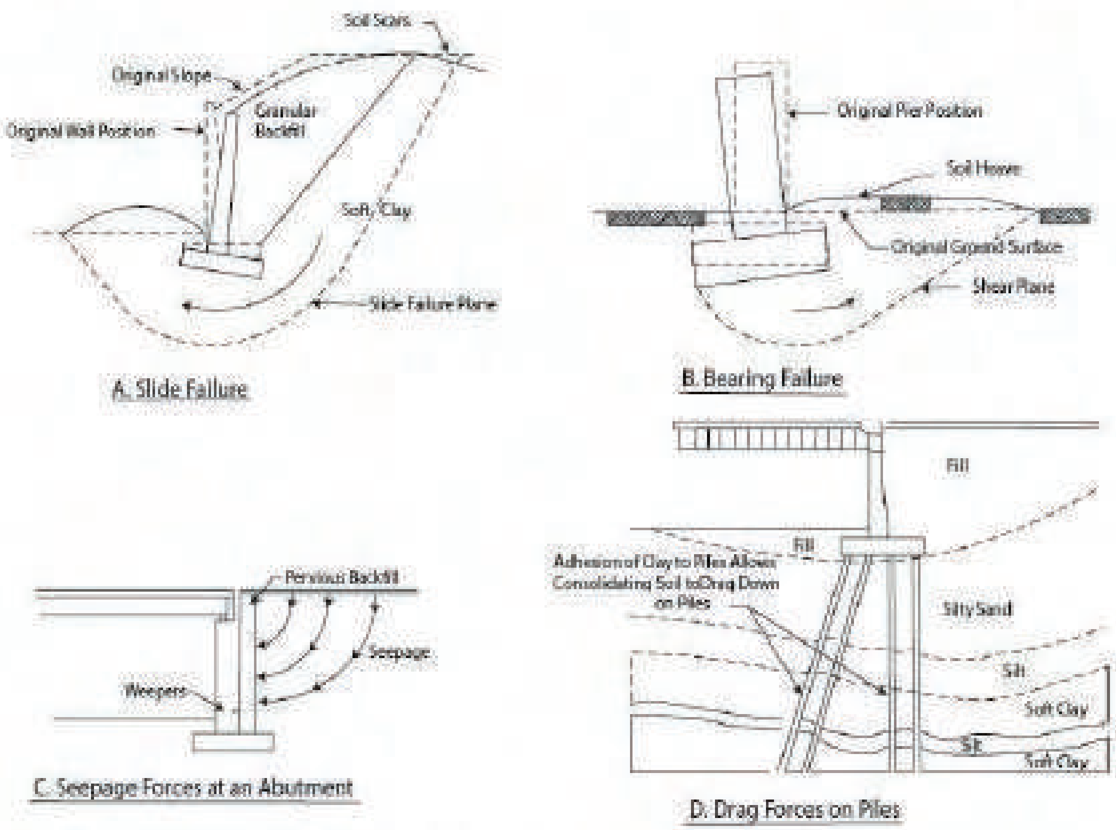


Figure 10.21: Common Causes of Foundation Failure

10.3.3 Repairs to Mitigate Underwater Differential Settlement

Channel scour can cause undermining of footings resulting in differential settlement of pier. Corrective work includes the following:

Preliminary planning includes

- Will shoring be required if the substructure will be lowered to an elevation below existing condition.
- Thoroughly evaluate condition of foundation under pier footing.
- Establish new elevation with footings leveled and stabilized.
- Design new bearing pedestals to bring superstructure to proper grade.

Resource requirements are

- Diving equipment
- Work boat
- Concrete drilling equipment
- Steel dowels
- Concrete pumping equipment
- High strength pre-tailored grout bags
- Reinforcing steel
- Jacks for bringing the superstructure to grade

A procedure for correcting underwater differential settlement follows:

Correction of Underwater Differential Settlement

1. Remove traffic
2. Install turbidity curtain and other devices to maintain water quality. Alternatively, cofferdam could be used, and repairs constructed in the dry.
3. Install concrete levelling still to ensure pier stability suring excavation. The still consists of an appropriately positioned concrete grout bag extending the entire width of the pier.
4. Remove protruding boulders under footing
5. Excavate to level footing using high-pressure water jets subjects to environment water quality requirements.
6. Instal grout bags and fill with pressurized concrete to mold to and completely fill the cavity under pier. Engineered design of scour countermeasures installed below the depth of total scour is required.
7. Place grout bags around periphery of pier to increase footing size and depth, thereby reducing further potential for undermining.
8. Install horizontal and vertical reinforcement through the grout bags.
9. Drill and grout dowels on 3-foot centers existing stem and footing to anchor new work.

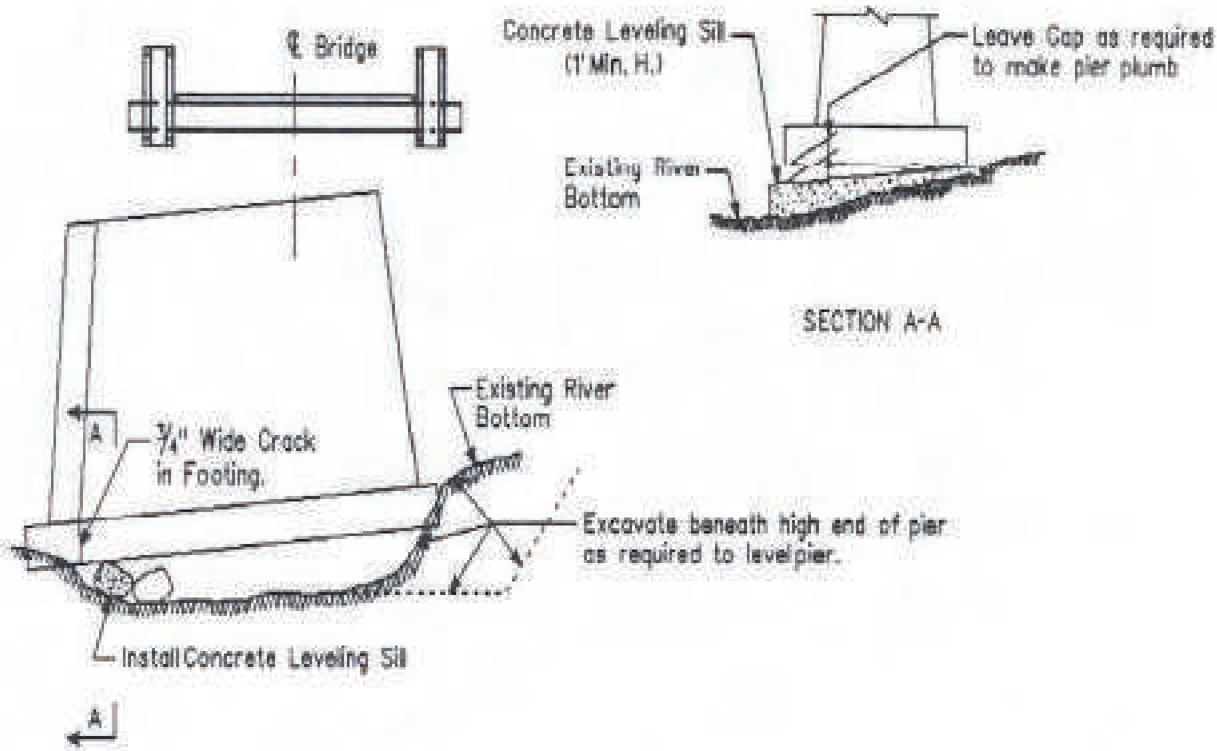


Figure 10.22: Pier Settlement Stabilization

Where serious settlement is expected (either due to live loads or seismic loads), a soils and/or structural engineer should be consulted prior to taking measures to prevent the damage to the abutment or pier. A footing that is resting upon piles may require additional piles to stabilize it.

Pier Settlement Stabilization Repair

1. Excavate around the footing.
2. Remove concrete to expose the edges of lower mat of reinforcing steel.
3. Clean the existing concrete and reinforcing steel.
4. Drive all additional new piles (not required for spread footing)
5. Form the new extended footing
6. Lap the new reinforcement to the existing exposed bars. If lapping is not feasible, drill and grout the new reinforcement to the existing concrete.
7. Place new top mat bars and the reinforcing cage.
8. Place and cure the concrete in the extended footing.
9. Backfill over the footing.

Figure 10.23 shows how additional piles could be added to the footing and the footing widenedand thickened

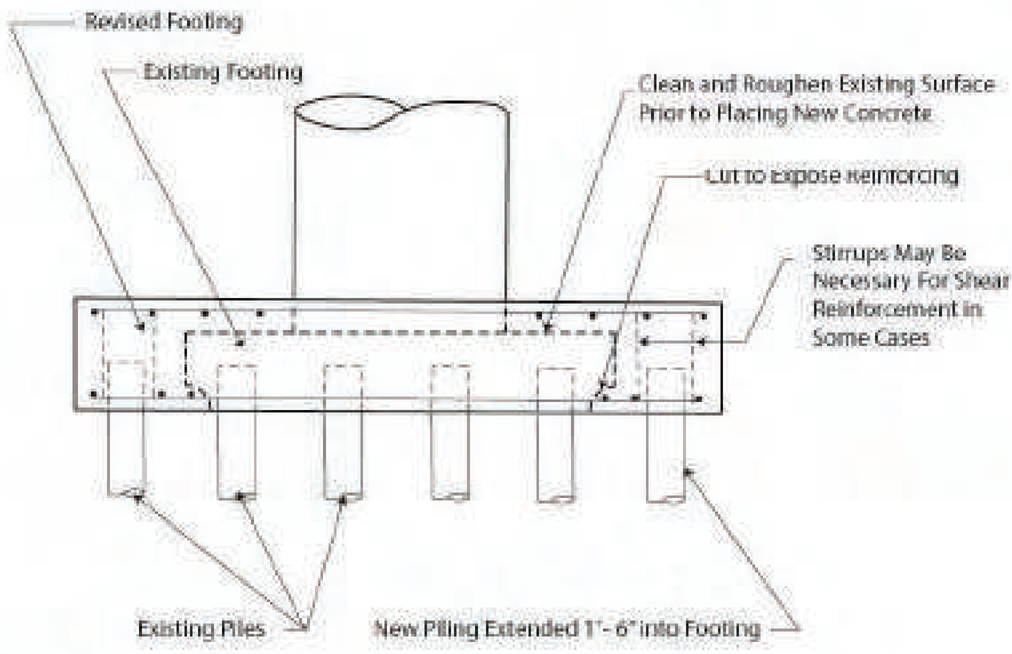


Figure 10.23: Increasing Live Load Capacity of Existing Footing

10.3.4 Undermining Repairs

When making repairs to bridge undermining the following should be considered:

- Has the undermining been previously repaired with an engineered solution to the scour problem?
- Will the repair be temporary or permanent? A temporary repair can be as simple as replacement of the eroded material back into the scour holes.
- Should the repair be engineered to ensure it extends to below the scour depth?

Most repairs for scour around bridge piers and abutments will involve the placement of both riprap and concrete. There are several special considerations that apply to the placement of these materials around bridge substructure units.

Placement of concrete to repair scour or undermining of substructure units usually requires either dewatering or underwater placement of concrete. In either case proper placement, good forms, and skilled personnel are essential. Dewatering may be accomplished by constructing cofferdams, or if environmental regulations permit, diversion of the flow away from the repair area. The primary disadvantage of dewatering with cofferdams is the clearance required for driving sheet piling. General precautions for concrete placement under wet or dry conditions include:

- An analysis should be performed to ensure that pile support would not be overloaded.
- Forms should be prevented from moving and should not be removed prematurely. Prebagged concrete or concrete pumped into fabric forms are often used in place of conventional forms.
- Concrete should not be placed in running water or be allowed to drop through water as this could wash the cement out of the concrete.

An example of an undermining repair is shown in Figure 10.25, showing (a) Existing conditions before the scour remediation work, (b) Access and mobilization to place water control, (c) Sandbag water control in place, (d) Dewatering operations, (e) Exposed footing showing undermining, and (f) Placement of concrete to fill voids under footing. The completed repair is shown in Figure 10.25.

Figure 10.24: Final Condition with Streambed Restored

Underwater placement can be accomplished by underwater tremie, pumping, bagged concrete, and prepacked concrete. Descriptions and special considerations for each of these methods are briefly discussed in the following paragraphs.

A tremie is a tube with a hopper at one end and a discharge gate at the other. It is used to place concrete under water by gravity flow. The discharge gate end is closed until the tremie is filled with concrete and lowered to the point where the concrete is to be placed. Once the pour begins, the discharge end must be kept submerged in the newly placed concrete and the tremiehopper must be kept filled with concrete. If this is not done, the pipe will fill with water. Multiple tremies are needed to reduce lateral travel and when reinforcing steel restricts the movement of the tube.

Figure 10.25: Undermining Repair Sequence

Placement of concrete by pumping is similar to tremie placement. Since, the concrete is pumped rather than gravity fed it is somewhat easier to control the discharge. A manifold can connect multiple hoses. Concrete can be placed underwater in bags made of a porous material such as burlap. The bags are partially filled with concrete and then placed by workmen in shallow water or by divers in deeper water. An example of grout bags used to prevent undermining is shown in Figure 12.18. Bags may be filled with dry concrete and wetted during placement. Concrete may also be pumped into fabric forms specially sized to fill a void under the footing. Prepacked concrete involves filling the forms with coarse aggregate and pumping in a grout. The grout displaces the water and fills the voids in the aggregate. Special equipment and techniques are required for this method.

Figure 10.26: Grout Bags Used to Prevent Undermining

10.3.5 Tremie Concrete Repairs

Undermining of footings that are not on piles can result in reduction of load capacity, settlement, tipping, or failure of the structure. Undermining of footings that are supported by piles can also be a serious problem. Exposure of the piling reduces the pile load capacity and exposes the piling to increased corrosion and abrasion. The load-carrying capacity of the bridge is also reduced because the footing has less support. Repair of undermined pier foundations is accomplished by the use of a tremie concrete encasement to fill the void and installation of riprap to prevent future undermining. An example of a tremie concrete scour repair is shown in Figure 10.27.

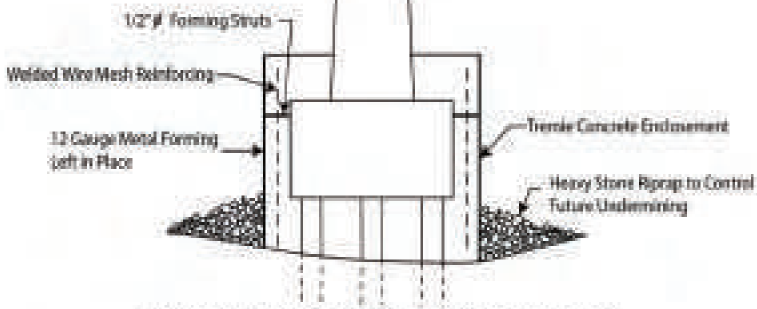


Figure 10.27: Tremie Concrete Scour Repair

Planning should include the following:

- Analyze the flow characteristics to determine the cause of the problem.
- Consider of the additional weight of the concrete encasement on the piling and soil foundation.
- Fabricate metal forming and reinforcement.

The following will be needed:

- Pile driving equipment if cofferdams are used
- Pumping or tremie concreting equipment
- Crane or other lifting equipment

Tremie Concrete Scour Repair

1. Clean all exposed concrete surfaces of aquatic growth and loose or deteriorated concrete to ensure a good bond.
2. Place welded wire mesh around the footing. Rebars may sometimes be used to withstand shear load if the encasement significantly spreads the footing.
3. Set forms and pour tremie concrete.
4. Leave metal forms in place.

An alternate to the preceding procedure is to substitute dry-mixed concrete riprap in bags forthe steel forms, as shown in Figure 10.31 below.

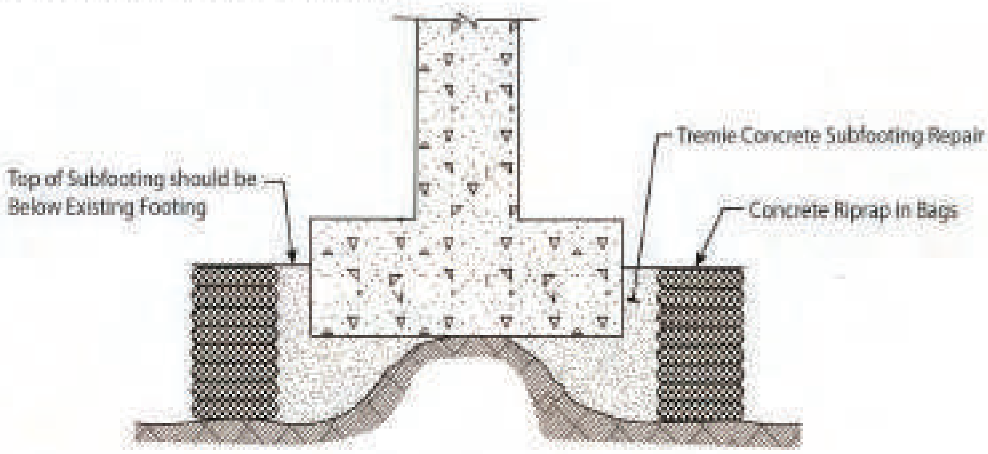


Figure 10.28: Bagged Riprap Scour Repair

10.3.6 Mortar Filled Tube Scour Repair

For small voids under the footings, a technique using fabric tubes filled with mortar and grout injection pipes is an alternative that can prove to be cost effective. See Figure 10.32 for an example of tremie repair using fabric tubes.

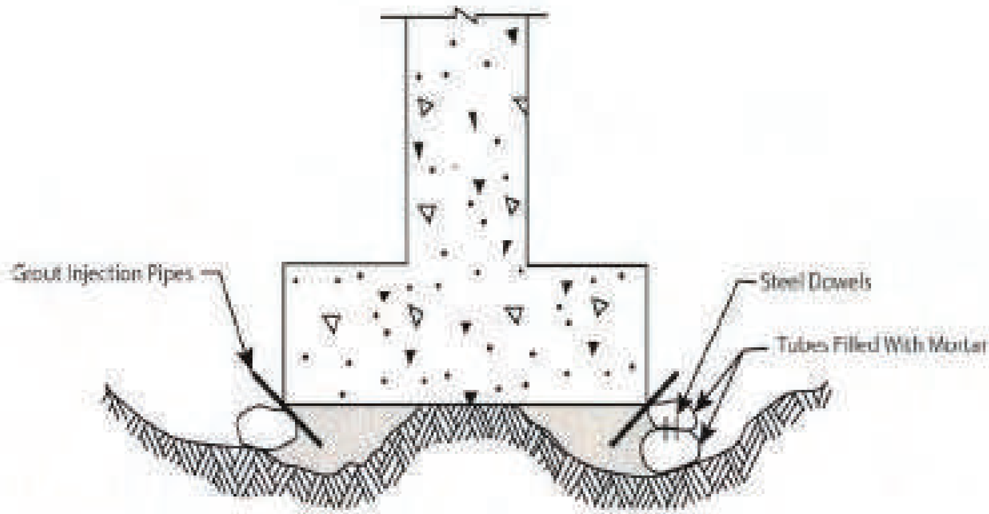


Figure 10.29: Mortar Filled Tube Scour Repair

10.3.7 Eroded Scour Repair

The undermining of abutment footings results from causes similar to the undermining of pier footings. The consequences are also similar with the additional hazard that the abutment is likely to be asymmetrically, not evenly, loaded due to the approach fill pushing against it. These forces may tend to tip the abutment toward the streambed. The magnitude of asymmetric loads, as well as dead men that may have been provided to resist the loads, should be ascertained in evaluating safe conditions during repair. See Figure 10.33 for an example of eroded scour repair.

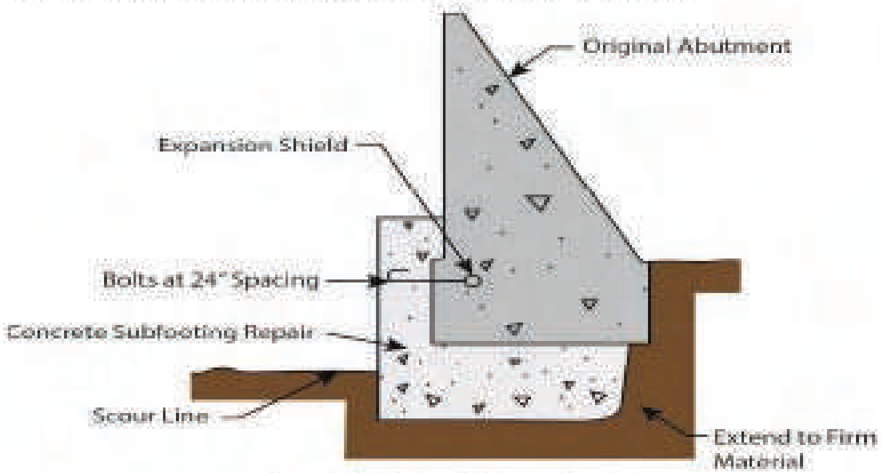


Figure 10.30: Eroded Scour Repair

Planning for the work must include the following:

- Analyze the flow characteristics to determine the cause of the problem.
- Evaluate safety problems during repair due to potential instability of the abutment.
- Analyze the hydraulic effect of stone riprap on the flow through the opening under the bridge

The following equipment is usually needed:

- Equipment for placing riprap
- Pile driving equipment if needed to form the new footing
- Crane or other lifting equipment
- Concrete drilling equipment

- Concrete pump and tremie equipment

Eroded Scour Repair

1. Remove loose material and silt from the foundation area.
2. Clean exposed concrete surfaces that will interface with subfooting.
3. Drill holes on 2-foot centers in existing concrete and install anchors.
4. Erect forms for the face of the subfooting.
5. Place concrete for subfooting using mix that is sufficiently plastic to fill all voids
6. After the concrete has eached design strength, remove the forms and add stone riprap. Hint: What size rock is not getting washed downstream. Use riprap equal to this size or larger.

10.3.8 Streambed Repair

The effectiveness of rebuilding a streambed depends on whether the scour problem is isolated in an area around the bridge or whether the streambed has been generally lowered. When the streambed has been generally lowered, it is best to extend the concrete footings below the scour line. This takes advantage of the deeper channel to reduce flow velocities. This procedurealso aids in minimizing the construction of the channel by placement of riprap. Maintaining the maximum possible depth and width of a channel aids in reducing flow velocities which in turn reduces the scour action and the probability that any riprap used will be undermined or dislodged. An example of streambed paving repair is shown in Figure 10.34.

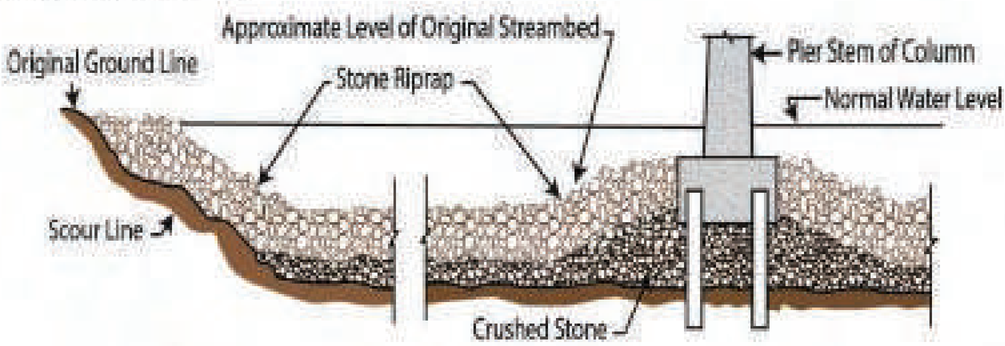


Figure 10.31: Streambed Paving Repair

The planning should include the following:

- Determine whether the streambed is generally lowered.
- Determine whether the extension of concrete footings below the scour line is feasible.
- Determine the velocity of flow and the size of riprap and crushed stone necessary to resist the scour.

The following material and equipment are required:

- Riprap, stone, or crushed stone
- Equipment such as front-end loaders, excavators, or cranes to place the material.

10.3.9 Streambed Paving Repair

1. Place crushed stone in the channel to an elevation approximately 2 feet below the proposed top of the stream bed taking care to fill voids below the footings.

2. Add a layer of appropriately sized riprap for the stream over the crushed stone. Engineer should be contacted to determine the appropriate size and weight of riprap. The riprap should above the high-water line at both sides of the channel.

10.3.10 Riprap Placement

The following factors should be considered when placing riprap around piers or abutments:

- Care must be exercised when dumping riprap around existing structural units. The large stones required can easily chip or break the concrete elements. Placement of riprap around piers must often be done from a barge.
- Placement should be made in even lifts to avoid unbalanced loads on footings.
- An analysis should be made to ensure that footings or pile supports would not be overloaded.
- The stone must be of suitable size for the anticipated flow conditions.

Riprap should not extend above the original streambed. Riprap that extends above the original streambed will act as an obstruction. The turbulence resulting from riprap improperly placed around a pier can cause localized scour at other piers or at the abutments. See Chapter 15 – Channel and Waterway for more details.

Planning must include the following:

- Evaluate the condition of the structure and the foundation to determine whether it is repairable and whether the pier can be stabilized in its present location.
- Evaluate the need for temporary supports until repairs are complete when traffic must continue to use the bridge.
- Design the stem enlargement and fabricated reinforcement.

10.3.11 Miscellaneous Abutment Repairs

10.3.11.1 Repairs to Mitigate Lateral Movement in Abutments

The force of earth and stone in the bridge approach behind the bridge abutment tends to push the abutment forward and may tend to rotate (tip over) the abutment. These forces may exceed the resistance of the abutment if the fill behind the abutment is unstable or the abutment is not adequately anchored. An example of such as situation is the mounding of material in the median to prevent errant vehicles from traversing down the abutment slope.

Deadmen are used to provide a counter force to shoving or overturning pressures on the substructure. Deadmen are heavy masses (weights), usually concrete blocks, attached to the abutment with long steel rod. The deadmen are located in stable earth well behind the abutment to provide an anchor that prevents overturning of the abutment. See Figure 10.35 for a schematic of a deadman anchor installation.

Planning includes:

- Calculations to determine the magnitude of the forces to be resisted by the deadman
- Determining the required size of deadman, size of restraining rod and whether piles are required.

The resources required will include:

- Excavation equipment
- Concrete
- Miscellaneous hand tools

- Light lifting equipment
- Drills

Deadman Installation

1. Excavate the area where the deadman are to be placed and provide a trench for the restraining rods.
2. Drive piles for the deadman, if required.
3. Place framework and concrete for the deadman. Note that the side of the deadman facing the abutment should be cast without forms. All forms may be eliminated if the condition of the excavation permits.
4. Drill through the abutment stem, the portion below the seat, and place the restraining rods. Wrap and cast with tar or provide other means to protect rods from corrosion.
5. Bolt the restraining rods at the deadman.
6. Place the water beams and tighten the rods (See figure 10.32)
7. Grout holes in backwall. Back fill.

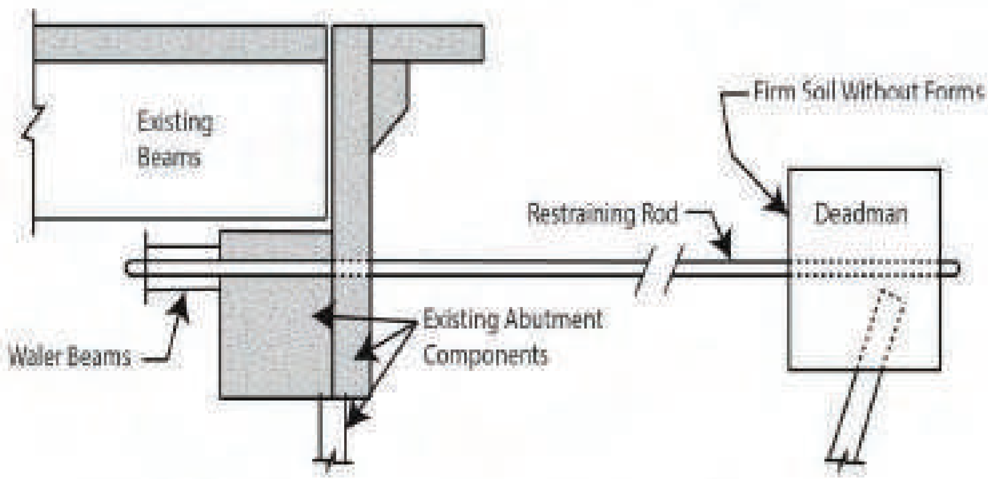


Figure 10.32: Installation of a Deadman Anchor

10.3.11.2 Bridge Seat Repair

If spalling and deterioration of the bridge seat concrete underneath a bearing is found to be severe enough and failure of the beam seat is imminent, repairs should be performed in these areas. The following is a suggested procedure for repairing spalled concrete bridge seats.

Repair of Spalled Bridge Seat Concrete

1. Install traffic control devices (if necessary) and secure the work zone.
2. Jack the existing superstructure, if necessary, depending on the extent of the concrete deterioration.
3. Remove the existing bearing devices.
4. The limits of the repairs shall be sawcut (or other) along neat lines to a depth of 1 inch where practical to produce a clean edge. Remove deteriorated and unsound concrete. If removal exposes reinforcing steel, if over 50 percent of any bar is exposed, removal shall extend an additional 1 inch beyond the bar. Missing or deteriorated reinforcing steel shall be replaced

5. Once removal of concrete is performed, if there is exposed reinforcing steel it shall be cleaned by mechanical cleaning and high pressure washing with water that contains to detergents or bond inhibiting chemicals. Where reinforcing steel has corrosion, it shall be sandblasted to a white metal finish. If it is found that existing concrete is unreinforced, dowels or concrete anchors may be required to ensure the new concrete bonds and does not "pop out" of existing concrete.
6. Where new concrete is placed in contact with existing concrete, owner specifications shall be followed. If no specification exists, epoxy bonding compound shall be used in accordance with the manufacturer's instructions and applied to the existing concrete prior to placement of repair material.
7. Place new concrete material.
8. Allow a minimum of 3 to 7 days for the concrete to cure (at the discretion of the owner/agency) prior to installing bearing devices and lowering the superstructure.
9. Install bearing devices
10. Lower the superstructure back into proper position.

Particular attention should be given to older unreinforced bearing seats. When unreinforced bearing seats start to deteriorate, rapid deterioration from freeze and thaw cycles can produce substantial bearing loss over a short period. This is because the concrete in unreinforcedbearing seats is not confined by the rebar.

10.4 FRP Repairs

Fiber reinforced polymers (FRP) fabrics are used to increase the axial and shear capacity of concrete columns and also to protect columns against intrusion of corrosive and deleterious materials. In seismic areas, these fabrics are primarily used to strengthen columns against earthquake loads. For column wrapping, FRP with carbon fibers are usually preferred to FRP with glass fibers. Although slightly more expensive, FRP with carbon fibers offer higher tensile strength, i.e., 350 ksi versus 220 ksi.

It is important that prior to wrapping a column, the condition of the concrete is assessed forany evidence that sound concrete may be critically contaminated with chlorides. If chlorides arepresent in the sound concrete, there is potential for corrosion of the reinforcing steel and deterioration of column after it is wrapped, which may be difficult to inspect. Thus, if tests show that concrete is critically contaminated with chlorides, one of the following measures maybe taken:

- Do not wrap the column.
- Extract the chlorides from the column by electro-chemical methods prior to wrapping the column. This procedure requires a specialized contractor and can take up to 2 months.
- Admix a corrosion inhibitor in the repair/patch concrete. Subsequent to repair, apply an effective spray-on type corrosion inhibitor on all unrepaired surfaces. Let the surface completely dry before wrapping the column. This procedure is only recommended when the concrete is not heavily contaminated with chlorides. An engineer should assess the condition of the concrete and approve wrapping the column. The corrosion inhibitor manufacturer recommendations should be closely followed.

A clean concrete substrate is essential to the effectiveness of the FRP system in achieving the design strength and the intended design objectives. It is necessary to completely clean the substrate of any bond inhibiting materials and residue to accommodate the successful application of the FRP system Cleaning may be performed with blast cleaning, air blower, pressure washing or other equivalent means. Air cleaning equipment must be equipped with oil traps. The cleaned surface must be protected against re-deposit of any bond inhibiting materials prior to the application ofthe FRP system.

All defective areas of concrete must be removed prior to installing a FRP. First examine the existing conditions to assess the quality of the concrete substrate, identify potential obstructions, and verify the dimensions and geometries necessary for placement. Defects may include loose and broken debris or delaminated and spalled sections of concrete, voids and honeycombs, and deteriorated concrete. Any void larger than 1/2 inch in diameter and depth should be filled with repair material. The repair material should have strength greater to, or equal to the strength of the original concrete, but no less than 4.5 and 5.5 ksi at 7 and 28 days.If moisture intrusion is significant, water protection, weep holes, and water conveyance must be provided before full reconstruction.

FRP wraps are only effective when they are fully bonded to the substrate. FRP is considered a bond-critical application. If the bond fails, so does the FRP repair. Checking for bond can be as simple as looking for air bubbles and pockets to using nondestructive testing such as ultrasonic scanning or infrared thermography. Most construction specifications also require sample test specimens that can be sent to the laboratory where destructive bonding tests can be performed.

To ensure the FRP is in full contact with the substrate, all surfaces should be freshly exposed and free of loose or unsound materials (abrasive or water-blasting techniques). Any localized out-of-plane variations (form lines) should not exceed 1/32 inches. All irregular surfaces or variations should be ground away or smoothed over with an epoxy putty.

All cracks in the substrate wider than 0.01 inch should be filled using pressure injection of epoxy according to specifications (see section on crack repair). The crack should be free of loose, unsound or bond inhibiting materials such as oil, efflorescence or moisture. NCHRP Report 514, ACI 546R, and ICRI 03730 list recommendations and provides guidance for the installation of bond critical applications.

Movement of cracks wider than 0.01 inch may cause delamination or fiber crushing in externally bonded FRP systems. Crack injection helps restore concrete strength and prevent water leakage behind the FRP system. Ambient and concrete surface temperatures should be within 50 oF to 95 oF or as per the resin manufacturer recommendations. Moisture levels on all contact surfaces should be less that 10 percent at the time of installation of the FRP system. Moisture on fiber sheets can cause problems with wet-out and cure of the system. Surface moisture should be measured with a mortar moisture meter, or alternatively, an absorbent paper.

Application of the system should not proceed if any moisture vapor transmission is present. Moisture vapor transmission from concrete surface through uncured resin may cause air pockets and surface bubbles, compromising the bond between the FRP system and the concrete. Any bubbles that develop from moisture vapor transmission can effectively be injected with an epoxy filler. However, some manufacturers use moisture to activate the bonding resin. All applications should follow the instructions of the manufacturer. In most applications, the FRP system can be applied while the structure is in service. Shoring may be provided to either support the existing structure prior to repair, or to reduce its initial deflections prior to strengthening. Shoring can also be used to induce an initial camber in the system, effectively stressing the FRP system.

Necessary equipment for installation will vary depending on the system requirements. The equipment may include:

- Resin Impregnators
- Rollers
- Sprayers
- Lifting/Positioning Devices

Column Wrapping

Note: Manufacturer guidelines shall be followed for any specific application.

1. Surface preparation and column wrap should include the full exposed column height plus 2 feet below ground.
2. All concrete surfaces should be repaired (including spalls and delaminations) and epoxy injection crack sealing performed. Surface should be free of sharp edges that can damage the fabric. Surface voids and depressions should be filled with epoxy.
3. Surface should be completely dry at the time of application of fabric. Newly repaired or patched surface should be cured at least 7 days prior to wrapping.
4. One prime coat of manufacturer's epoxy should be applied to the surface and should be allowed to become tacky to touch
5. Fabric, usually about 2 to 3 feet wide, should be saturated at the job site with resin (usually epoxy) as per the specified fiber-resin ratio.
6. Saturated fabric should be wrapped around the column by hand lay-up using methods that produce a uniform, constant tensile force that is distributed across the entire width of fabric.
7. Entrapped air, if any, should be rolled out before the resin sets.
8. Subsequent layer(s) should be applied continuously (or spliced) until specified number of layers is achieved at a section. Adjacent sections should utilize a butt joint.
9. The system should be protected against water and rainfall for at least 4 days following installation.
10. After the system is cured, a protective/aesthetic top coat is applied fiberwrap surface.

Wet lay-up systems may be installed using dry or pre-pregnated fiber sheets and saturants. Alternatively, wet lay-up systems can be applied using special equipment, such as a saturator, which will automate and speed up the installation process.

The term resin is a generic nomenclature used to identify all polymers employed in wet lay-up systems. Depending on its function, resin is more specifically identified as primer, putty and saturant. It should be noted that not all FRP systems utilize putty. Care should be taken when fully mixing the two-part resins, as excessive agitation using electric mixers may cause froth and bubbles to form, resulting in voids in the mixture. The viscosity of a mixed resin that has exceeded its pot life will continue to increase, adversely affecting its ability to penetrate the concrete surface or saturate the fiber sheet. Primer is to be applied to the concrete surface to penetrate the open pores using a brush or a clean roller. The primer will effectively help hatch and strengthen the external layer of concrete and will improve the bond between the concrete substrate and the FRP system. The primary function of the putty (if used) is to provide a smooth concrete surface. Adding silica sand to the putty may improve its stability and prevent swelling. The resin that impregnates the fibers is the key component to form the FRP laminate that repair or retrofits the concrete member. The rate of coverage of the resin is listed on the materials data sheet supplied by the manufacturer. The amount generally depends on the type of resin, the ambient temperature, and the fiber sheets prior to curing. This installation procedure is applicable to a single fiber sheet or the first fiber sheet or ply in a multi-ply application, as shown in Figure 10.36. Alternatively, the fiber sheet may be separately impregnated using a resin-impregnating machine before placement on the concrete surface.

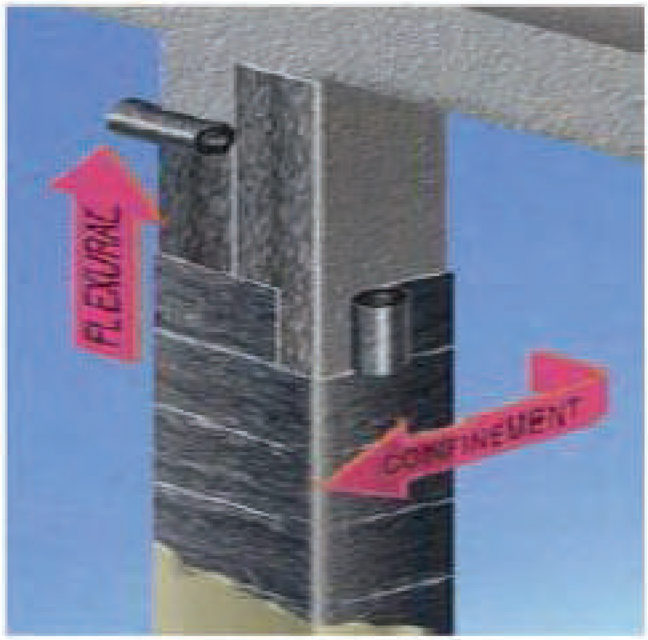


Figure 10.33: Advantages of Multi-Ply FRP Application

For ease of handling and to avoid wrinkling, fiber sheets are typically cut in segments shorter than 15-to-20-foot lengths. Metal serrated rollers are often used to force resin between the fibers and to remove entrapped air. However, caution should be taken not to use excessive forces, as rupture of the fibers could occur. Equally important is that rolling must be performed parallel to the fiber direction. Given the vast number of such systems, the method of placement can vary by manufacturer. It is best to follow the recommendations of the manufacturer regarding the timing and sequence of stacking, overlap and banding, horizontal and vertical joints, staggering of splices and overlap and butt joints.

Use appropriate safety protection while cutting pre-cured sheets. Use appropriate safety protection while cutting pre-cured sheets. The FRP system should be allowed to cure as recommended by the manufacturer. Curing is a time and temperature dependent process and can take up to several days in ambient temperature. In some FRP systems, pressure must be continuously applied through external means to prevent sag and pull-off during cure. Temporary protection in the form of plastic screening or tenting may protect the system while installation or curing is underway. Rain, dust, dirt, excessive sunlight, extreme temperatures, high humidity and vandalism are common threats that can be lessened with protection during construction.

Sharp corners should be rounded by grinding to a minimum ¾-inch radius (Figure 10.34). Rounding the corners prevents stress concentrations and voids between the FRP and the concrete. Surface irregularities should be ground smooth and all surfaces should be flat or convex to ensure full bonding of the FRP to the substrate. Large voids should be filled with a repair material compatible with the existing concrete.

Various applications for the use of FRP in the repair and rehabilitation of concrete substructures are shown in Figure 10.35 through Figure 10.37.

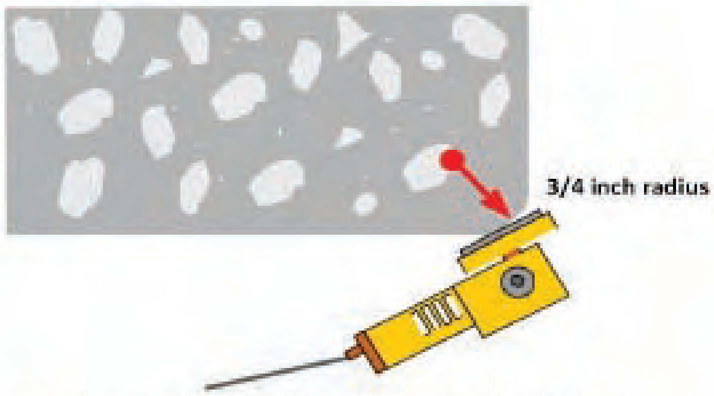


Figure 10.34: Grind Sharp Corners to 3/4 Inch Radius

Figure 10.35: Strengthening a Spandrel Arch with FRP

Figure 10.36: Pedestal Repair with FRP

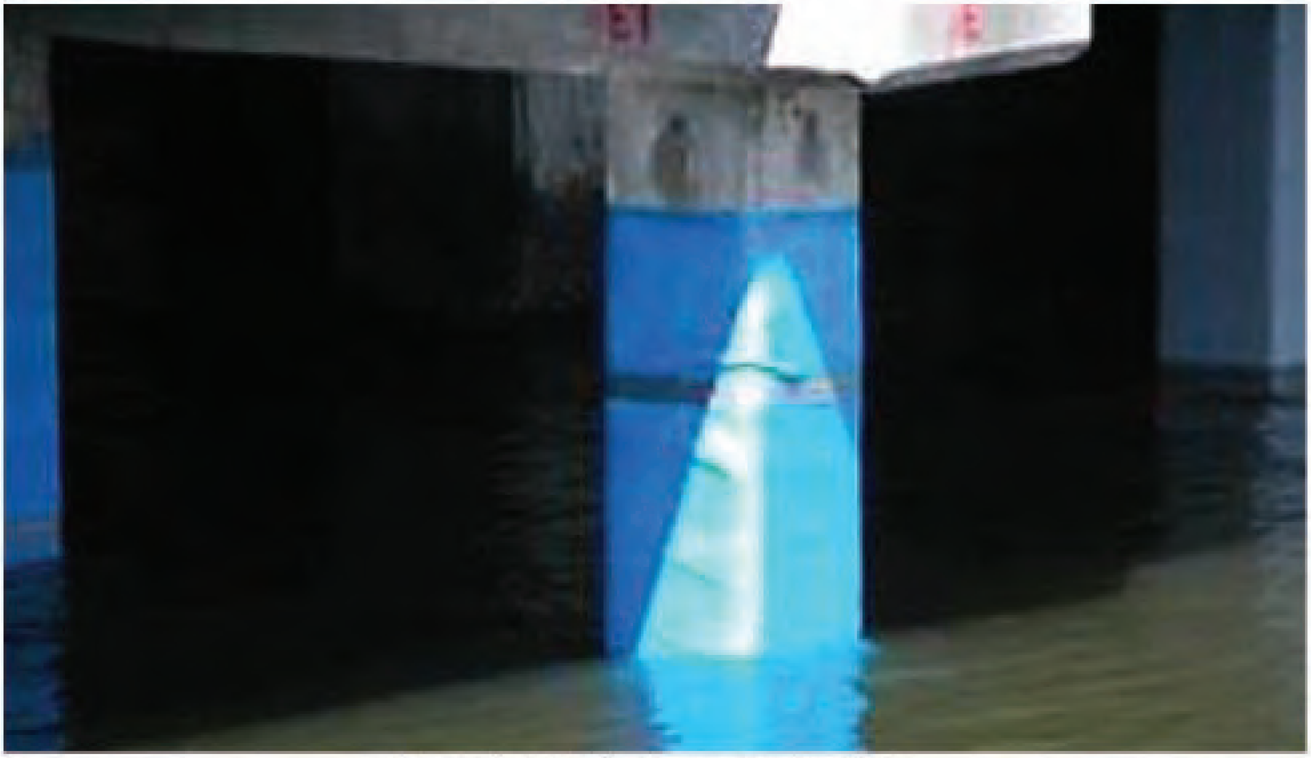


Figure 10.37: Completed Column Repair with FRP

10.5 Post-Tensioning Piers and Bents

Concrete pier caps may develop cracking due to flexure and/or shear. External post-tensioning may be applied to reduce crack growth rate and to strengthen the cap. A competent engineer should design this type of repair before the repair is initiated.

Application of Post-Tensioning Piers

1. Epoxy inject all cracks in the pier cap and allow the epoxy to harden.
2. Obtain steel cables (or rods) for post-tensioning and PVC, HDPE, or polypropylene pipes as ducts for the bars for corrosion protection. Note that HDPE or polypropylene piping is preferred over PVC for greater environmental resistance and higher ductility.
3. Erect all PVC pipe supports at both sides of the pier cap. Locate existing stirrups and horizontal bars in the cap prior to installing expansion bolts for the supports.
4. Erect PVC pipes (with post-tensioning steel inside) to the supports on the pier cap.
5. Erect post-tensioning anchorage assembly at the both ends of the pier cap.
6. Post-tension the system to the required load per bar. Use a sequence to balance the loads during post-tensioning.
7. Grout the ducts and seal the post-tensioning anchorage to prevent moisture penetration which can cause corrosion.

An example of external post-tensioning rods used in pier containment is shown in Figure 10.38

Figure 10.38: External Post-Tensioning Rods used in Pier Containment

10.6 Spalling/Exposed Rebar of Bored Pile

Due to scouring some of bored pile head areas below a pile cap appear above ground surface with spalling cover concrete/missing concrete section and exposing rebar. Main cause of spalling can be supposed as lack of pile head treatment length, meanwhile, missing concrete section can be supposed as wrong measurement of the pile top elevation.

Patching Maintenance of bored concrete pile is performed to restore small areas where sound concrete is damaged by spalling, scaling and impact. This method of Maintenance is generally applied using trowel and require none or minimum formworks.

The other hand, Filling pile concrete is performed to restore missing concrete section of the bored pile where concrete of the section missed due to wrong measurement of the pile top elevation. Patching of pile concrete is applicable to the piles whose concrete spalling with rebar exposure. Patching of pile concrete applies to polymer cement mortar. Filling pile concrete is applicable to the pile which has missing section of concrete with rebar exposure. Filled concrete is Portland cement.

Photo 10.39: Missing concrete and Exposed rebar

Table 10.2: Specifications of Polymer Cement

Property	Test Method	Unit	Specifications
Thermal Expansion	ASTM C531	mm/mm C	2.0 x 10-5
Slant Shear Bond to Concrete	ASTM C882	N/mm2	1.5 /above
Compressive Strength (7days x 20)	ASTM C57917	N/mm2	20 /above

1. **Corrosion Protective Coating**

The Protective Coating of rebar shall conform with the requirements of the specifications in Table 10.3.

Table 10.3: Specifications of Corrosion Protective Coating to Rebar

Property	Test Method	Unit	Specifications
Compressive Strength	ASTM D695M	N/mm2	75
Flexural Strength	ASTM D790M	N/mm2	40
Tensile Strength	ASTM D638M	N/mm2	30
Tensile Shear Bond to Steel	ASTM D1002	N/mm2	10
Slant Shear Bond to Mortar	ASTM C882	N/mm2	15

2. **Excavation**

Excavate surrounding soil of the pile until damaged depth plus 20 cm. Temporary cofferdams by such as sand bags and a submersible pump shall be considered, if necessary. With consideration of safety, in case, excavation depth is required deeper than 1.0m, a new pile shall be constructed just nearby the damage pile.

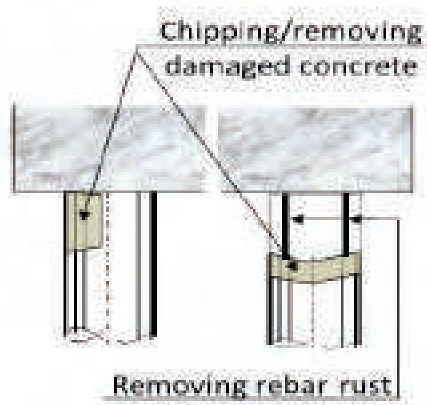


Figure 10.40: Chipping/removing damaged concrete

3. **Chipping/removing damaged concrete**

Damaged concrete shall be removed by chipping works using an electrical jack hammer, chisel. Surface of the concrete shall be clean and dry. Brushing or high-pressured air blowing will be applicable to this work.

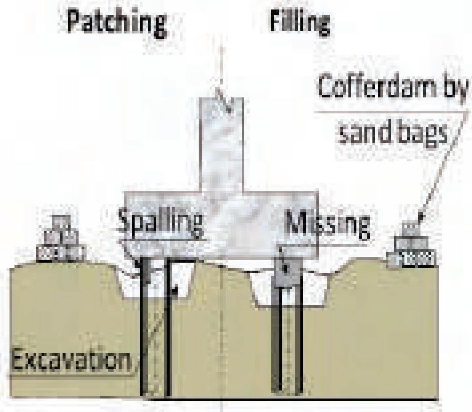


Figure 10.41: Chipping/removing damaged concrete

4. **Removing rust from rebar**

   Rust of rebar shall be removed by using wire brush. Zinc rich primer shall be applied on the rebar surface after removing rust immediately.

5. **Applying Epoxy primer**

   After curing zinc rich primer on rebar, Epoxy primer shall be applied on the concrete and rebar surface under dust and water free condition.

6. **Installation of formworks**

   Patching of pile concrete will not require form works. Filling concrete will require formworks which are10 cm or bigger than the pile radius, however, it is considerable to use surrounding soil wall instead of formwork. Formworks shall be considered concrete pouring mouth and concrete flow checking windows. The formworks shall be installed on gravel foundation which protects penetration of soil and mud into the formworks.

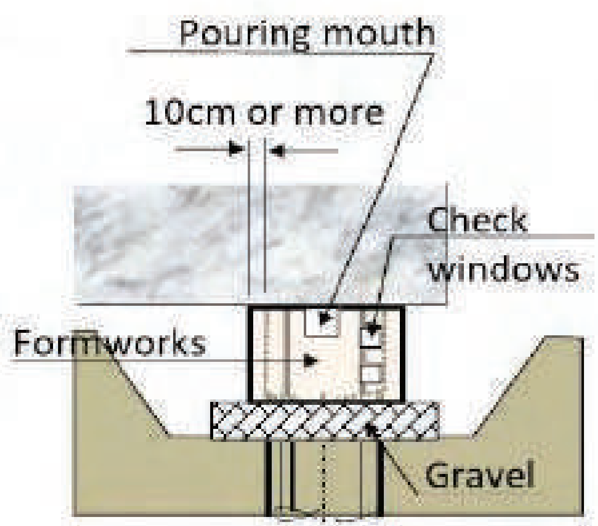


Figure 10.42: Installation of formworks

10.7 Applying polymer mortar/Pouring concrete

i) Applying polymer mortar - The mortar should be placed in layers of about 20mm thickness. Compact each layer thoroughly over the entire surface using a wooden trowel or hammer. Generally, there should be no time delays between the placing and compacting of layers. The Maintenance mortar shall be mixed using equipment (normally a force action mixer) of a type approved by the Engineer.

The mixing liquid shall be added to the dry components and thoroughly mixed to achieve a uniform consistency, unless otherwise approved by the Engineer. The mortar shall then be applied to the bonding agent using hand packing and trowel to the satisfaction of the Engineer.

Figure 10.43a: Surface condition – suitable for ploymer application

Figure 10.43b: Surface condition – suitable for polymer application

Figure 10.43c: Surface condition of bottom slab – suitable for ploymer application

Figure 10.44: Application of polymer mortar

Figure 10.45: Exposed bar of bottom of girder

Figure 10.46: Application of polymer mortar

ii) Pouring concrete - A mechanical batch mixer should be used to ensure homogeneity, workability and good board life. Clean, potable water shall be used and the maximum amount added shall be consistent with optimum workability. Hand mixing shall not be permitted unless approved in writing by the Engineer, who should outline hand mixing procedures. The finished color should not be analyzed until the addition and full mixing of the cement materials and water are complete. Uniform color requires consistent material proportioning. Concrete/cement mortar shall be pumped through the pour access holes. Spacing for pour access holes shall not exceed 600 mm. Vibrators, placed on the outside face of the formwork, shall be used to achieve proper consolidation. The maximum time allowed between the delivery of grout to the site and the grouting process shall not exceed 60 minutes.

Figure 10.47: Pouring concrete

iii) Curing - All types of cement Maintenances need thorough and continuous curing to develop strength and impermeability, and to minimize drying shrinkage while bond strength is developing Curing of the Maintenance mortar shall be in accordance with the polymer modified additive manufacturer's instructions. Where curing agents are specified by the manufacturer, they shall be applied immediately after the surfaces have been scarified for the next Maintenance mortar layer or toweled to a finish.

10.8 Pile Rehabilitation

Pile Rehabilitation can be done by two methods: pile posting and pile restoration.

10.8.1 Pile Posting

Pile posting involves the complete removal and replacement of a damaged section of pile with anew section of similar cross section. The new section is positioned with ¼-inch gaps at the top and the bottom and is held tightly in place with wedges. Steel pins are driven into the new pile section through bore holes in the existing pile sections. The holes are bored at a steep downward angle above each joint spaced at 90 ° apart. The sides of the joint are sealed and the joint filled with epoxy. An example of pile posting is shown in 48.

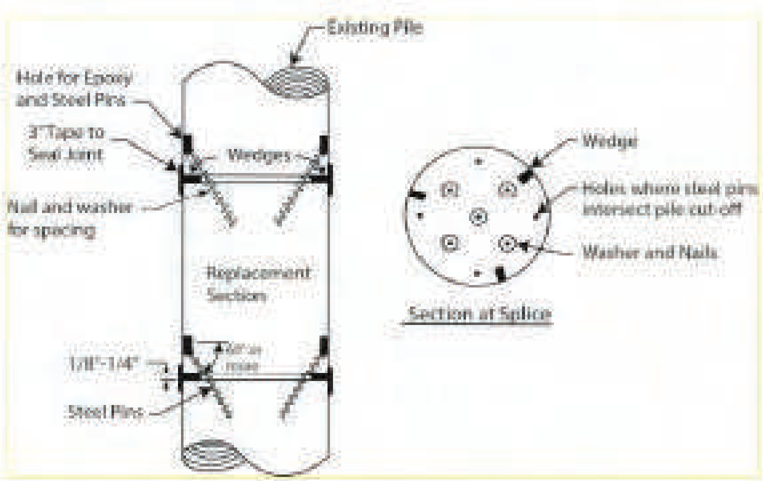


Figure 10.48: Pile Posting

10.9 Preventative Maintenance of Steel Sub-structure

Under ideal conditions, structural steel will last indefinitely with no strength loss. However, when steel is exposed to electrolytes, such as water or soil, it becomes a conductor of current.If there are dissimilar conditions in the metallic conduction circuit or in the electrolyte, a corrosion cell is formed. The rate of corrosion is determined by the magnitude of the current flow and this is controlled by the degree of dissimilarity between the conditions. The main methods of corrosion prevention are:

- Good housekeeping
- Keep drains open
- Keep exposed areas clean (flush or pressure wash)
- Spot paint as necessary
- Painting
- Galvanizing
- Cathodic Protection

Corrosion of structural steel is usually easy to locate by visual inspection and can generally be controlled with proper preventive maintenance. Items which may indicate corrosion of steel substructure components are shown below:

- Look for any cracked or broken members.
- Look for bent, bowed or distorted steel element.
- Where rocker bents are designed to rotate freely on pins and bearings, look to see that such movement is not restrained.
- Look to see if steel pier caps have rotated.
- Look for section loss greater than 20 percent.

Preventive maintenance of steel bridge substructure components consists mainly of measures to protect the steel from corrosion. The preservation of steel involves protection from exposure to electrolytes, such as water or soil. When deicing salt is added to the electrolyte, there is a dramatic increase in the rate of corrosion of the structural steel. Corrosion is usually easily spotted by visual inspection.

10.9.1 Protection of Steel

Protection from corrosion can take various forms, including:

Weathering Steel: This special type of steel forms its own protective coating and theoretically does not need painting. However, many state highway departments have indicated variable performance from bridges constructed with this type of steel. The protective patina is formed as the steel goes through wet/dry cycles. In locations that remain moist, either from debris, high humidity (i.e., near a waterfall), or persistently in the shade, the patina does not form and the steel continues to rust. Sheets of very thin, flake rust can easily be removed by hand or hammer, eventually leading to significant section loss and loss of strength. Substructures constructed from weathering steel should be monitored for excessive corrosion and painted if necessary.

Paint: Typical painting requirements are based on whether the steel is new or is to be repainted. Bridge paint is often a three-coat system, with a prime coat (commonly a zinc-rich primer), an intermediate coat (for moisture protection), and a top coat (for weathering resistance). It is critical to follow manufacturer's recommendations to maximize the longevity of the paint system.

Cathodic Protection: Zinc or aluminum anodes are attached to H piles to abate corrosion of steel in salt or brackish water. Small zinc anodes are used when less than 8 linear feet of pile is exposed. Large zinc or aluminum anodes are used when greater than 8 linear feet of the pile is exposed.

Hot-dip galvanizing is recommended for new, replacement, or existing components. Zinc-rich paint may also be used. Care should be taken to touch up the protective coating after tightening the nuts on anchor bolts and other rail connections.

Galvanizing generally refers to hot-dip galvanizing which is a way of coating steel with a layer of metallic zinc. Galvanized coatings are quite durable in most environments because they combine the barrier properties of a coating with some of the benefits of cathodic protection. If the zinc coating is scratched or otherwise locally damaged and steel is exposed, the surroundingareas of zinc coating form a galvanic cell with the exposed steel and protect it from corrosion.

Galvanizing, while using the electrochemical principle of cathodic protection, is not actually cathodic protection. Cathodic protection requires the anode to be separate from the metal surface to be protected, with an ionic connection through the electrolyte and an electron connection through a connecting cable, bolt or similar. This means that any area of the protected structure within the electrolyte can be protected, whereas in the case of galvanizing, only areas very close to the zinc are protected. Hence, a larger area of bare steel would only be protected around the edges.

10.9.2 Common Maintenance Activities

Confinement shells are fairly durable requiring only minimal maintenance. Steel shells require repainting similar to other steel components on the bridge. Steel confinement shells may have weld or base metal tears or broken bolts following seismic events. Confinement shells constructed from carbon or glass fiber wraps may be subject to deterioration from sunlight, high pH or moisture. Any signs of fiber layer delamination, broken fibers or tears in the materialshould be reported to an engineer for appropriate repair specifications and methods. This may include removal and replacement of the damaged FRP wrap.

10.9.3 Viscous Dampers

10.9.3.1 Overview

Viscous dampers are used on some structures to absorb seismic energy and to limit the forces imparted on the structure. Viscous dampers are constructed of steel and look something like large shock absorbers, as shown in Figure 10.54. The dampers are generally connected betweenthe bottom of the superstructure and the substructure although they can be configured inother ways. Viscous dampers typically consist of a steel cylinder filled with silicone oil and a piston system that moves back and forth through the fluid during a seismic event. The piston head has space or slots on the edges that allow the heavy fluid to slowly squeeze past the piston head as it moves inside the cylinder, as shown in Figure 10.55.

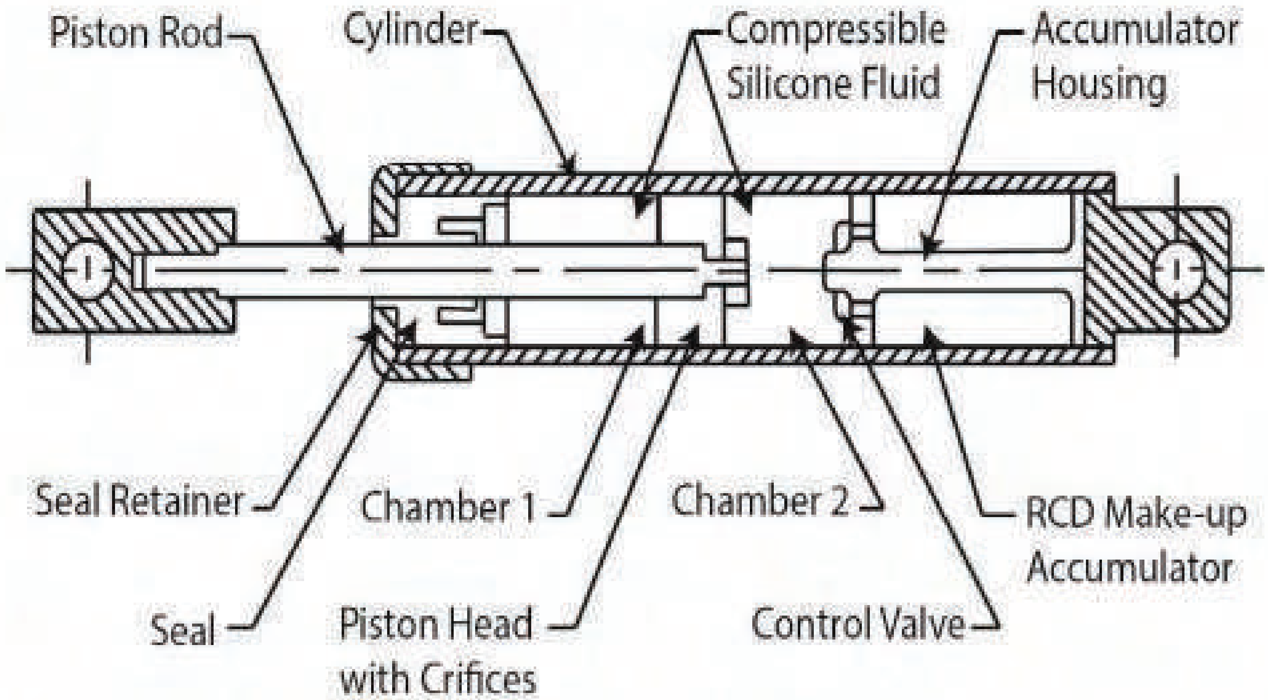


Figure 10.49: Viscous Damper Cross Section

Figure 10.50: Viscous Dampers

10.10 Repair and Rehabilitation of Steel Sub-structures

Steel substructures can consist of piling, pile bents, frames and towers. Most steel substructures utilize bolting or welding in the original design and these connection types must be considered in repair and rehabilitation.

10.10.1 Welding

It is common practice to use welding for shop fabrication of steel members and for welding pieces in preparation for maintenance activities. Field welding is relatively difficult to perform properly and requires individuals with the necessary skill and physical ability. It is equally difficult to properly inspect welds that carry major stresses under field conditions. In the shop, automatic machines make the majority of the welds and the rest are made under ideal conditions. Highly sophisticated equipment using X-rays, gamma rays, or ultrasonics can also be used to inspect the welds.

Welding is the process of joining pieces of steel plate together to form one cohesive piece. For this to occur the steel areas to be joined are heated to the point of becoming almost fluid, at which time weld material is added as a sort of glue to join the pieces together. Welding is so sophisticated since the heat affected zone around the weld can actually cause cracking if it is heated too much or allowed to cool too fast. Insulating material is usually automatically applied to the weld to help it cool down properly but that material can be affected by outside conditions such as wind. The process, if performed correctly, will make the steel act as one bridge element. If not, the weld can cause premature cracking and dramatically reduce the service life of the bridge.

Often during rehabilitation, widening and strengthening projects, it is necessary to make field welds. This operation requires proven expertise. The welder must be tested and have a certificate of qualification. It is also important that the qualification cover the type and position of field weld to be performed. A structural engineer should review the operation to ensure the strength or structural integrity of the joining members are not altered by the connection or the heat of the weld.

Deteriorated steel can be repaired by adding sections when there is sufficient working space to weld or bolt them in place. Loss of section should be evaluated by an engineer to determine if repair or replacement is warranted. The web and flanges of the steel section can be strengthened by welding steel plates extending far enough above and below the deteriorated area to carry the full load on the pile.

Welded repairs should not be performed unless sufficient knowledge of the existing steel is available to know if the steel is weldable. Chemical tests can be used to determine whether unknown steel is weldable. The chemical composition of a metal is important in determining its weld-ability. The likelihood of cold cracking depends on the carbon equivalent (CE) of the steel. When the CE is below 0.55 percent, cold cracking is not likely and no special precautions are needed for field welding. When the CE is above 0.55 percent field welding should only be performed by a welder experienced in field welding of bridge repairs. Any field welding should be performed a certified welder and should not be performed on members where fatigue of the weld could be a problem. Poor quality welded repairs on tensile members can actually do more harm than good.

Field welding is more likely to result in flaws than shop welding due to a lack of control of such factors as moisture, temperature and welder access. Bolting is always preferred over field welding.

There are situations where welding is used by bridge crews for the following types of repairs:

- Repairing defects such as nicks and gouges
- Adding reinforcement segments such as plates
- Adding bracing members

- Replacing a portion of a steel member

For field welding of piles, where extreme section loss is present in the pile at the interface with the footing, repairs can be made by welding plates to form an angle with one leg against the footing and the other against the pile. Stiffeners should be placed across the angle as necessary. These angle plates should be placed on both flanges. When the welding is completed, all of the exposed piles should be given a heavy, protective coating. Fill should then be placed around the piles up to the bottom of the footing.

10.10.2 Bolting

There are thousands of bridges still in service which have riveted connections. The majority of these structures have been in service for 50 years or more, since riveting was a relatively common fabrication procedure until about 1960 or so. During the period when riveting was being phased out in favor of welding, a number of bridges were fabricated using shop rivets with high strength bolts used for field connections. Corrosion can build up between the plates of the riveted members. The corrosion then expands and pops off the rivet heads. Where this occurs, repairs are normally made to the connections with bolts. If a rivet has popped off, the other rivets in the area of the failed rivet should be checked by tapping with a hammer. Good rivets will ring, bad rivets will thunk. This may save having to go back to the same location after the next inspection to replace additional rivets.

High strength bolts should be used to replace deteriorated rivets. If rivets are found to be deteriorated to the extent that they do not contribute to the strength of the connection, the connection should be analyzed by a competent engineer to determine if the member should be jacked to restore the original dead load distribution. If only a handful of rivets require replacement, they may be replaced individually with no special procedure. If only one rivet has popped off, the other rivets in the area of the failed rivet should be checked by tapping with a hammer. Good rivets will ring, bad rivets will thunk.

When a connection must be completely re-fastened, begin at the center of mass of the connection, and proceed outward in a balanced manner. Bolting may be used as a repair method or as a supplement to other methods. Replacement of damaged elements with a new piece of steel fastened with high strength bolts is a recommended repair method. Procedures are discussed in this section on the proper pre-tensioning of the bolt to ensure a proper clamping force of the steel plates to prevent movement. However, the ultimate strength of a connection is independent of the bolt pretension and slip movement. Figure 10.56 shows the markings required on the bolts as per ASTM Specifications. Certain markings are mandatory. In addition to the mandatory markings, the manufacturer may apply additional distinguishing markings.

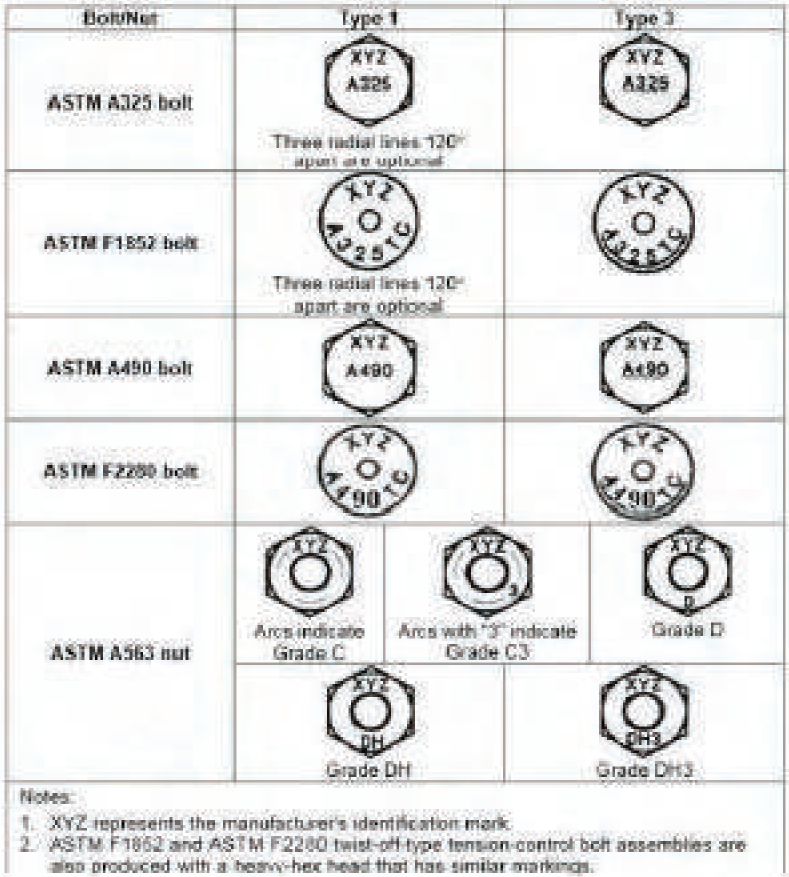


Figure 10.51: ASTM Heavy-Hex Nuts Marking Standards

The principal features of heavy-hex structural bolts that distinguish them from bolts for general application are the size of the head and the unthreaded body length. The head of the heavy-hex structural bolt is specified to be the same size as a heavy-hex nut of the same nominal diameterso that the ironworker may use the same wrench or socket either on the bolt head and/or on the nut. The nominal dimensions of standard holes for high-strength bolts is 1/16-inch larger than the bolt installed.

Washers provide a hardened non-galling surface under the turned element, particularly for torque-based pre-tensioning methods such as the calibrated wrench pre-tensioning method and twist-off-type tension-control bolt pre-tensioning method. Circular flat washers that meet the requirements of ASTM F436 provide both a hardened non-galling surface and an increase in bearing area that is approximately 50 percent larger than that provided by a heavy-hex bolt head or nut.

All bolts, whether black, galvanized, or weathering steel, must be lubricated when installed. Most manufacturers apply a water-soluble oily lubricant to black bolts, nuts and washers as a part of their production operations. If the fasteners are exposed to rain, snow, dew, condensation or other moisture conditions, this lubricant may be washed off. This lubrication will also evaporate after a period of time when left in open containers. Bolts and nuts should not be stored in exposed weather. The most effective lubrication is placed on the threads of the bolt, the threads of the nut and the inside face of the nut. If a bolt, nut or washer has lost its lubrication, it is important that the component be re- lubricated prior to installation. The type of lubrication to be used is not specified, but typically a similar oil- based product, stick wax, bee's wax, liquid wax or spray lubricant can be used. Should any of the bolts, nut or washers show rust, the rust must be cleaned from the surface of the fastener component and then be re-lubricated. Dirt, sand, grit and other foreign material must be cleaned off the bolts prior to installation, with re-lubrication when necessary.

Bolts are first brought to a "snug tight" condition. "Snug tight" is defined as "the tightness achieved with the full effort of a worker with an ordinary spud wrench or a few hits of an impact wrench that brings the connected plies into firm contact". Once "snug tight", a second application of force brings the tension on the bolt to the required loading. For field applications, ensuring that the final application of force brings the force in the bolt to the required loading can be determined by several methods: "turn of the nut", torque or calibrated wrench, twist-off bolts, and Direct Tension Indicators (DTIs) are commonly available.

The most common technique for pre-tensioning (or pre-loading) a bolt is the "turn-of-the-nut" method. This method applies an additional rotation of the wrench a predetermined amount after the nut has been tightened to a snug fit. This method involves tightening the fastener to an initial "snug tight" condition and then applying a prescribed amount of turn to develop the required preload. The actual preload will depend on how far the nut is turned as well as how much preload was established prior to the turning.

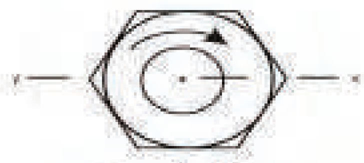
Turn of the Nut

1. Sung the joint to bring the assembly into firm contact. Apply a few impacts with impact wrench until solid sound or apply full effort with a spud wrench.
2. Inspect the joint to verify "snug tight"
3. Match mark bearing face of the nut and end of the bolt with a single straight line.
4. Using a systematic approach which would involve appropriate bolting pattern, apply the required turns as shown in table 10.4. The amount of turn past snug tight is based on the ration between the bolt length and diameter, as well as slope disposition of the outer steel plies.

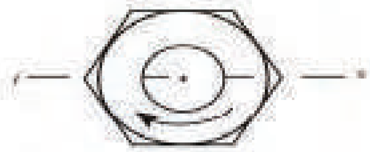
Table 10.4: Turn of the Nut Rotation Table Using Condition Under Bolt Head and Under Nut

Bolt Length	Both faces flat (normal to bolt axis)	One face sloped, but not more than 1:20	Both faces sloped, but not more than 1:20
Less than or equal to 4D	1/3 Turn	1/2 Turn	2/3 Turn
More than 4D and lessthan or equal to 8D	1/2 Turn	2/3 Turn	5/6 Turn
More than 8D and lessthan or equal to 12D	2/3 Turn	5/6 Turn	1 Turn

Once the bolt is "snug tight", a mark on the wrench socket is aligned with the marker line "x". The sequence is shown in Figure 10.58. A mark is made on the nut and extends onto the end of the bolt. This allows the inspector to see that the nut has been turned relative to the bolt the prescribed amount, in this case ½ a turn, to the "y" mark.



Snug Position



Turn - of - Nut
1/2 Tension Position

Figure 10.52: Turn of the Nut Method

Torque or calibrated wrenches measure the torque required to turn the bolt; they do not measure the tension on the bolt. It is generally a specification requirement that fasteners be oily to the touch prior to being installed. When compared to oily fasteners, bolts that have lost their lubrication may require as much as twice the torque to install them, and their ability to reach their proper tension force is questionable. An unlubricated bolt and nut system when tightened may strip, twist and even fracture. In some cases for bolts, re-lubrication mandates the retesting of fasteners in a Skidmore-Wilhelm (or similar device) prior to installation in the structure. This verifies the effectiveness of the re-lubrication. Highly efficient lubricants can actually increase the risk of thread stripping, so this condition is also checked.

A correctly calibrated wrench is critical for a proper connection. Re-calibration must be done daily before work begins or:

- When the lot of any component of the fastener assembly is changed
- When the lot of any component of the fastener assembly is re-lubricated
- When significant differences are noted in the surface condition of the bolt threads, nuts or washers
- When any major component of the wrench including lubrication, hose and air supply are altered

Twist-off-type tension-control bolt assemblies have a splined end that extends beyond the threaded portion of the bolt. During installation, this splined end is gripped by a specially designed wrench chuck and provides a means for turning the nut relative to the bolt. Twist-off- type tension-control bolt assemblies must be used in the as-delivered, clean, lubricated condition.

Many twist-off bolts use a special lubricant that is not as oily as common structural bolts. Contacting the manufacturer of the twist-off bolt system is encouraged prior to re-lubrication. These fasteners are particularly sensitive to inadequate lubrication and over-lubrication, and loose bolts or broken bolts may result.

To measure bolt tension another option is use of direct tension indicators (DTIs). A DTI is a washer like device that is placed on one or the other end of all bolts, and after snugging the joint by partially (but not fully) compressing the DTI, all the DTI's are "crushed" to the point where a feeler gage cannot be inserted half way around, or to the point where the silicone pockets have been squeezed out for "squirter" style DTIs. DTI's are completely independent of the torque resistance of the bolt assembly, and in theory by simply visually inspecting the DTI 'bumps' you should be able to verify bolt tension. However, there can be installation issues and it is recommended that a feeler gauge be used to verify that the DTI has been fully compressed.

During installation, care must be taken to ensure that the direct-tension-indicator arches are oriented to bear against the hardened bearing surface of the bolt head or nut, or against a hardened flat washer if used under turned element, whether that turned element is the nut or the bolt. This is so that the arches are deformed by compression only and not by galling. The torque tension relationship is based solely on the compressibility of the arches. Inspection by using a feeler gage (on a sample of the bolts only) can be done by anyone at any time. If the DTI is put on the nut end of the bolt, tightening can be done by one person because it is not necessary to hold the bolt roll. Final tensioning should be done as per a pre-described bolt tightening pattern.

10.10.3 Splicing

Splicing involves adding additional steel attached by bolts to a defective area of a member to transfer a load around that defective member. Steel H-piles may be damaged particularly if located in waterways where they may be struck by heavy barges or near roadways as in work zones where they may be struck by heavy equipment. Damage in the form of bent, torn or cut flanges may effectively reduce the cross section and load-bearing capacity so that repair must be performed. A steel pile that cannot be easily supplemented because of access or scheduling may be strengthened by repairing with bolted channels as a temporary measure.

Planning should include the following:

- Select appropriate channel size to meet strength and dimensional requirements.
- Determine length of damaged area and secure steel channels of selected size that have been fabricated in appropriate lengths with necessary hardware.

Equipment and tools necessary will include:

- Equipment for drilling bolt holes
- Protective coating material
- Necessary staging

Steel Pile Strengthening by Splicing

1. Clean damaged pile.
2. Locate extreme limits deteriorated section
3. Channel section should 18 inches longer than the distance between these limits.
4. Throughly clean area to which channel is to be bolted.
5. Clamp channel section in place against pile.
6. Locate and drill holes through channel and pile for high strength bolts.
7. Place bolts and secure
8. Remove clamps
9. Coat with protective coating.

An example of steel pile strengthening is presented in Figure 10.59.

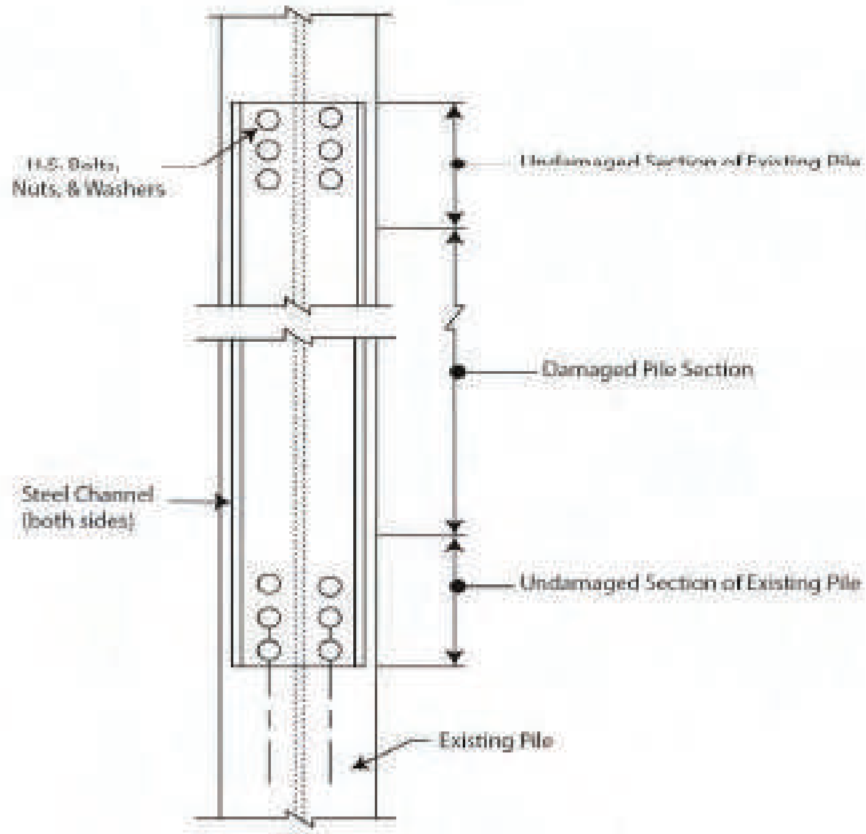


Figure 10.53: Steel Pile Strengthening

10.10.4 Jacketing

Pile jacketing of steel piles is basically the same as that described previously for concrete piles. Both flexible and rigid forms can be used. Often fiberglass and plastic forms are used because of ease of erection for underwater applications. Prior to pile jacketing, marine growth and corrosion are cleaned.

Stands-offs are placed on the pile flanges before the forms are installed and concrete is placed. Figure 12.34 shows stand-offs inside a flexible form. Welded wire fabric is typically used to reinforce the concrete against cracking. Concrete jackets can cause accelerated corrosion on a steel pile when both concrete and water are in contact with the steel. A corrosion cell will develop either below the bottom of jacket or above the top of jacket. Concrete jackets should be extended well into the mudline and, well above the high waterline. Cathodic protection could be included in the repair. When steel piles require additional support or protection, an integral pile jacket can be placed around the steel piling. The encasement of the steel piles is accomplished by filling a fiberglass form with Portland-cement grout. After the concrete hardens, the fiberglass form remains in place as part of the jacket. The integral jacket provides protection to steel piles above andbelow the water. If the pile has deteriorated to the point that additional steel support is required, cover plates can be added to the pile prior to placing the jacket or a reinforced concrete jacket can be designed.

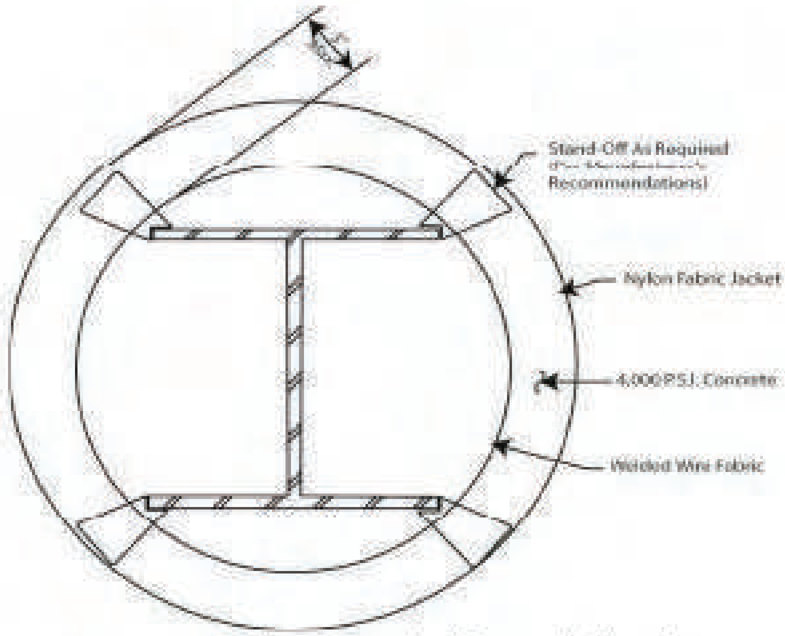


Figure 10.54: Flexible Formed Pile Jacket

Installation of Integral Pile jacket

1. Clean the steel surfaces by sandblasting the surfaces clean of oil, grease, dirt and corrosion (near white metal)
2. Place the pile jacket form around pile.
3. Ensure standoffs are attached to the form.
4. Seal all joints with an epoxy bonding compound and seal the bottom of the form of the pile.
5. Brace and band the exterior of the form to hold the form in place.
6. Dewater the form. Fill the bottom 6 inches of the form with epoxy grout filler.
7. Fill the form to within 6 inches of the top with a portland cement grout filler.
8. Cap the form with a 6 – inch fill of epoxy grout.
9. Slope the cap to allow water to run off.
10. Remove the external bracing and banding and clean off the form of any deposited material.

All exposed steel should be protected against corrosion. Steel piles must be protected by coatings that prevent the dissolved oxygen in the water from contacting the steel. Epoxy coating systems and polyvinyl chloride barriers have been used. The portion of a steel pile in the water and beyond the concrete jacket has especially potential for galvanic corrosion. Zinc anodes can be attached to H piles to abate corrosion of steel in salt water as shown in Figure 10.61.

Small anodes are used when less than 8 feet of pile is exposed. Large anodes are used when greater than 8 feet of the pile is exposed. It should be noted that anodes will be consumed in time and the life of the anodes will depend on its weight.

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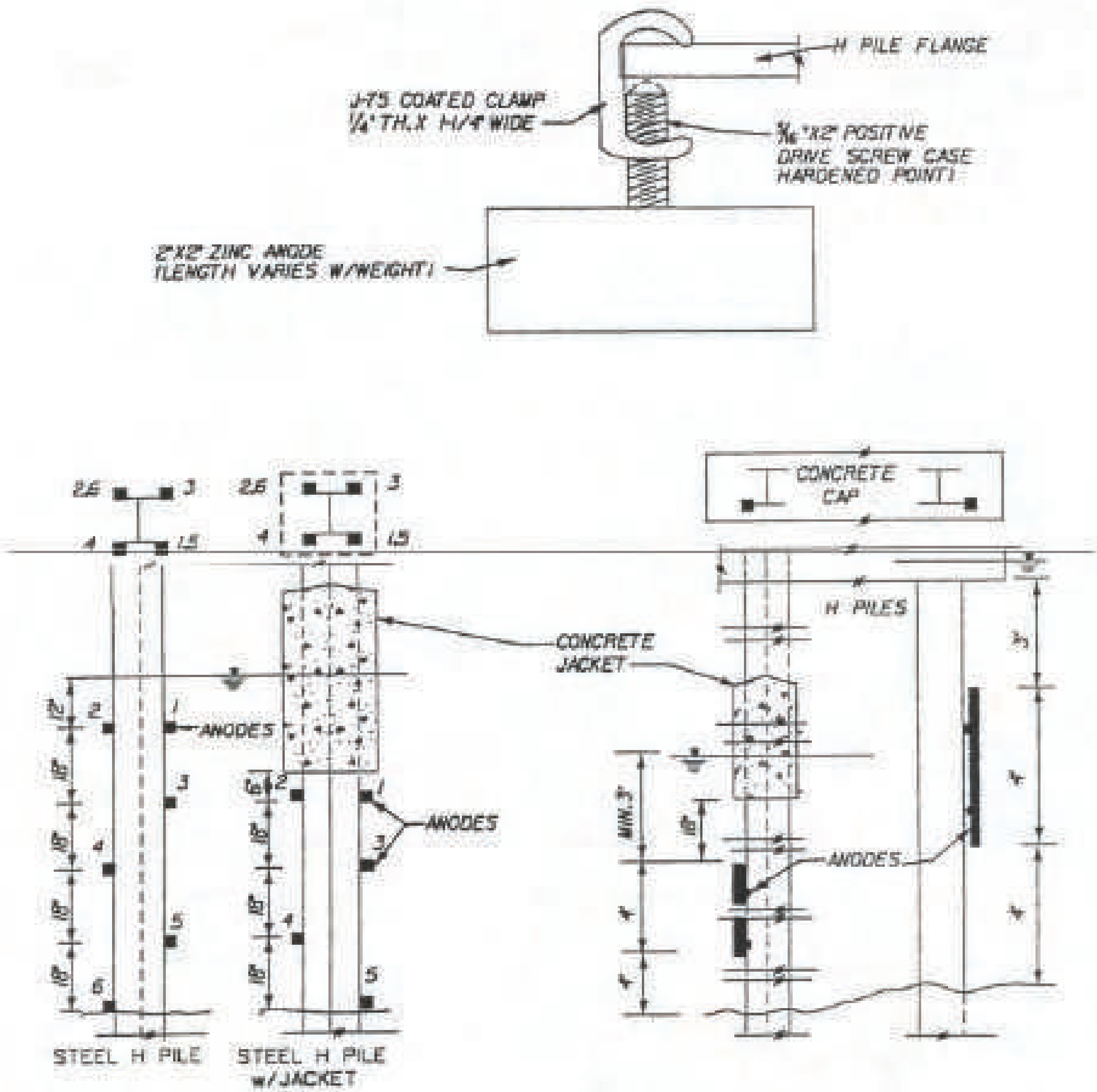


Figure 10.55: Corrosion Protection of H Pile by Zinc Anodes

10.10.5 Supplemental Bracing

As truck loads continue to get bigger, the demand on many aging bridges increases. Slender steel structural elements widely used in bridge superstructures and braced substructures to resist these loads are built primarily for tension, however, and can buckle under compressive loads.

Supplemental bracing can be used to increase the allowable capacity of a member. The bracing reduces the unsupported length and adds more material to the existing member.

10.10.6 FRP Repairs

When steel piles require additional support or protection, an integral pile jacket can be placed around the steel piling. The jacket can be made by filling an FRP form with Portland-cement grout or FRP wrapping as shown in Figure 10.62.

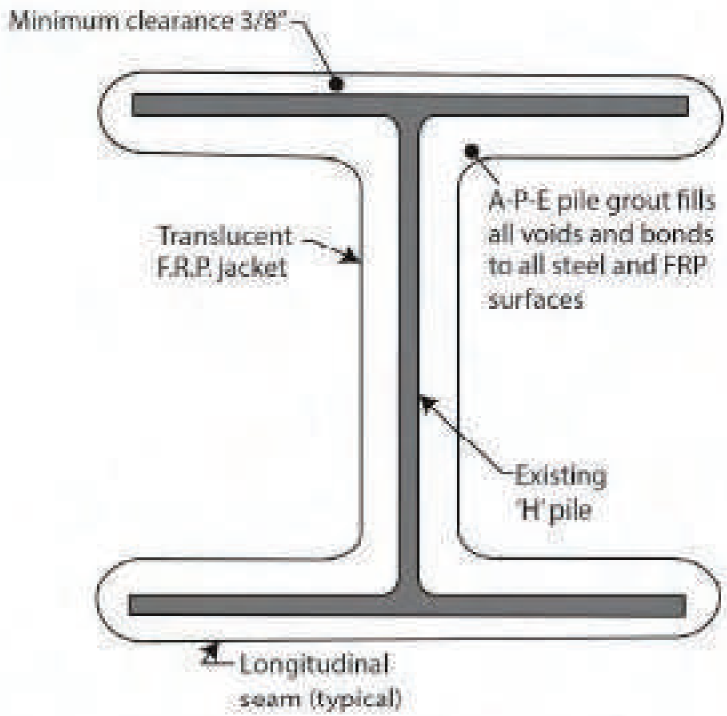


Figure 10.56: FRP Jacket for Strengthening Steel Piles

10.11 Other Activities for Bridge Maintenance

10.11.1 Shoring and Temporary Supports

Shoring is normally the temporary support of structures during construction, demolition, reconstruction, etc. in order to provide the stability that will protect property as well as workersand the public. Shoring systems collect the load with headers/sheathing, deliver it into the post/struts, and then to distribute it safely into the supporting structure below. The system must include load plates on each end to spread out the loading. A heavily loaded post can punch thru a concrete slab as well as into the ground.

Placing columns under the superstructure can require some creativity. Bridges with minimal vertical clearance do not allow enough room for cranes or other lifting equipment to work beneath the superstructure. Shoring materials should be light weight and constructed in parts, so that they can be transported and gauged to meet loading requirements. An example oflifting a support column in shown in Figure 10.63.

Figure 10.57: Lifting a Support Column

Shoring should be built as a system that has the following:

- Header beam or other elements to collect the load.
- Post or other load carrying element that has adjust ability and positive end connections. This means that the ends have a good connection to the load carrying member but there is also a way to adjust the height up or down without losing the end connections.
- Sole plate, bearing plate, cribbing, or other element to spread the load into the ground or other structure below. See Figure 10.55.
- Lateral bracing to prevent system from racking (becoming parallelogram), and prevent system from buckling (moving sideways).
- Built-in forgiveness (will give warning before failure). Example: If vertical shore is proportioned properly, (posts with length to width ratio of 25 or less) one can hear the header or sole plate crush against the post prior to the post starting to fail.

Systems used for substructure repairs are primarily intended to provide vertical support, but should have some lateral bracing for stability. This lateral stability is usually expressed as a percentage of the vertical load, typically between 2 percent minimum with 10 percent a reasonable goal. Shores need to be strong, light, portable, adjustable, and reliably support the structure. Systems should be used that are positively interconnected, laterally braced, and have slow, predictable failure mode.

A typical shoring scenario would begin with the placement of spot shores to provide initial stability, followed by individual multi post shore systems with in-plane bracing, then followed by pairs (or greater numbers) of multi post shores that are "X" braced together as two- dimensional systems.

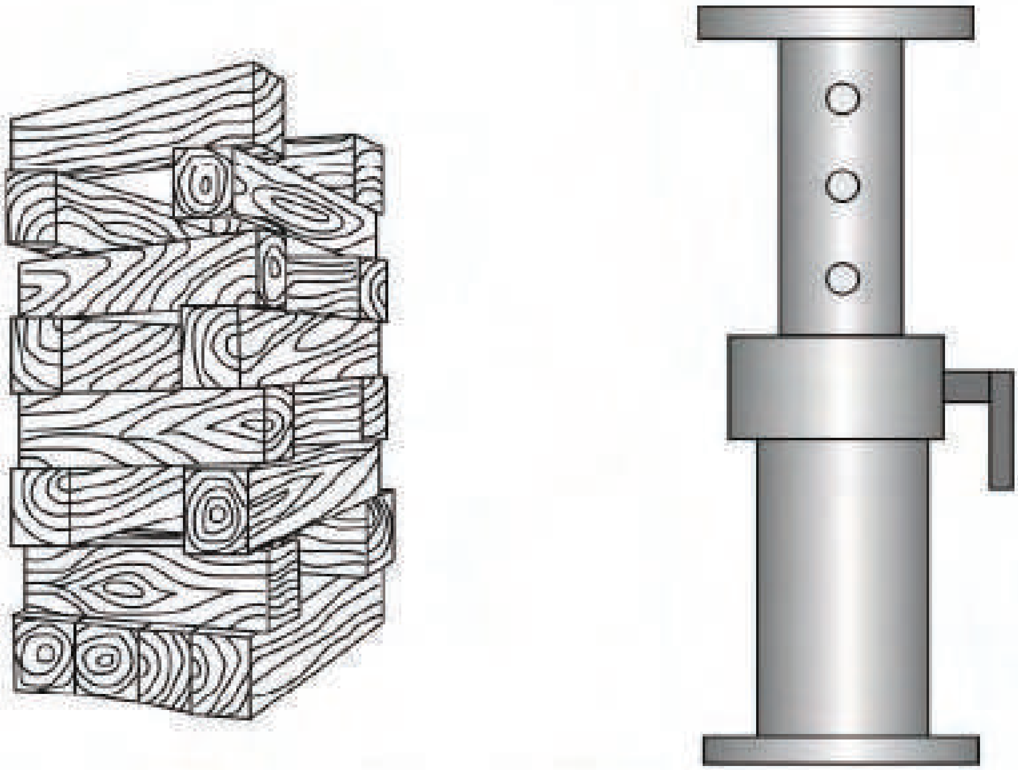


Figure 10.58: Timber Cribbing (left) and Pipe Jack (right)

Cribbing is made from composite plastic/rubber and wood and the minimum length of each piece should be 24 inches. Wood is the material of choice when constructing shoring systems because of its outstanding load-carrying capabilities and the fact that when lumbers exceed its load-carrying capabilities it will give collapse warning signs, such as creeks, groans and visible crushing on the header and sole plates. The height of the crib stack should not be greater than three times the width of the stack.

- Minimize the overhang of the wood. It should be not be more than the shortestdimension of the wood.
- Make sure each layer lines up with its matching layer.
- Minimize the tilt of the stack. It should not exceed more than 30 degrees out of plumb.

Properly built, cribbing can support tremendous loads. A four-member crib stack built using 4x4 lumber can support 24,000 pounds. The same crib stack constructed from 6x6 lumber can support up to 60,000 pounds.

Raker shores are useful in bracing heavy walls that have cracked and/or are tilted (Figure 10.65). The shoring is installed diagonally so the wall and ground must be able to resist both vertical and horizontal loading, and that loading may vary based on the angle of the diagonal brace. A positive connection to both the wall and ground are recommended. The wall and ground portion of the raker can be connected through drilled-in anchors or if possible, by bearing the wall plate against an existing projection in the wall surface such as a ledge. A projection can be manufactured, such as a mounted cleat, that the raker will bear against.

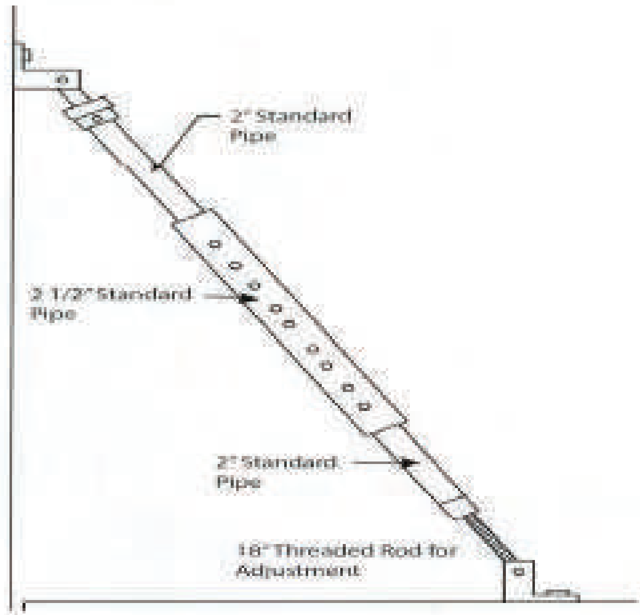


Figure 10.59: Raker Shore

Raker shores should be placed from 8 feet on center, depending on wall type and condition. They should be designed by engineers that have experience with these systems. Rakers should be built away from their installation site and carried into place. The capacity of rakers is usually limited by the cleat connections and/or the connection to the ground.

More and more bridges are relying on temporary shoring to preserve serviceability until repair funds become available. Figure 10.66 is an example of a deteriorated concrete bent cap shored up with vertical steel bracing.

Figure 10.60: Temporary Steel Shoring used to Support Deteriorated Concrete Pier Cap

10.11.2 Scaffoldings for Bridge Rehabilitation/Strengthening

There are two types of scaffoldings used for rehabilitation/strengthening of the existing bridges. One is suspended scaffolding, which is used for the rehabilitation/strengthening work for the superstructure. The other is the prefabricated scaffolding, which is used for work on the sub-structure.

i) Suspended scaffolding type A - This type of scaffolding is hung by chains under the superstructure. Preparing and setting up safety equipment and facilities such as feces, handrails and safety nets are crucial. Note internal scaffolds shall be installed if the clearance between bottom of the deck slab and floor is over 2m. This type is applied for deck slab and girder work. The structure of this type is shown in Figure 10.67.

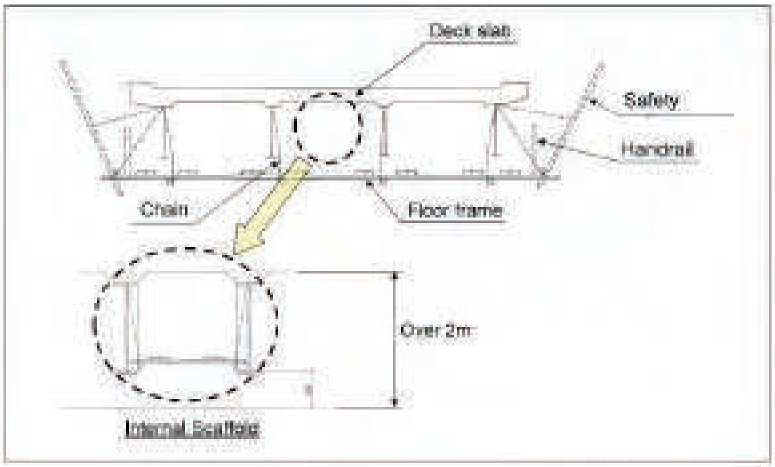


Figure 10.61: Suspended scaffolding type A

ii) Suspended scaffolding type B - This type is installed on the sides of the superstructure with chains and steel frames. This type is applied for work on railing and curbs. The structure of this type is shown in figure 10.68.

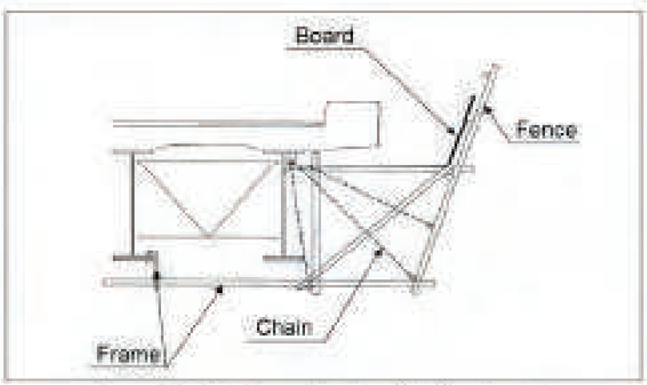


Figure 10.62: Suspended scaffolding type B

iii) Suspended scaffolding type C - This type is installed on the circumference of piers by chains. It is applied for work on bearings, unseating prevention systems and expansion joints. The structure of this type is shown in figure 10.69.

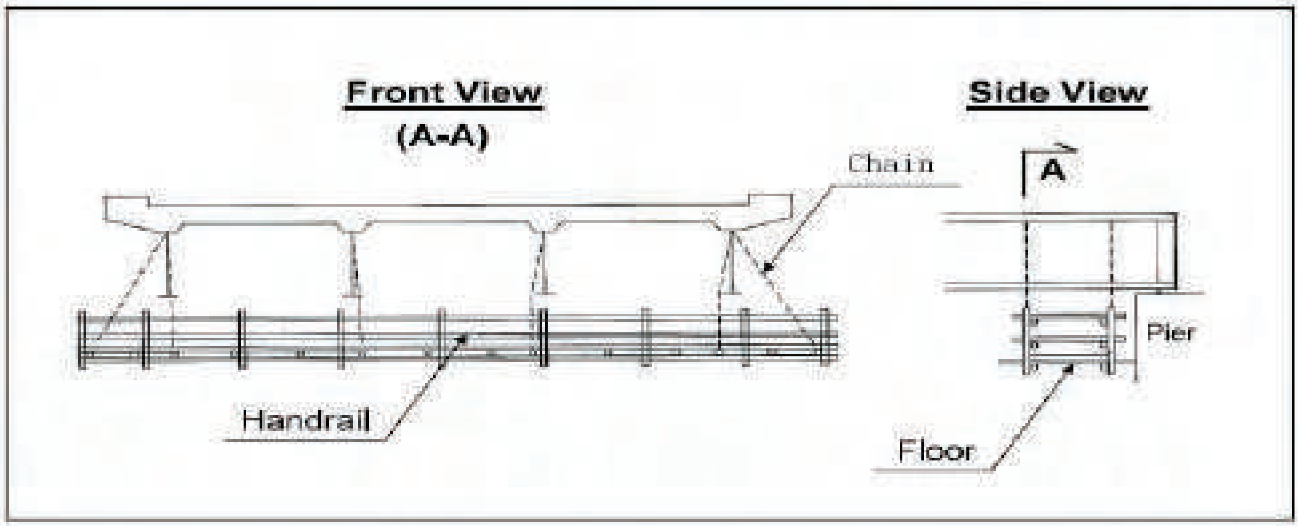


Figure 10.63: Suspended scaffolding type C

iv) Prefabricated Scaffolding - This type is built to assemble a prefabricated frame. It is applied for building the body of a substructure. The structure of this type is shown in figure 10.70.

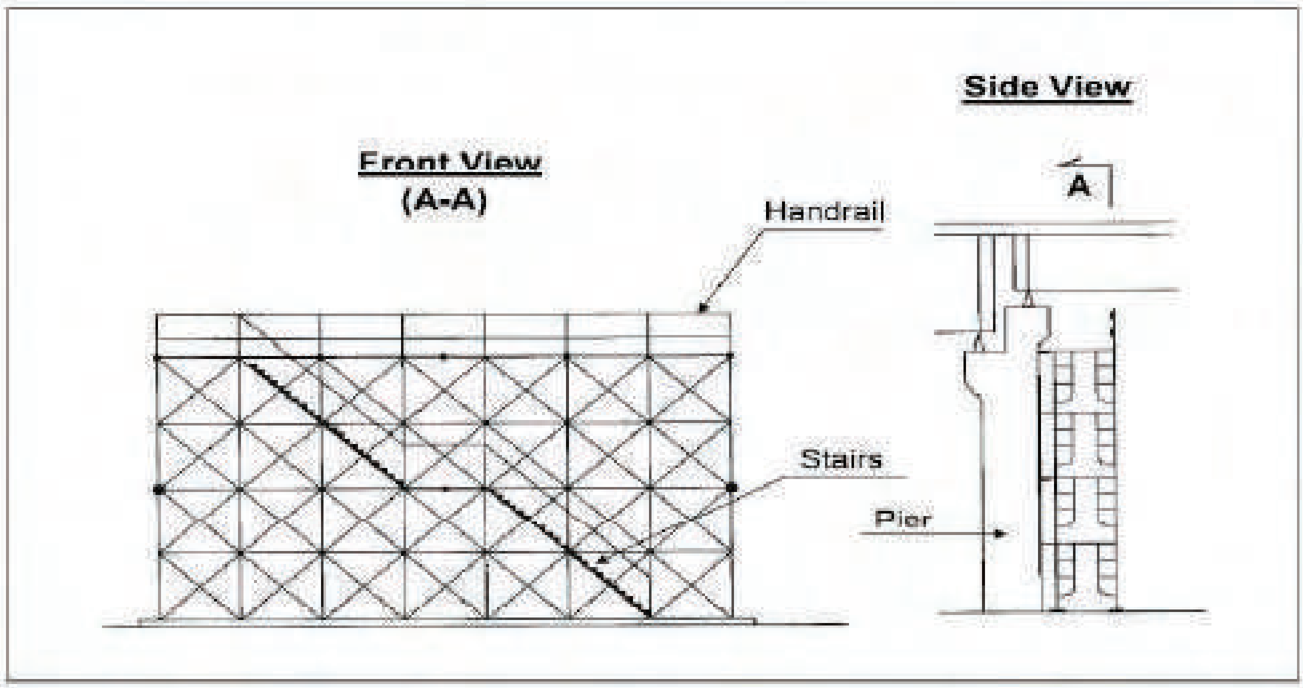


Figure 10.64: Prefabricated Scaffolding

10.11.3 Necessity of scaffoldings

In case all main rebar of the girder is required replacement, installation of scaffoldings is necessary. Meanwhile, in case of partial replacement of the main rebar of the girder, necessity of the scaffoldings is depending upon stress condition of the girder after removing some of rusted rebar. Examination of stress condition of the girder will be carried out with consideration of load distribution effect by cross beams, traffic restriction and reducing safety factor of remaining rebar.

10.11.4 Installation of the scaffoldings

In case installation of the scaffoldings required, requirements of the scaffolding are as follows:

- ✓ Scaffolding member shall be strong enough against imposed load from the girder.
- ✓ Buckling strength of the scaffolding member shall be examined.
- ✓ Stability of the scaffolding system shall be examined.
- ✓ Bearing capacity of a foundation of the scaffolding structure shall be examined. Any settlement of the scaffolding structure will not be allowed. Therefore, the foundation of the scaffolding structure shall be designed carefully.

The scaffolding structure shall be remained until strength of new concrete reaches its design strength.

10.12 Bridge Jacking

If the deterioration is caused by loads, or in case of extensive concrete deterioration, the superstructure may be lifted (to take the load off the substructure) prior to repair. Also, repair may require raising the superstructure to provide workspace.

Bridge Jacking

1. Plan to remove traffic from the bridge during jacking.
2. Determine the size, number, and location of jacks that are required.
3. Ensure that jacking will not damage joints, bearing assemblies, or area supporting jacks.

The resources that will be needed should be determined. They may include:

- Jacking equipment
- Form carpentry
- Blocking to hold structure in case jacks fail
- Concrete sawing and chipping equipment
- Traffic control to move loads away from jacking area

The suggested procedure for installing a temporary bent for bridge jacking follows.

Temporary bent for bridge jacking

1. Construct a temporary bent for supporting jacks and blocking if jacking from abutment or pier elements cannot be accomplished.
2. Remove traffic from the bridge while jacking the superstructure.
3. Lift jacks in unison to prevent a concentration of stress in one area and possible damage to the superstructure.
4. If the bridge will carry traffic during repairs, restrict vehicles away from repair area as much as possible.
5. Saw cut around concrete to be removed and avoid cutting reinforcing steel.
6. Remove deteriorated concrete to horizontal and vertical planes using pneumatic breakers.
7. Add new reinforcing steel where required.
8. Apply bonding material to prepare surface that will interface with new concrete. Bonding material shall not dry out prior to casting the new concrete, otherwise, do not apply a bonding

material.

9. Form as required and cast new concrete.
10. After concrete has reached required strength, remove forming, blocking jacks and temporary supports.

10.13 Emergency Repairs

When the damage to a bridge is an immediate safety hazard (see example in Figure 10.71), the priorities are different than on other site visits. The objective is to assess the urgency and begin appropriate actions.

A procedure to implement an immediate closure should be developed by every bridge owner sothat it can be enacted quickly when the need occurs. Crews should be familiar with their agency's policy for closing a bridge to highway and pedestrian traffic. The procedure should include contacting appropriate people within the agency, contacting police, erecting signs, establishing a detour, and contacting the media. If the bridge damage obviously warrants closure, the procedure should be implemented. If there is a question whether the problem warrants closure of the bridge or only restricting its use, an engineer should be consulted to help make that decision.

Figure 10.65: Problem Bridge

After the immediate safety issues are resolved, the repair urgency is determined and implemented accordingly. It may be necessary to plan the repair as the work proceeds. For example, after the type of repair is determined, the manpower and equipment are mobilized while the repair details are resolved. Special provisions for working at night and lodging the repair crew near the site may also be necessary.

11. 1 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 may be required).
2. Identify locations for patching by asphalting contractor.
3. Check whether water from the bridge deck is channeled 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 drains to protect the batter and channel water in the waterway to minimize erosion.

11.2 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.

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 minimize future maintenance.

Steel armouring should be secured or replaced to retain the infill; uneven asphalt should be repaired to provide a smooth well-drained surface.

11.3 Identifying Scour and Erosion – Waterway Mechanics

Scour those results in the undermining of foundation units is one of the most common causes of bridge failure. Streams are dynamic; they change position, shape and other characteristics with variation in flow and the passage of time. When a channel is modified near a bridge, or a new bridge/culvert is installed, this local change will often lead to a change in the channel characteristics both up and downstream of the bridge. Similarly, channel modifications up or downstream of a bridge can affect the channel characteristics at the bridge.

The tendency of a stream channel to scour and migrate is dependent on many factors, including:

- Stream Size
- Stream Velocity
- Flow Habit (Ephemeral, Flashy, Perennial)
- Bed and Bank Material
- Valley, Floodplain & Natural Levee configuration
- Channel Pattern (Meandering, Straight, Braided, and branched)

The amount of material that is transported, eroded, or deposited in a stream channel is a function of sediment supply and channel transport capacity. This concept is described in Figure 11.1 with a definition sketch of sediment continuity applied to a given channel reach over a given time period. Sediment supply is provided from the tributary watershed and erosion occurring in the upstream channel. Transport capacity is a function of the sediment size, stream velocity and geometric properties of the channel. When the transport capacity equals sediment supply, a state of equilibrium exists. When this equilibrium is disturbed, erosion, scour, or deposition will occur.

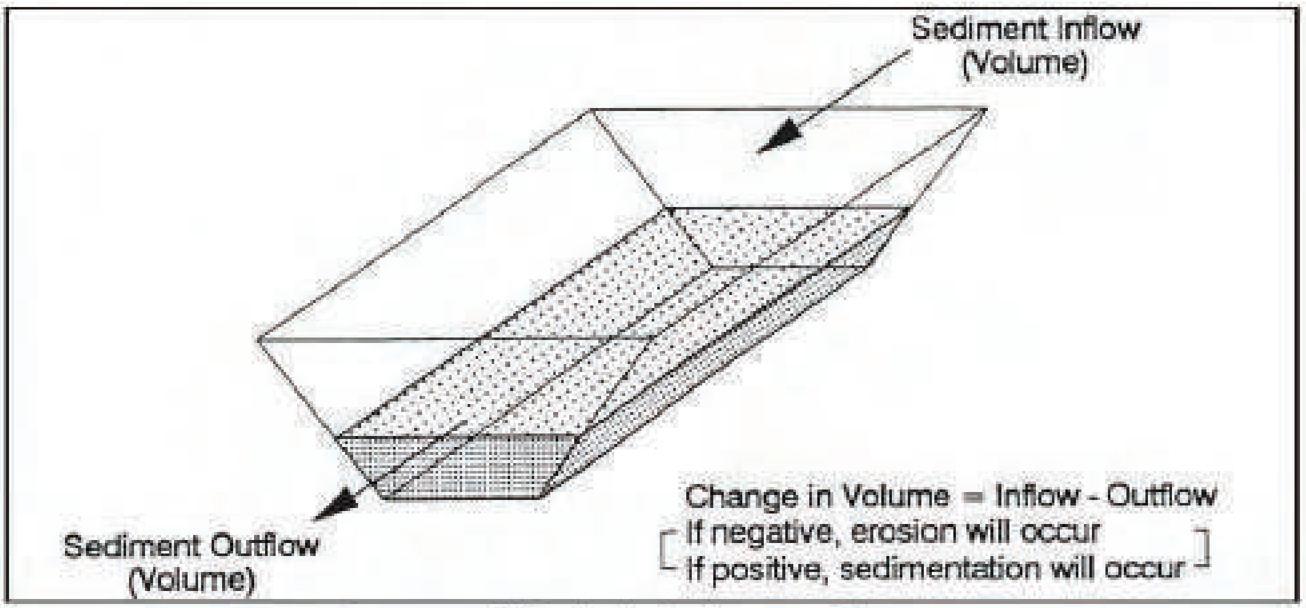


Figure 11.1: Definition Sketch of Sediment Continuity Concept

Migration occurs along a channel reach as bank materials are eroded at the outside of bends and deposited along the inside of bends, as shown in Figure 11.2. The figure shows modes of meander loop development, including (a) Extension, (b) Translation, (c) Rotation, (d) Conversion to a Compound Loop, (e) Neck Cutoff by Closure, (f) Diagonal Cutoff by Chute, and (g) Neck Cutoff by Chute. Over time, migration can change the flow direction and alignment, thus affecting the efficiency of a bridge opening. Active bank erosion can be recognized by falling vegetation along the bank line, cracks along the bank surface, slump blocks (i.e., loosely consolidated materials or rock layers moving a short distance down a slope as a relatively coherent mass), increased turbidity, bent tree trunks and fresh vertical faces, as shown in Figure 11.3.

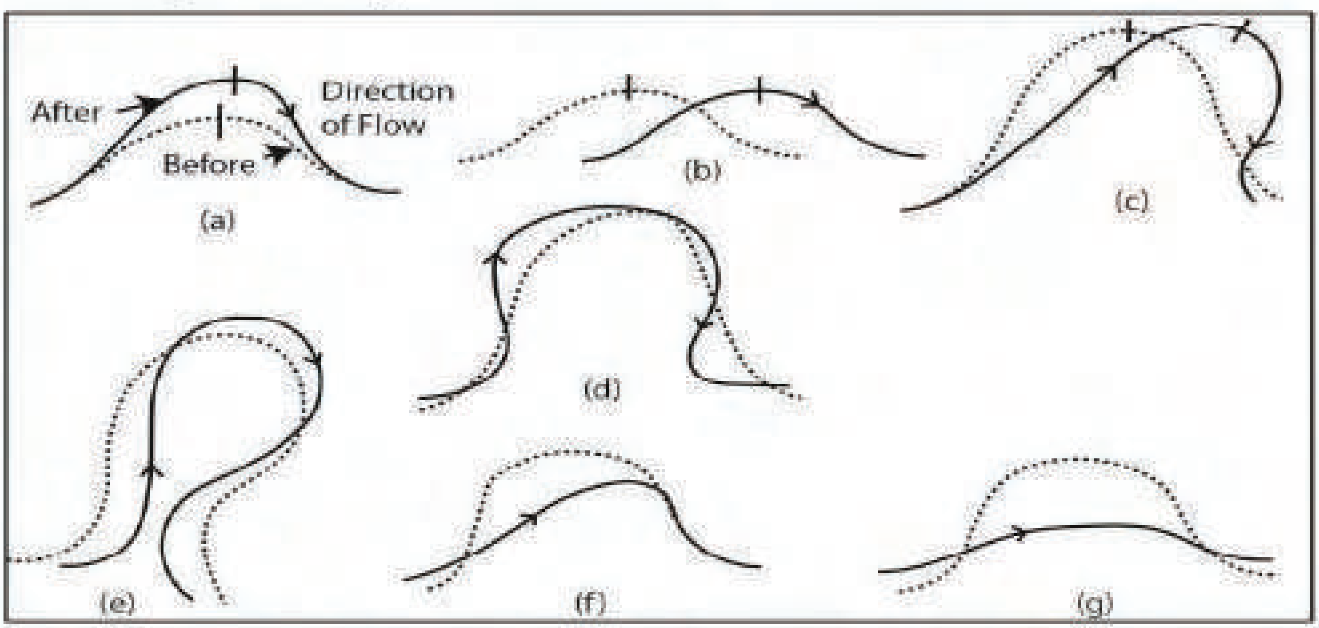


Figure 11.2: Modes of Meander Loop Development

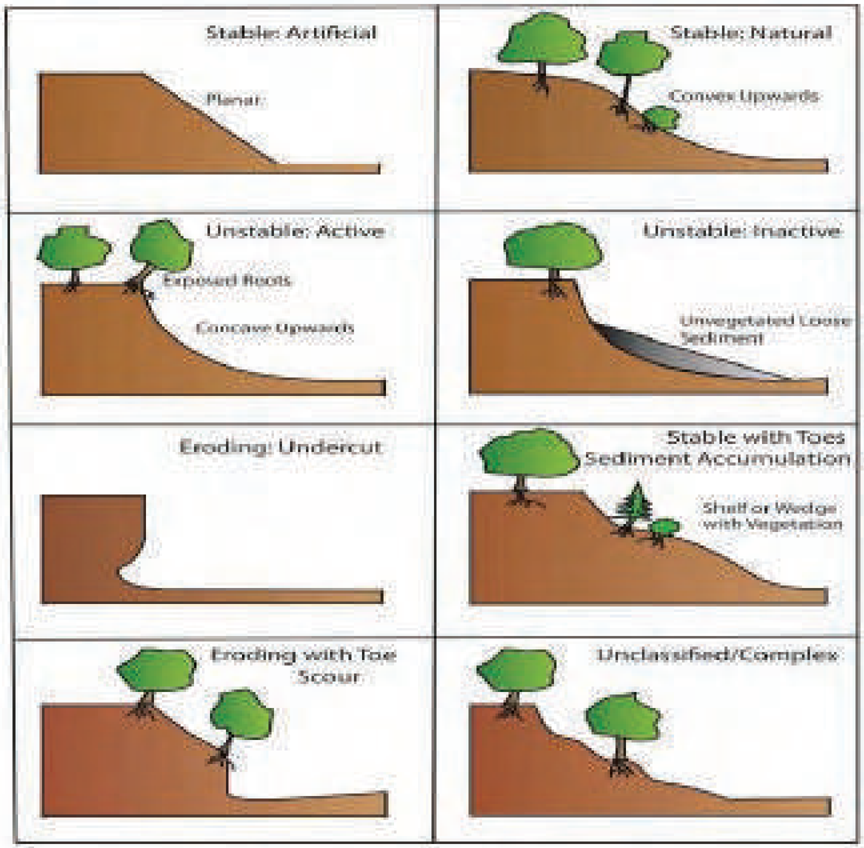


Figure 11.3: Classification and Morphology of Typical Bank Profiles

Aggradation and degradation are the vertical raising and lowering, respectively, of the streambed over relatively long distances and timeframes. The degree of aggradation and degradation are related to the sediment transport behavior of the waterway. Degradation can lead to the exposure and undermining of bridge foundations and increased susceptibility to local scour. Aggradation will reduce the hydraulic opening available at the bridge. Bed elevationchanges can be recognized by taking periodic fascia sounding measurements from a fixed reference point and comparing the readings over time, i.e., channel profiles. Following points should be looking for:

- Bank profiles that are not stable
- Evidence of scour around piers and abutments
- Evidence of debris creating problems around the bridge.

Scour at bridges consists of three additive components:

1. Long term aggradation and degradation of the stream channel.
2. Contraction scour due to constriction or the location of the bridge, as shown in Figure 11.4. The figure shows an example of flow structure including macro-turbulence generated by floodplain/main channel flow interaction, flow separation around abutment, and wake region on the floodplain of a compound channel.
3. Local scour, as shown in Figure 11.5 for a cylindrical pier.

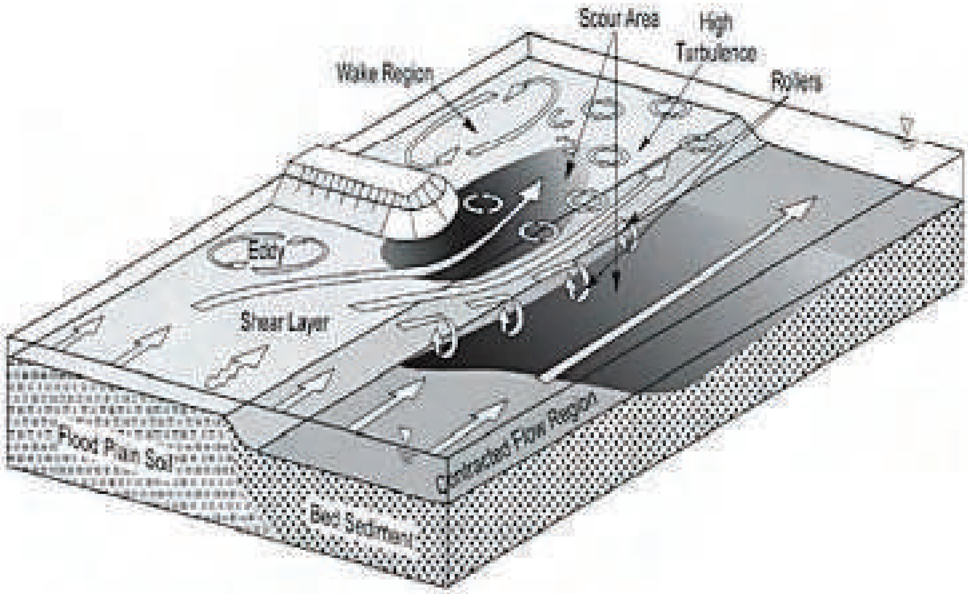


Figure 11.4: Construction Scour Example

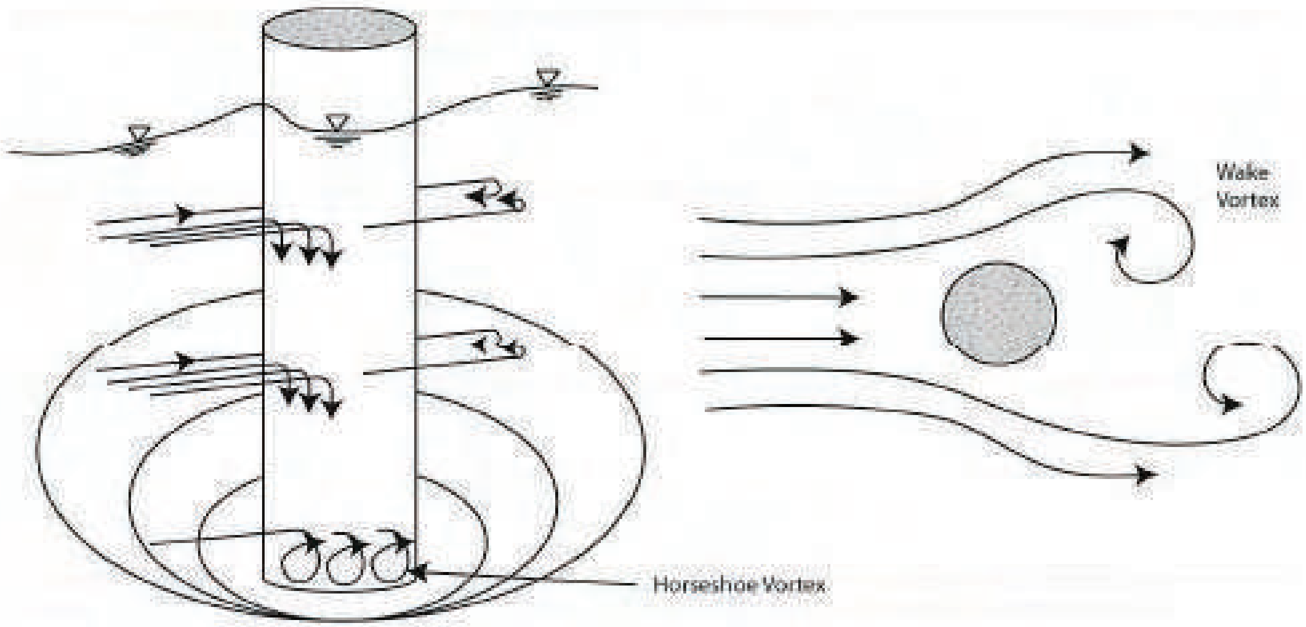


Figure 11.5: Schematic Representation of Scour at a Cylindrical Pier

11.4 Preventive and Basic Maintenance for Channels and Waterway

11.4.1 Debris Removal Management

Waterborne debris (drift), composed primarily of tree trunks and large limbs, often accumulates at bridge piers, abutments and under-deck elements. High water events can increase the amount of debris in the waterway and accelerate debris accumulation.Accumulated debris restricts and redirects water flows through the bridge opening leading to flooding, damaging loads, and foundation scour, as shown by the example in Figure 11.6.

Consideration should be given to schedule debris removal to occur prior to NBIS regulated underwater bridge inspection operations. Accumulated debris is a diver safety hazard and will limit diver access to areas with high scour susceptibility.

Figure 11.6: Increased Scour at Bridge Piers as a Result of Debris

An effective debris removal program can improve the efficiency of the bridge opening and reduce scour potential during the next high-water event.

Debris removal operations may be environmentally sensitive, as shown in Figure 11.7 and Figure 11.8. Coordination with local environmental regulatory agencies may be required for non-emergency work. Best management practices for debris removal include:

- Only cut material when necessary. Turn the debris to allow it to flow through the structure if downstream structures will not be affected; note this practice may not be environmentally acceptable for all bridge owners.
- Minimize machinery disturbance to the stream bank and bed materials. Where possible, use specialized equipment such as a crane, operated from the bridge deck.
- Perform any required work in flowing channels during the work window permitted for the specific stream body.
- Repair and restore bank areas which may be impacted by drift removal machinery.

Figure 11.7: Debris Removal Operation

Figure 11.8: Debris Removal Operation

If a structure has a tendency to accumulate debris (specially in flash-flood prone areas; i.e Sylhet and Hil Districts) and is configured such that debris removal is difficult, debris deflectors can be constructed near the structure. Alternatively, containment gates can be constructed at a convenient location upstream, as shown by the examples in Figure 11.9 and Figure 11.10. More specifically, Figure 11.9 shows a post and rail debris rack, in place for 35 years for light to medium floating debris, installed 100 feet upstream of the culvert. Figure 11.10 shows timber debris fins with sloping leading edge.

Figure 11.9: Post and Rail Debris Rack Installed 100 Feet Upstream of Culvert

Figure 11.10: Timber Debris Fins with Sloping Leading Edge

11.5 Repair and Rehabilitation of Channel and Waterway

Knowledge of the mechanics of stream migration and erosion can be used to predict future conditions and implement repairs for observed problems. Effective countermeasures can be employed to control stream migration and to protect foundations from local scour.

Maintenance countermeasures typically consist of river training and armoring techniques which are designed either to modify the flow or resist erosive forces.

River Training Structures are those which modify the flow by altering stream hydraulics to mitigate undesirable erosional and or depositional conditions at a particular location or in ariver reach. This type of structure is typically classified by its orientation to flow:

- Transverse Structures are countermeasures which project into the flow field at an angle or perpendicular to the flow (bend way weirs, groins, check dams)

- **Longitudinal Structures** are countermeasures which are oriented parallel to the flow or along a bank-line (bulkheads, toe-dikes, levees)
- **Areal Structures** are other countermeasure treatments such as channelization, flow relief, and sediment detention

Armoring Countermeasures resist the erosive forces caused by a hydraulic condition. This type of countermeasure is typically classified by the armoring material and location. These systems can be either rigid or flexible. Rigid systems are typically impermeable but are subject toundermining failure. Flexible systems can conform to changing conditions but are subject to removal and displacement failure. Types of armoring include:

- **Revetments** are designed to protect the channel bank.
- **Bed Armoring** is designed to protect the river bed.
- **Local Scour Armoring** is designed specifically to protect individual substructure elements from local scour.

Other countermeasure strategies include structural (e.g., foundation strengthening, pier geometry modification), biotechnical (e.g., vegetated geofabrics, woody mats, root wads) and monitoring.

Contraction Scour Countermeasures

The most typical countermeasures used for preventing contraction scour are revetments placed on the embankment fill slopes and spur dike/guide bank construction at the upstream side of the abutments.

Local Scour Countermeasures

Countermeasures can include modifications to move the scour away from the foundations, pier nose streamlining as well as armoring. The practice of heaping stones around a pier is not recommended because experience has shown that continual replacement is usually required. An engineered armoring system (detailing size, location, shape,and filtering) will result in a more robust protection.

Aggradation / Degradation Countermeasures

Check dams and detention structures can effectively be used to control bank slipping and caving and sediment deposits near bridges. In lieu of permanent structures, continuing maintenance (dredging / clearing of deposited material) has been used effectively to remove deposited sediment and maintain the hydraulic openings at bridges, as shown in Figure 11.11.

(a) (b)

Figure 11.11: Deposited Sediment Removal to Maintain Hydraulic Opening (a) Before, (b) After

Many countermeasure strategies involve work in streams which may be regulated by local environmental agencies. Consultation with these agencies is advised for non-emergency actions. Nationwide Permits are issued typically every four years to authorize common work items which have been determined to have minimal adverse impacts. The scope of proposed work items should be checked against the most recent issuance of Nationwide Permit No's 3 (Maintenance of Currently Serviceable Structures) and 13 (Bank Stabilization). If a bridge foundation has been determined to be scour critical as part of the bridge owner's scour evaluation program, the USACE will give priority to the bridge owner's request for authorization of the installation of scour countermeasures. Advanced notice of the proposed countermeasure design and construction schedule to the bridge owner and USACE is required.

In addition, the state environmental agency may also have jurisdiction over work done in and adjacent to waterways, so any channel or waterway work should also be reviewed for compliance with state environmental regulations. This not only applies to excavation and placement of fill (riprap), but may also apply to placement of cementitious materials in the waterway.

Countermeasures must be inspected periodically and after floods to check their performance. The design may need to be modified as a result of the inspection. The condition of the countermeasure should be documented with photographs to enable comparison between inspections. In most cases, countermeasures do not "cure" the scour or instability problem. Funding for continued maintenance of the countermeasures should be planned. Non-structural countermeasures are not considered permanent.

11.5.1 Placement of Riprap and Gabions

Riprap and gabion placements are flexible armoring techniques that can be used in various configurations to counter the erosive action of moving water. Riprap refers to a layer or facing of rock, placed on channel and structure boundaries to limit the effect of erosion. Gabions and mattresses refer to lose collections of stones encased in a wire framework (See Figure 11.12 through Figure 11.15).

- Revetments, bend way weirs and spur dikes to counter migration

- Bed armoring and check dams to counter degradation
- Revetments and guide banks to counter contraction scour
- Bed armoring to counter local scour

Riprap is a very common countermeasure due to its general availability, ease of installation, and relatively low cost. Riprap placements should be designed to resist particle erosion, substrate material erosion, and mass failure. Typical practices involve the use of filter fabric bedding, limiting slope angles, and trenching the toe below the anticipated contraction and degradation scour level. The basis of protection provided by the riprap is the mass and interlocking of the individual rocks, therefore careful attention needs to be given to placement technique and mat thickness.

Riprap is not considered a permanent repair to scour and must be periodically monitored at a minimum on the two-year inspection cycle. The following figures are intended to present a basic insight into riprap and gabion uses.

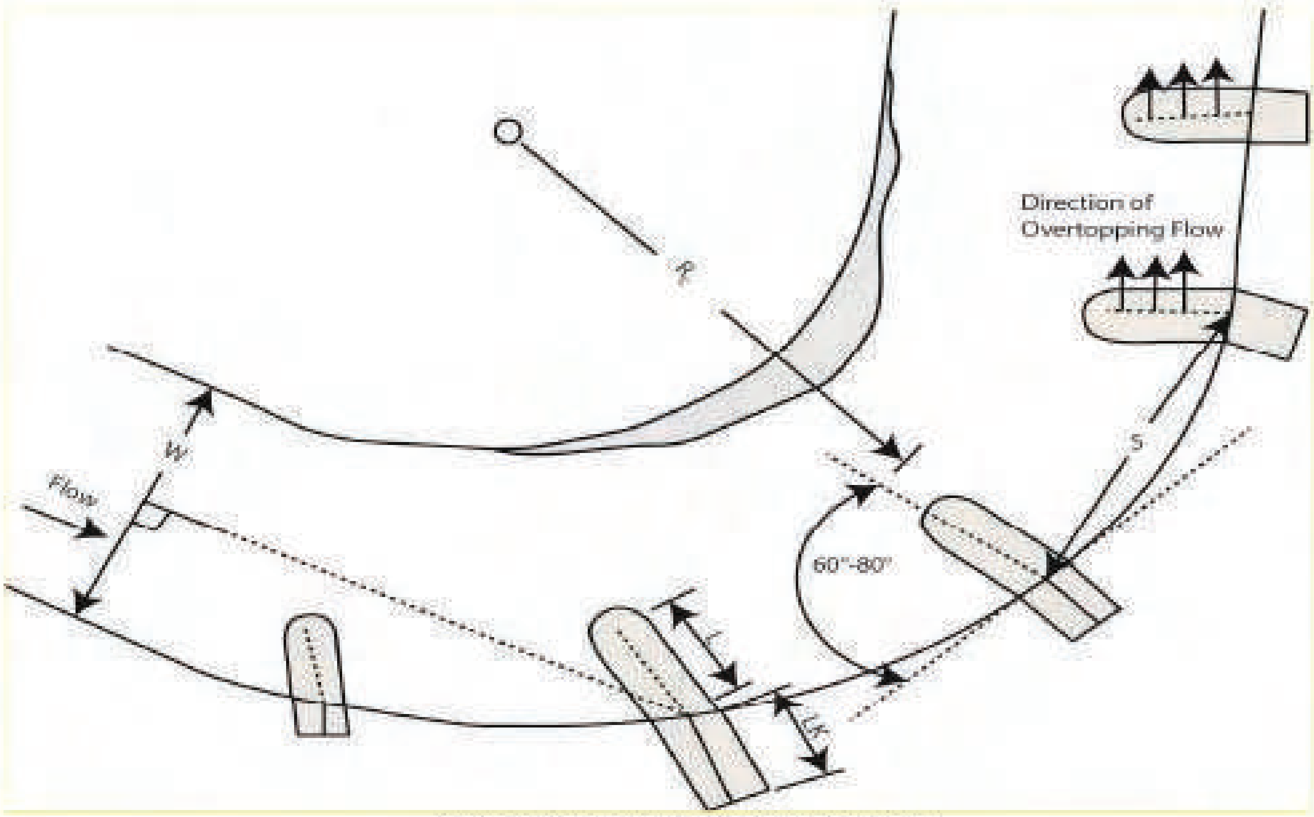


Figure 11.12: Bendway Weir Typical Plan View

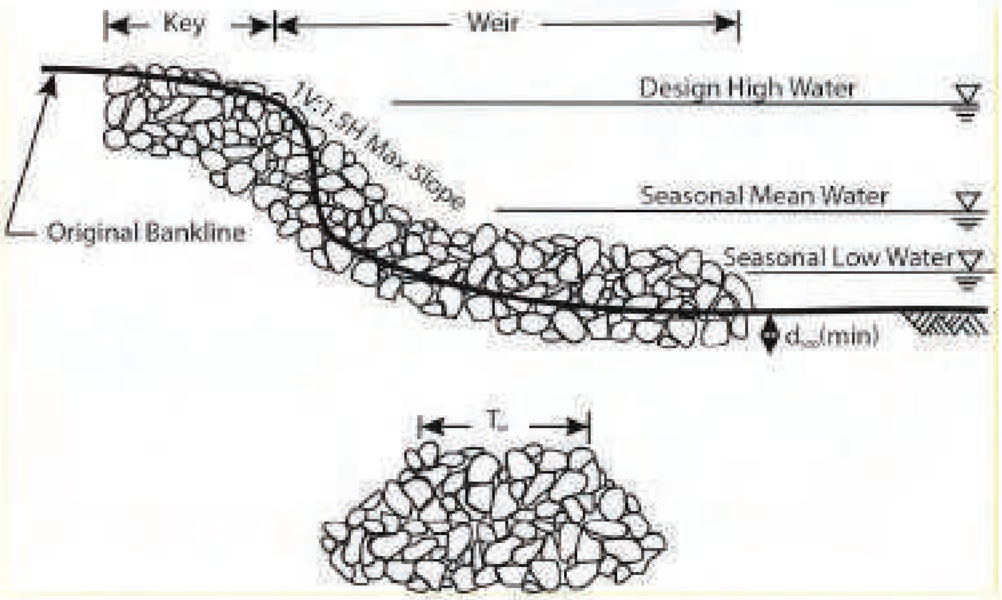
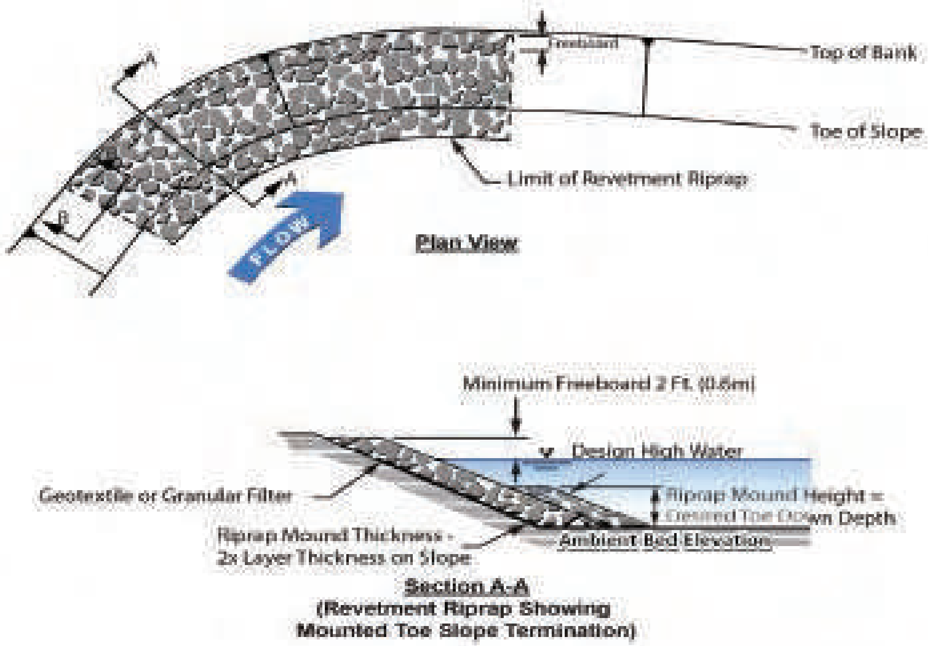
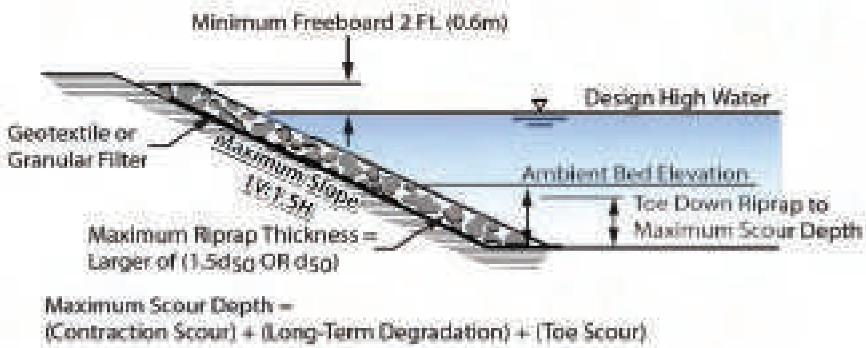
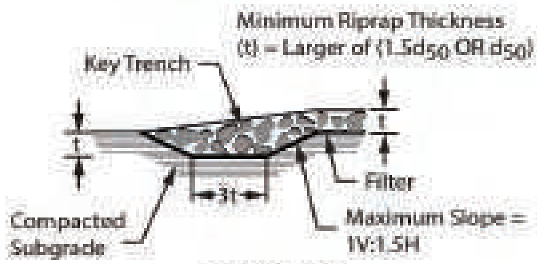


Figure 11.13: Bendway Weir Typical Cross Section



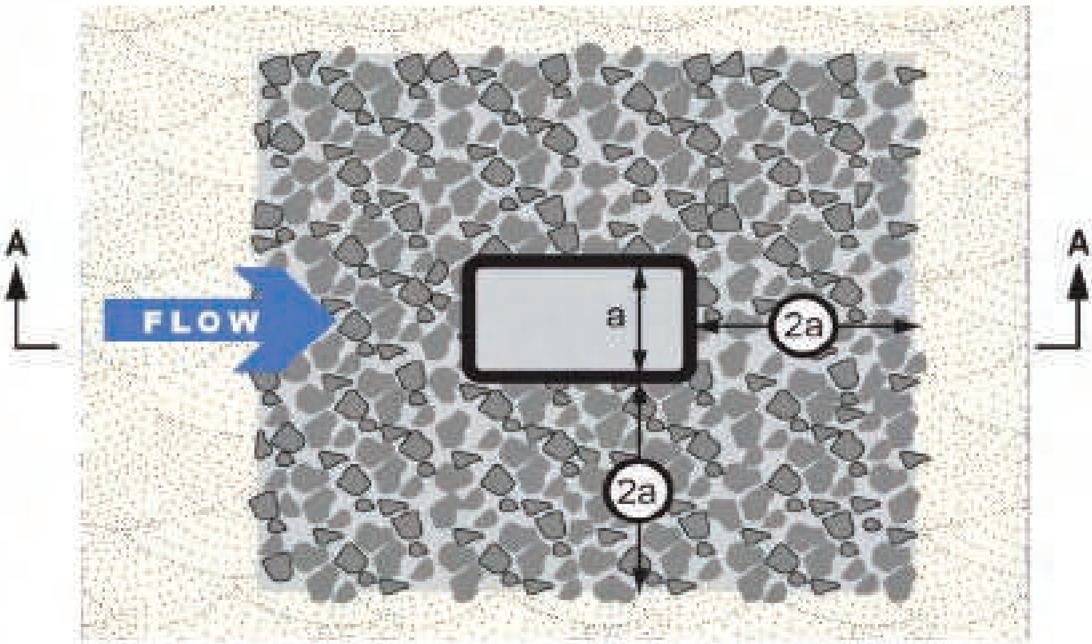


Section A-A
(Revetment Riprap Showing Toe Down Slope Termination)



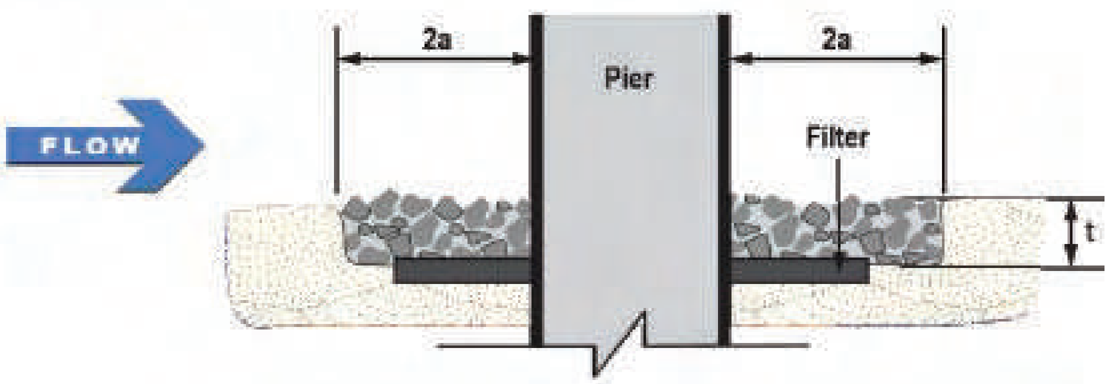
Section B-B

Figure 11.14: Riprap Revetment Details



Pier width = "a" (normal to flow)
Riprap placement = 2(a) from pier (minimum, all around)

Plan View



Minimum riprap thickness $t=3d_{50}$, depth of contraction scour and long-term degradation, or depth of bedform trough, whichever is greatest

Filter placement = 4/3(a) from pier (all around)

Section A-A

Figure 11.15: Riprap Layout Diagram for Pier Local Scour Protection

Advantages to gabions and mattresses are that the smaller stone (smaller than riprap) armoringcan ease placement and is more resistant to removal by the waterway velocity. Mattresses are usually 1.0 foot or less in thickness, whereas gabions are thicker and nearly equidimensional. The use of these devices is most effective in transitory streams associated with an arid climate. Corrosion and abrasive failure of the cage wire is a concern for gabion construction in perennial streams. Galvanized and PVC coated wires are commonly used to extend the expected life span of gabions. Gabions are not recommended for use in gravel bed streams or in saline or acidic waterways. To improve anchorage, the cages can be anchored to steep slopes with railroad spikes. Examples of gabion mattress design details are presented in Figure 11.16 through Figure 11.19.

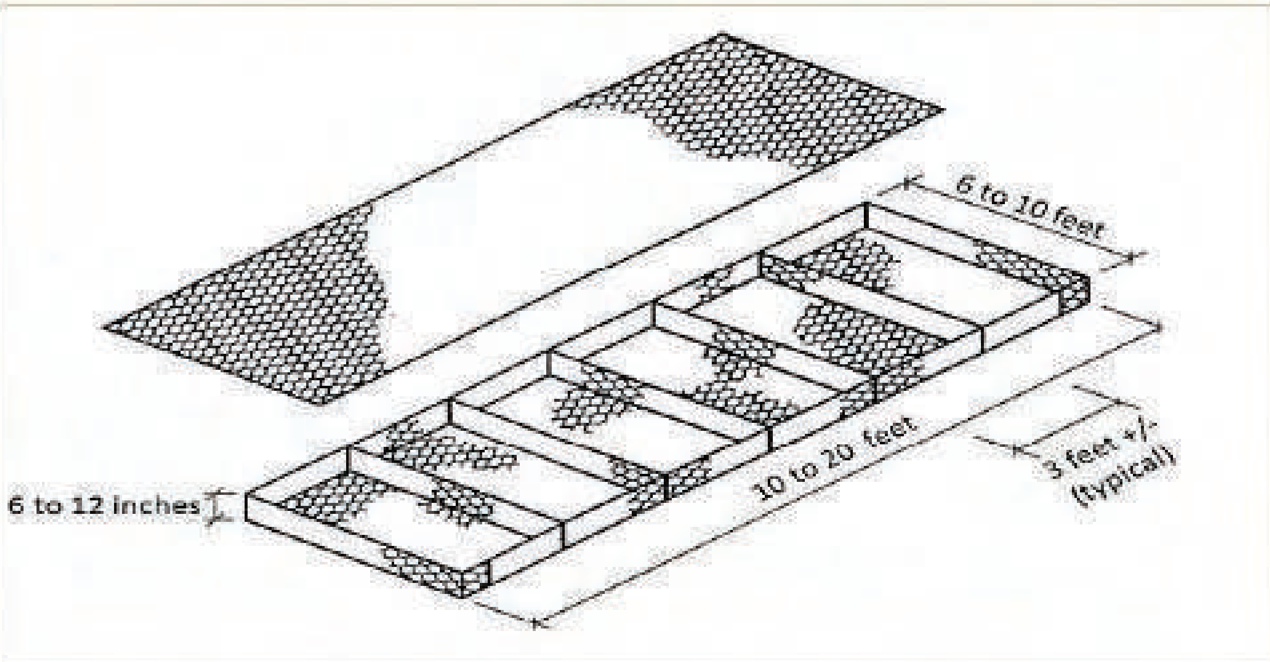


Figure 11.16: Gabion Mattress Showing Typical Dimensions

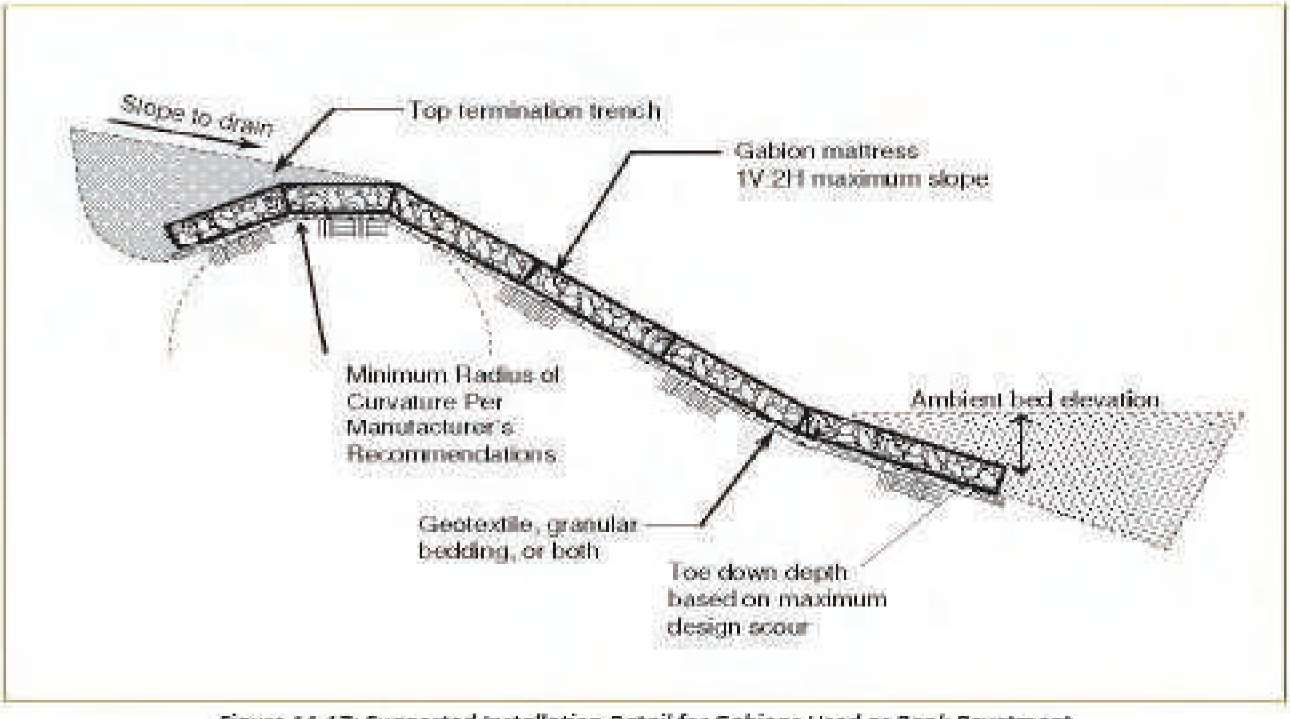


Figure 11.17: Suggested Installation Detail for Gabions Used as Bank Revetment

Figure 11.18: Field Installation of Gabion Mattresses on Channel Bed and Banks

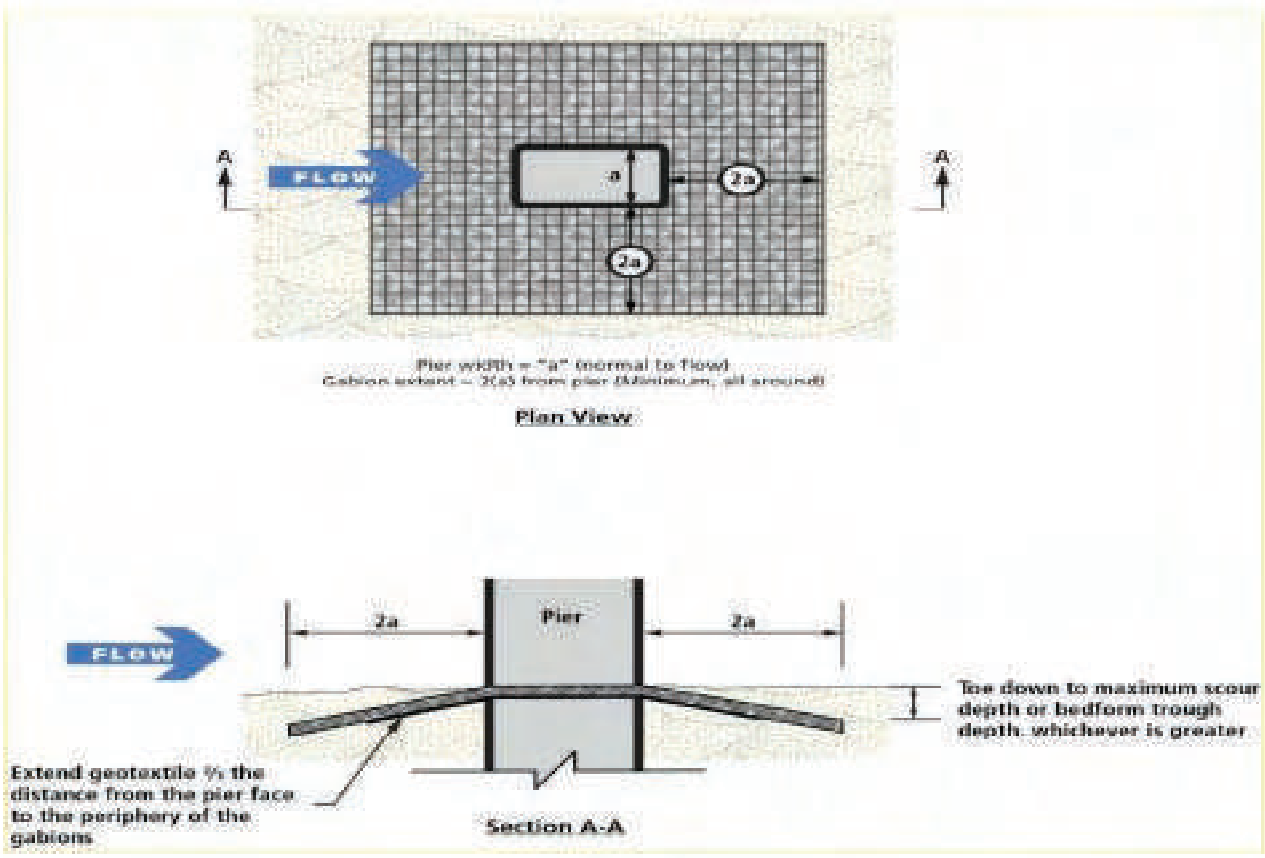


Figure 11.19: Gabion Mattress Layout Diagram for Pier Local Scour Counter Measures

Filters are essential to the successful long-term performance of porous armoring countermeasures such as riprap and gabions. The filter layer prevents excessive migration of the base soil particles through the voids in the armor layer, permits relief of water pressure under the armor, and distributes the weight of the armor to provide uniform settlement. There are two basic types of filters: granular and geotextile. Subgrade soils should be free of organic material. Divers should be used to verify underwater conditions are suitable for riprap placement. Filter placement should result in a continuous installation that maintains contact with the subgrade. Voids, gaps, and tears should be replaced or repaired.

Placing geotextiles under water is difficult. Some fabrics are buoyant and need to be anchored until the armor material is placed. Strong currents will create large forces on the fabric, causing the fabric to act like a sail, resulting in wavelike undulation. In deep water or strong currents, sand filled geotextile containers or proprietary mat systems can provide the filtering requirements. Geotextile should be placed so that upstream strips overlap downstream strips (1.5 feet dry / 3.0 feet underwater). Anchoring pins or weights can be used to keep the fabric in place. Granular filters should be placed with front-end loaders with slopes limited to 1V:4H. Tremie tubes can be used to place granular filter material underwater at bridge piers.

Riprap may be placed underwater or in the dry from land or water-based operations. Stones should be placed from the bottom working toward the top of the slope so that rolling and/or segregation does not occur. Riprap should be placed using methods that do not stretch, tear, puncture, or reposition the underlying fabric. Tracked and wheeled equipment should not be permitted to operate on lower lifts or finished application because they can destroy the interlocking integrity. Special purpose equipment, such as clamshells, orange-peel grapples, or hydraulic excavators, is available for installation. Sounding surveys, divers, sonar profiles, or remotely operated vehicles should be used to monitor and verify underwater placements.

Riprap and gabion mattresses can be grouted to control particle erosion and to create a smoother/more efficient hydraulic opening. Filters are not required for fully grouted riprap; however, drainage of pore pressure must be provided. A significant disadvantage of complete grouting is that the grout converts a flexible revetment to a rigid cover, subject to toe undercutting, out-flanking, and the possibility of sudden catastrophic failure. Partially grouted systems have been used to maintain system flexibility while increasing stability (Figure 11.20). Guidance suggests that the grout should fill between 1/3 and 1/2 of the total void spaces. Additionally, a filter layer should be used with partially grouted rip-rap

Figure 11.20: Close-Up View of Partially Grouted Riprap

Overhead restrictions should be considered when determining if riprap placement is a feasible alternative along abutment and pier faces obstructed by low superstructures. This is an example where gabions may be more practical than large riprap.

11.6 Tremie Concrete

Tremie concrete placement methods use a pipe or tube, through which concrete is placed below the water level. The lower end of the tube is kept immersed in fresh concrete, so thatthe rising concrete from the bottom displaces the water without washing out the cement content. Tremie placements should be isolated from fast moving currents. The concrete mix should be designed to flow readily and the vertical fall distance should be minimized to prevent segregation. Concrete admixtures are available to improve the concrete mix performance for tremie applications. Examples are anti-washout admixtures and flow- improving admixtures.

Tremie placements can be effectively used to repair foundation undermining after a local scour event. An example is shown in Figure 11.21. A means should be provided to allow the trapped water to escape as the concrete surface rises.

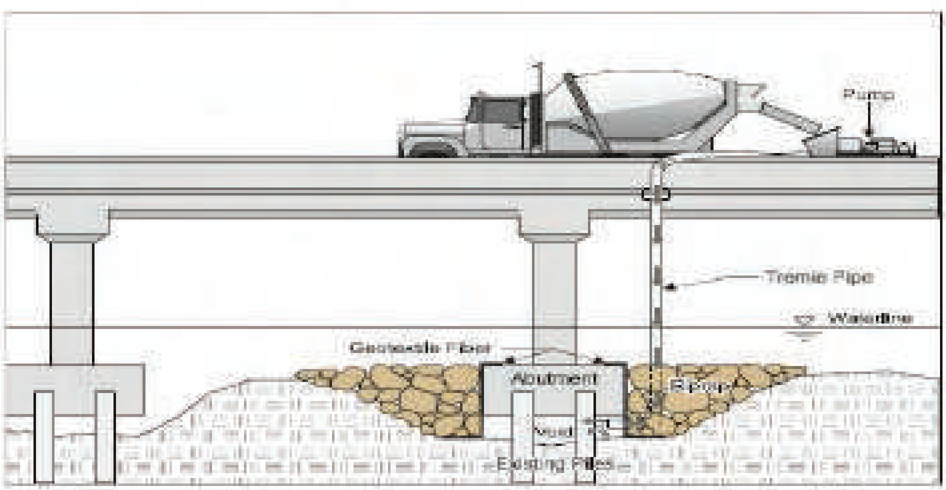


Figure 11.21: Tremie Concrete Placement used to Repair an Undermined Pile Cap

11.7 Grout Bag Placement

Concrete or grout filled bags and mattresses can be placed on dry bedding material or underwater by divers. The bags can be stacked and pinned together with rebar. The bags are fabricated in many shapes, sizes, and configurations with many proprietary systems available for a wide range of applications. Common applications for grout filled bags include riprap substitution (revetment armoring, groin construction, local scour armoring, etc.) and as facing formwork for foundation undermining repairs. Examples are shown in Figure 11.22 through Figure 11.26.

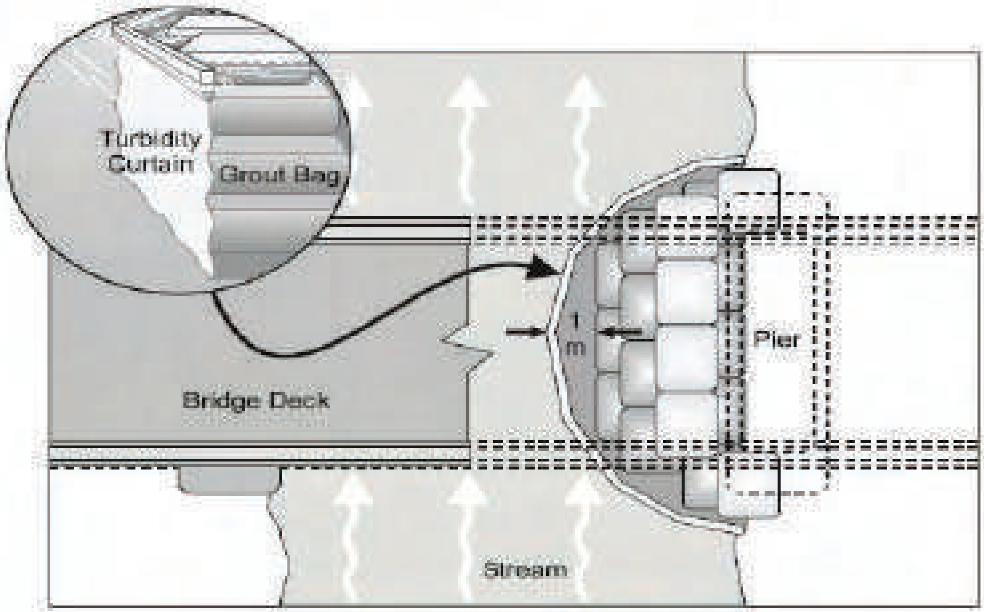


Figure 11.22: Grout Bags used for Local Scour Armoring (Riprap Substitution)

Figure 11.23: Grout Bags Installed around a Pier Nose

Figure 11.24: Grout-Filled Mat Used for Scour Protection at a Bridge Abutment

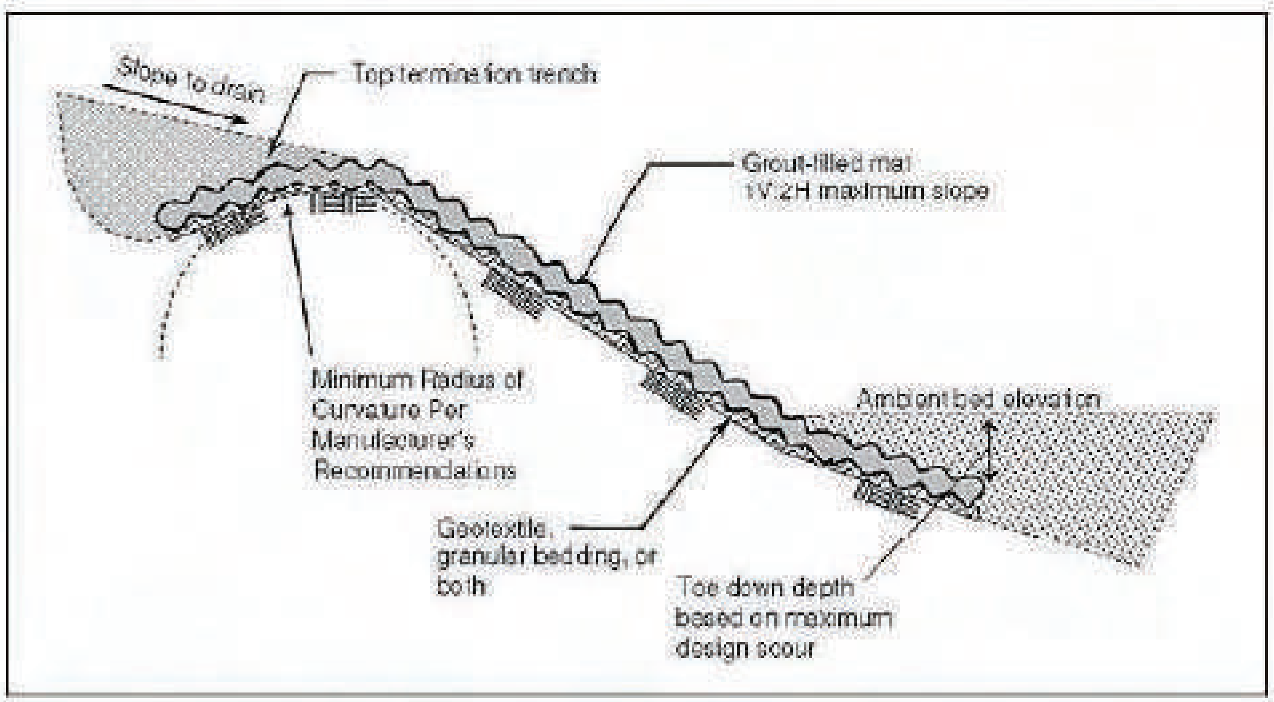
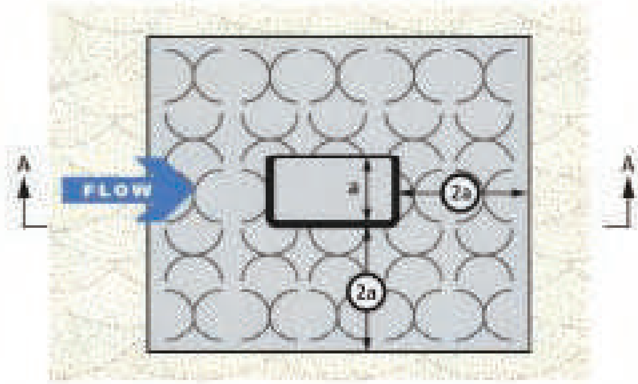
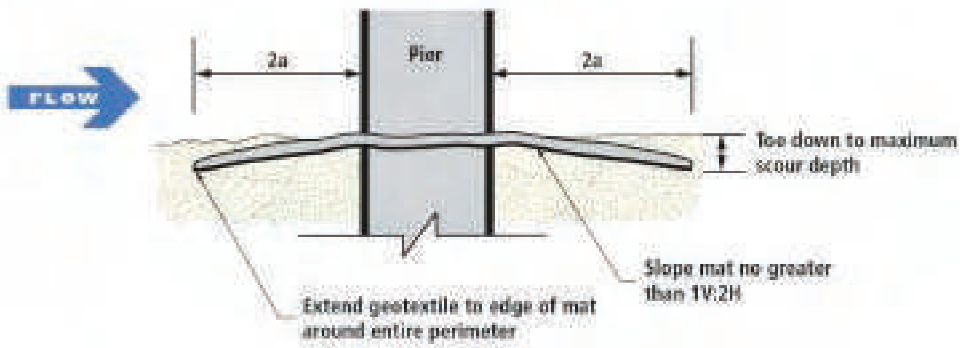


Figure 11.25: Suggested Installation Detail for Grout-Filled Mats Used as Bank Revetment



Pier Width = "a" (Normal to Flow)
Grout Mat Placement = 2(a) from Pier (Minimum, All Around)

Plan View



Section A-A

Figure 11.26: Layout for Grout-Filled Mats at Bridge Piers (Local Scour Prevention)

The grout should be designed to be pumpable with compressive strengths of at least 2,500 psi at 28 days. Admixtures are available to improve the flowability of the grout mix.

When stacked as forms for undermining void repairs, joints should be staggered between rows and anchored with rod dowels. Lower-level bags should be permitted sufficient set time to support the succeeding vertical course. Grout injection should be performed in a manner to avoid bag rupture, prevent cold joints from forming, and to prevent discharge of grout material into the waterway. Void injection and venting pipes should be inserted during bag installation and positioned to ensure that the enclosed volume can be completely filled, and the enclosed water displaced. A four-foot maximum spacing of injection/vent pipes is recommended.

11.8 Sheet Piling

Sheet piling can be effectively used to contain tremie concrete placements at foundations and as a countermeasure against stream migration (Figure 11.27), degradation (Figure 11.28), and local scour protection.

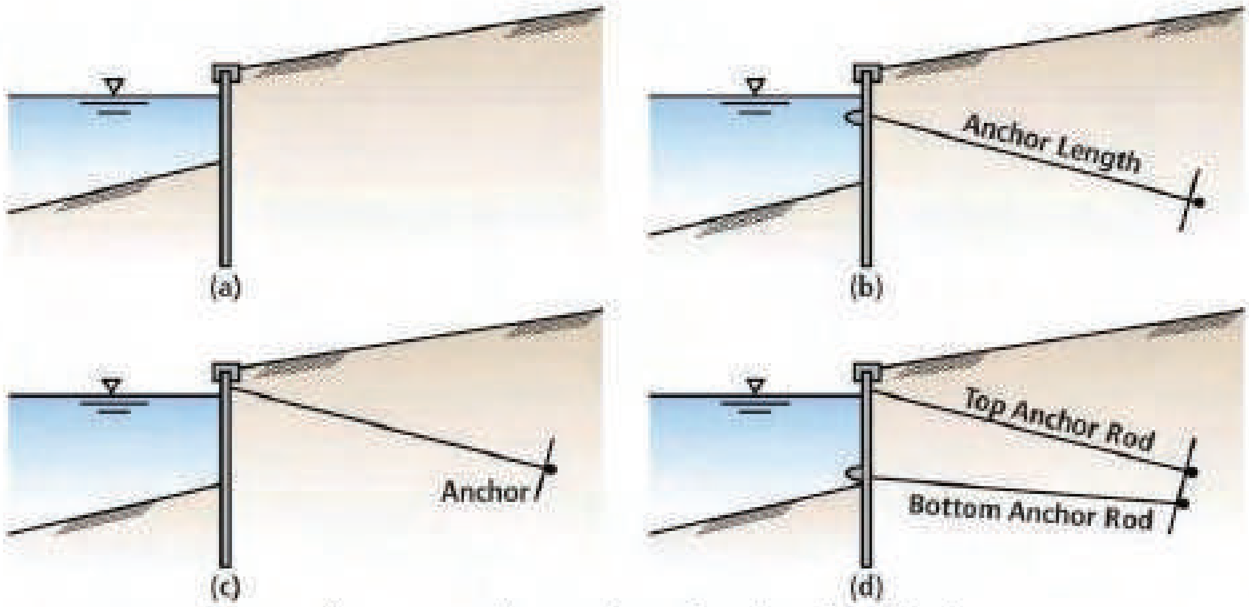


Figure 11.27: Anchorage Schemes for a Sheet Pile Bulkhead

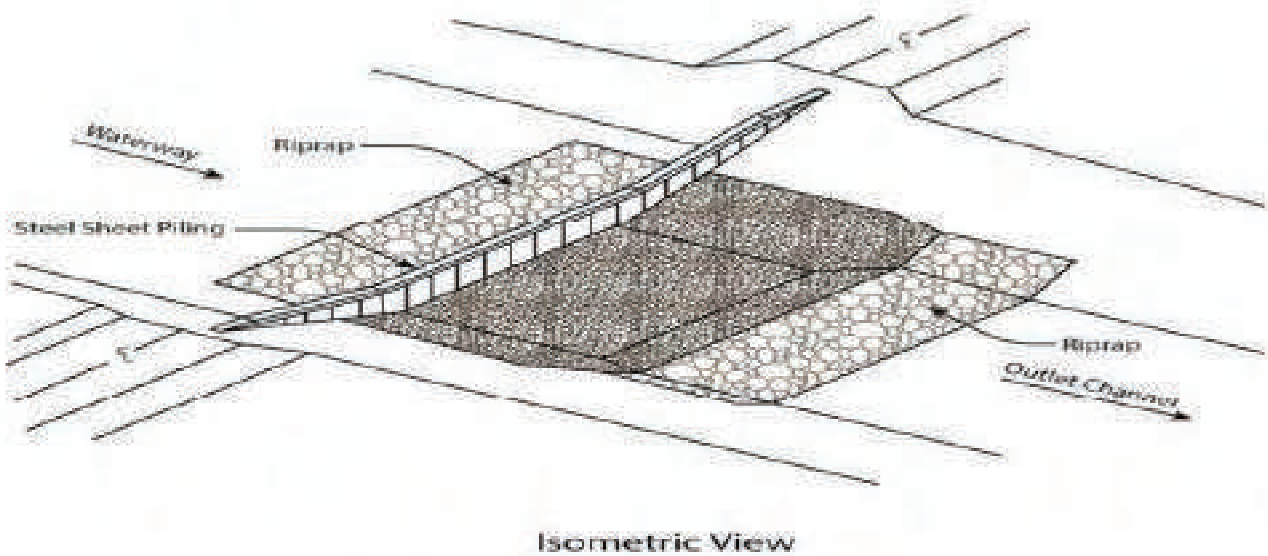


Figure 11.28: Isometric View of a Sheet Pile Check Dam

Sheet piling refers to the linear driving of adjacent pile elements into the existing soil to retain earth or prevent seepage. The piling can be constructed of interlocking steel, timber, or pre- cast concrete elements and can be configured with or without lateral anchorage. The pile elements are typically driven into the ground with crane mounted hammers, which are selectedfor the anticipated driving conditions.

Design of a sheet piling system requires knowledge of the existing soil conditions, evaluation of forces and lateral pressures, determination of the required penetration depth, anchorage selection and anticipated driving conditions. Pile elements should be structurally designed to resist the driving forces, surcharge loading, and the lateral earth forces encountered during typical and maximum anticipated scour conditions.

Selection of sheet piling solutions should consider overhead clearances for driving equipment, clearances to overhead and underground utilities, depth to impenetrable soil/rock layers and vibratory effects on nearby structures and facilities.

11.9 Articulated Block

Articulated block concrete (ABC) systems provide a flexible alternative to riprap, gabions, and rigid revetments. These systems consist of preformed units which either interlock or are held together with cables (or both) to form a continuous blanket. Example of the preformed unit shapes used in these systems are shown Figure 11.29. Typical uses include revetment and bed armoring, where the mat is placed across the entire channel cross section and for pier scour protection (see Figure 11.30 and Figure 11.31).

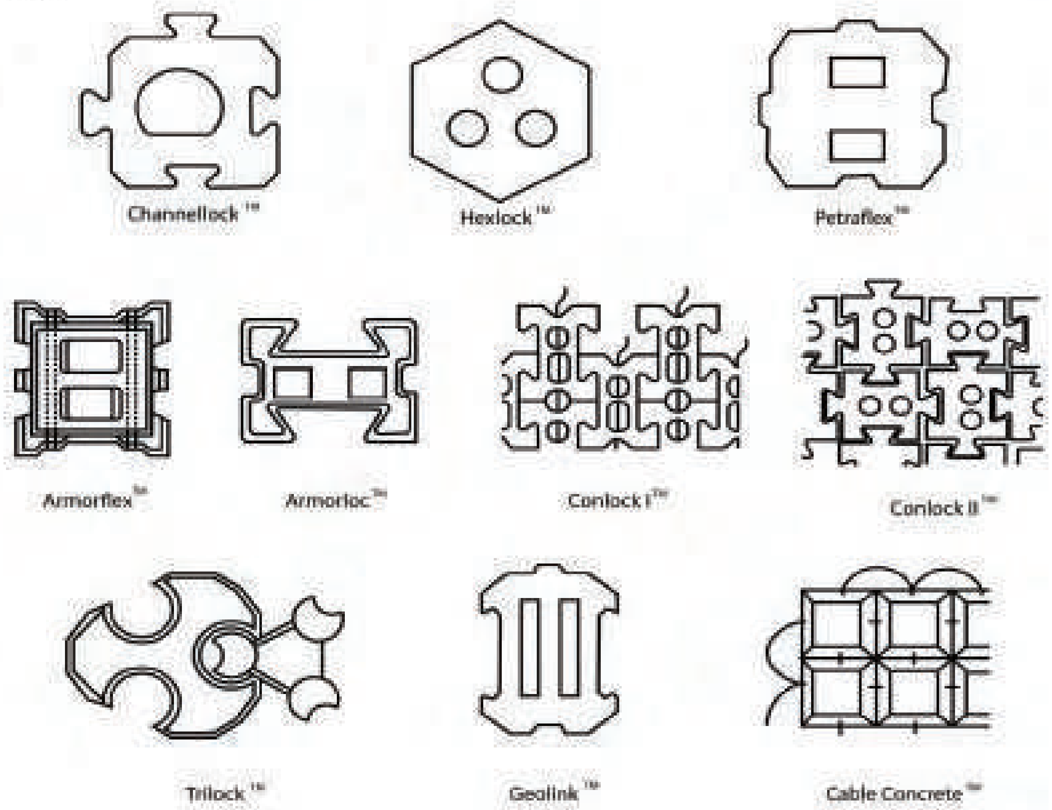


Figure 11.29: Examples of ACB Revetment Systems

Block systems vary in shape and size and will have unique design parameters suited to a range of anticipated hydraulic conditions. Block system should meet the physical requirements of ASTM D6684. In northern climates, the number of anticipated freeze/thaw cycles and corresponding weight loss cycles should be specified. Design and installation procedures shouldclosely follow the manufacturer's recommendations to prevent uplift pressure and loss of subgrade soil through piping and liquefaction, which can lead to progressive plucking failure.

Articulated block systems are typically installed with a geotextile filter, although granular filtering can be used in certain situations. Installation in perennial streams will likely require stream diversions or cofferdams. Some systems maintain sufficient open spaces for the establishment of vegetation.

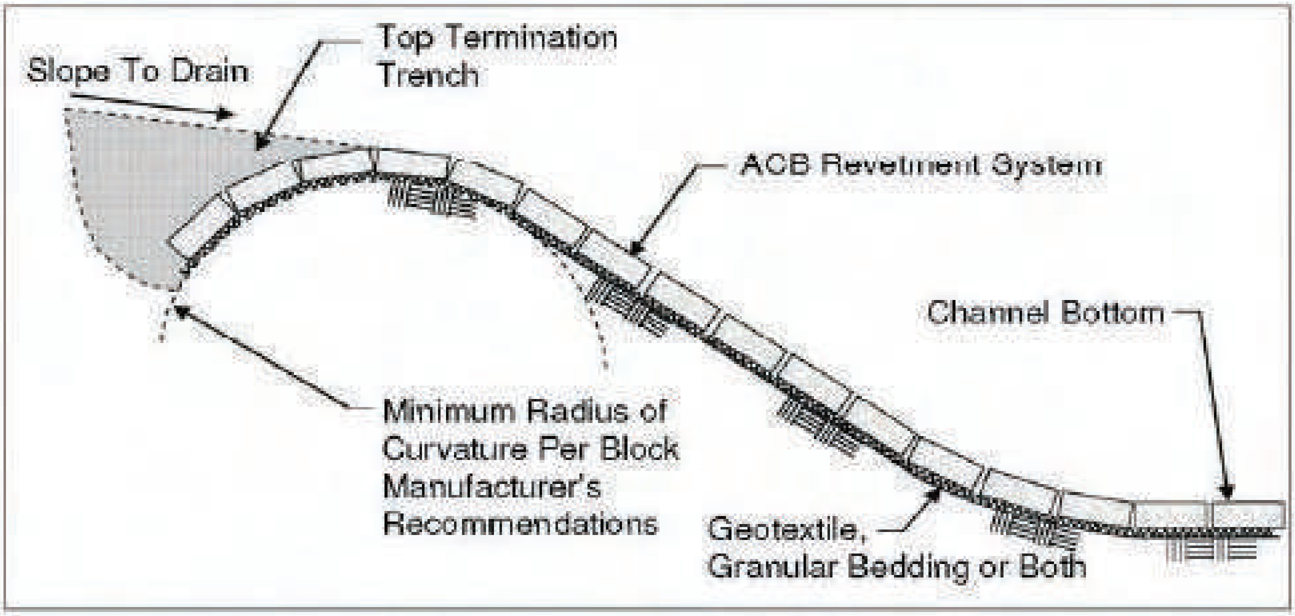


Figure 11.30: Recommended Layout Detail for Bank and Bed Armor

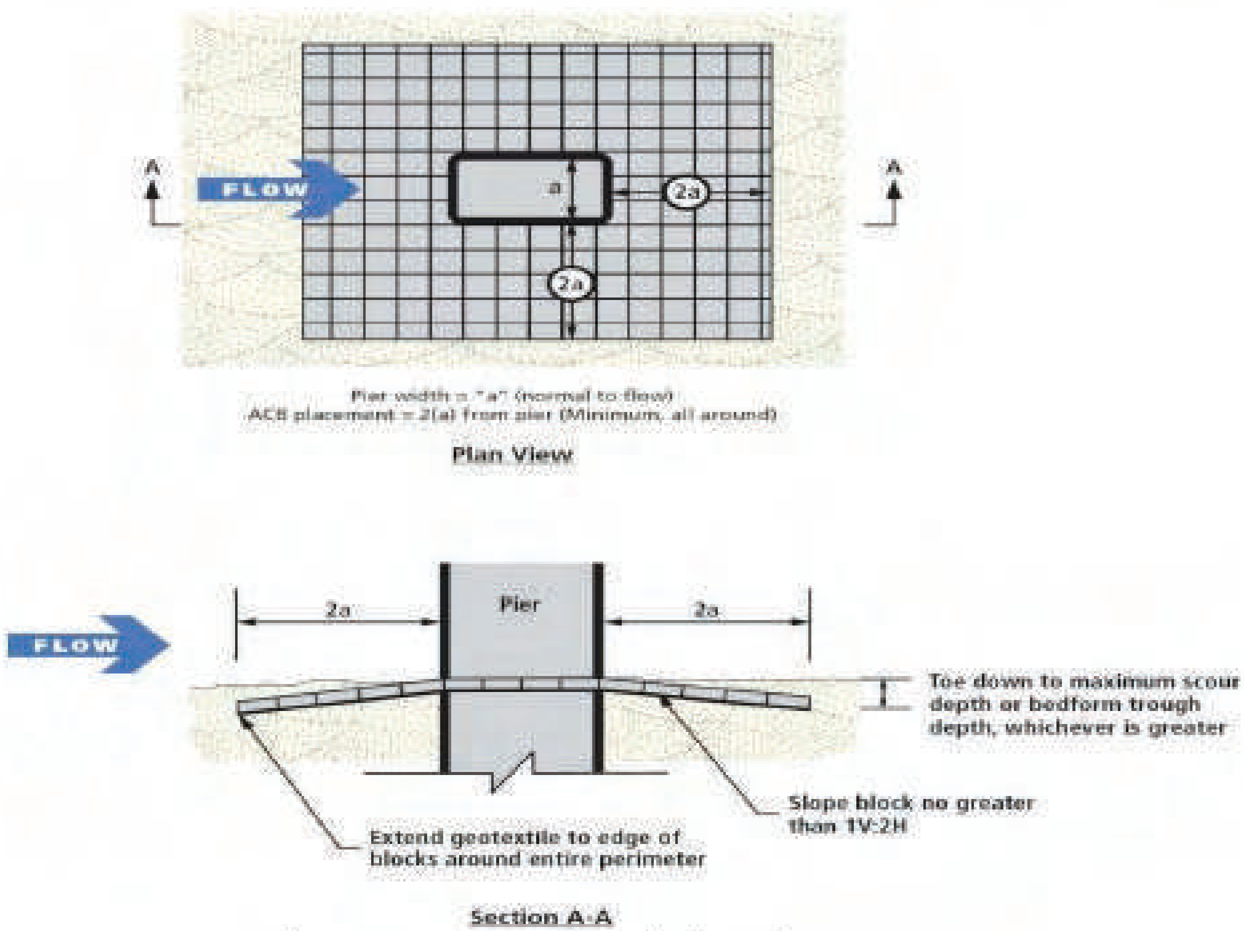


Figure 11.31: ACB Layout Diagram for Pier Local Scour Counter Measures

Appendix-01: Bridge Components

The RSDMS and RuBIMS 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.

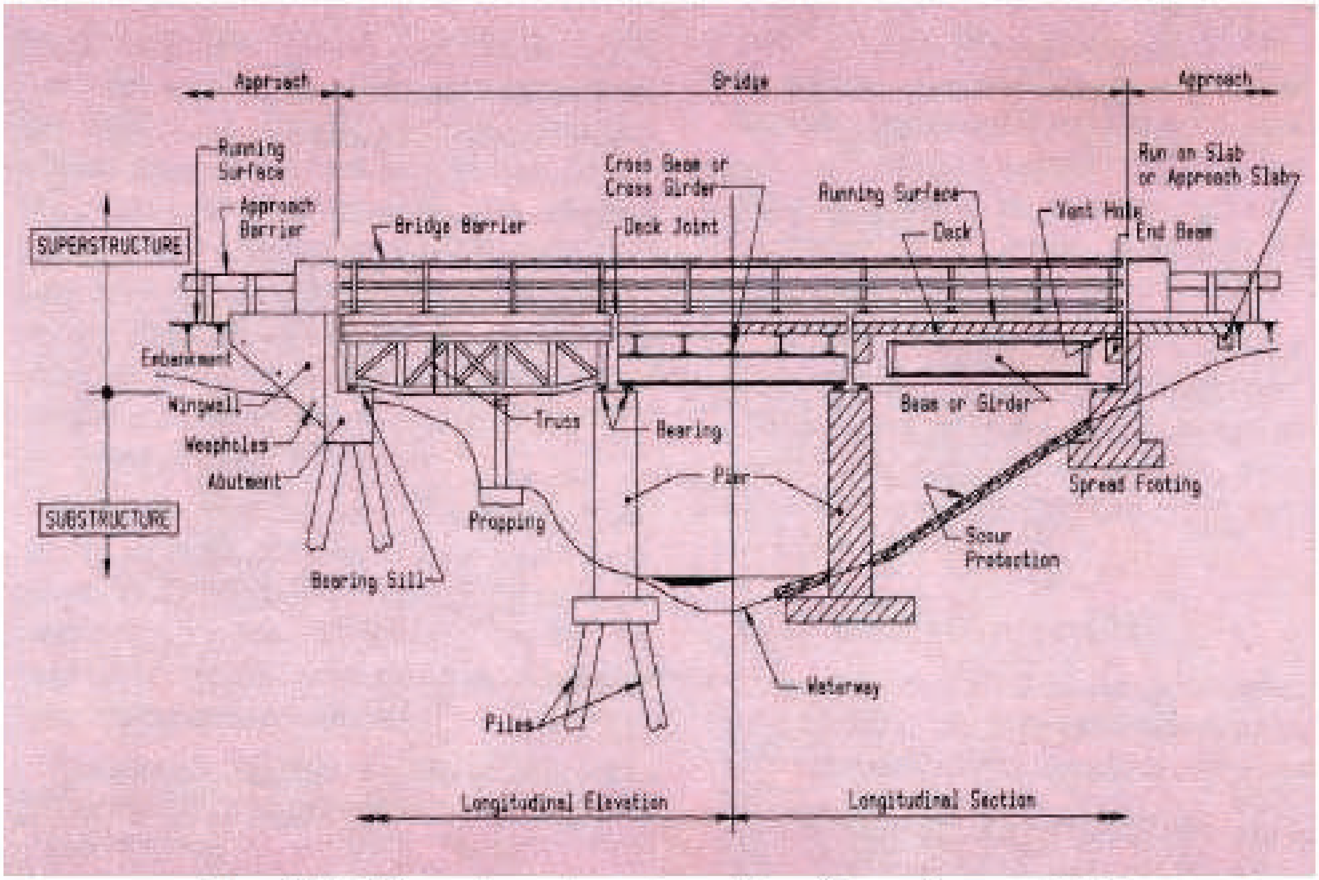


Figure A1.1: Bridge section and general terminology (Source: Austroads 1991)

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 RSDMS and RuBIMS for further details of the various structure and structural elements.

Appendix-02: 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 SOx or NOx, 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.

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.

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.

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. 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.

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.

Appendix-03: SupRB Bridge Maintenance Catalogue

Catalogue - A: Minor Maintenance					
All Type of Bridges (Except Arch Masonry Bridges, Lightweight Bridges, Iron Bridges, and Wooden Bridges)					
Activities	Segments/ Component/ Elements	Element Condition State (CS)	Structure Condition		Description of Items
			Super Structure	Sub Structure	
Cleaning, Removal and Disposal	Carriageways, footpaths, verges, expansion joints, ducts, drainage spouts of bridges	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)	Good (CS1)	• Clearing and grubbing by removal and disposal of all kinds of unwanted vegetation, bushes, debris, and so on. From carriageways, footpaths, verges, deck slabs, and so on. • Clean out stones, debris, and vegetation from expansion joints, remove debris, dirt, vegetation, damage to bearing such as tearing, deterioration, flattening, other abnormal deformation, loose bearings and mortars, and so on from bearing or bearing plinth/base. • Remove graffiti, vegetation, silt, and debris, including animal and fecal deposits from sub and super structures, clean out weep holes, and drainage pipes. • Clean surfaces of all signs, remove all notices and advertisements from signs, and so on. • Remove tree trunks and branches, especially around and between piers and abutments and clean out accumulation of debris and vegetation within 150 meters upstream or downstream of the structure. • Clear the drainage culverts, desilt waterways, drains and drainage structures, and restore the original water course.
Earth work	Approaches	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)	Good (CS1)	• Refill settled/eroded embankments close to abutments, slopes of approaches, shoulders with suitable material, and so on. • Refill earth masses below and around foundations with suitable material, and so on. • Minor bed protection to minimize scour required to keep the foundations unexposed. • Approach slope protection to prevent breaching of approach road.

Catalogue - A: Minor Maintenance					
All Type of Bridges (Except Arch Masonry Bridges, Lightweight Bridges, Iron Bridges, and Wooden Bridges)					
Activities	**Segments/ Component/ Elements**	**Element Condition State (CS)**	**Structure Condition**		**Description of Items**
			Super Structure	**Sub Structure**	
Protective works	Approaches	Fair (CS2)	Good (CS1)	Good (CS1)	• Minor repair/replacement of cement concrete (CC) blocks, toe walls of approaches. • Construct/repair/reconstruct protective works of approaches and so on.
Resealing and overlays	Approaches	Fair (CS2)/ Poor (CS3)	Good (CS1)	Good (CS1)	• Repair potholes, edge breaks, depressions, ruts, cracks, raveling/delamination, including approach settlement, remove unsound material and place hot mix asphalt for temporary repair, and so on. • Seal cracks providing chips sealing or any other suitable treatment options and so on. • Reseal/overlays of approaches (if necessary) and so on.
Repairing/ Replacement	Wearing course	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)	Good (CS1)	• Repair holes, ruts, cracks, unevenness, corrugation, shoving, and so on. • Repair/replace wearing course • Repair/replace of checker plates of steel deck of Bailey bridges, and so on.
	Expansion joint, drain pipes and outlets, abutment/ wing walls	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)	Good (CS1)	• Rake out and replace damaged or missing gap sealant of expansion joints. • Repair/replace damaged or worn-out drainages systems, extend/replace drainage pipes, and so on. • Re-pointing of loose mortar or re-facing of spalled screed of abutment/wing wall, and so on. • Replace missing bolts and tighten loose bolts, re-weld top cover plates where broken or loose, replace gaskets, and so on.
Repairing/ Replacement/ Painting	Rail bar, rail post, wheel guard	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)	Good (CS1)	• Repair/replace damaged reinforced cement concrete/steel railing, wheel guard, footpaths, and so on. • Paint reflectorized painting/coating on rail post, rail bar, wheel guard, and so on.
Painting	Steel members of truss and	Fair (CS2)/	Good (CS1)	Good (CS1)	• Paint steel members of truss and Bailey bridges (if necessary)

Catalogue - A: Minor Maintenance					
All Type of Bridges (Except Arch Masonry Bridges, Lightweight Bridges, Iron Bridges, and Wooden Bridges)					
Activities	**Segments/ Component/ Elements**	**Element Condition State (CS)**	**Structure Condition**		**Description of Items**
			Super Structure	**Sub Structure**	
	Bailey bridges	Poor (CS3)/ Severe (CS4)			
Road safety activities	Railing, rail posts, wheel guard, deck slab, and approaches	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)	Good (CS1)	• Repair/replace/construct all damaged signs, reinforced cement concrete guide posts, and so on. • Repaint all signs (reflectorized painting/coating) and so on.

Note: a. Replace - Only part of the component/element of the structure can be replaced.

Catalogue - B: Major Maintenance (Including Minor Maintenance)					
All Type of Bridges (Except Arch Masonry Bridges, Lightweight Bridges, Iron Bridges, and Wooden Bridges)					
Activities	**Segments/ Component/ Elements**	**Element Condition State (CS)**	**Structure Condition**		**Description of Items**
			Super Structure	**Sub-Structure**	
Repairing/ Retrofitting	Pile, pile cap, pier, pier cap, and abutment wall (sub structure)	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	Fair (CS2)	• Repair/retrofit/replace a damaged or serious settlement, deformed or visible reinforcement bars or spalling concrete due to corrosion of reinforcement of abutments, supports, pile, pile cap, pier cap/super structures, and so on.
Repairing/ Replacement	Bearing assembly	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	Fair (CS2)	• Repair/replace elastomeric bearing pads, repair minor damaged to concrete bearing seats, loose bolts, and so on.
Repairing/ Retrofitting/ Replacement	Wing wall	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	Fair (CS2)	• Repair/retrofit/replace a damaged or serious settlement, deformed or visible reinforcement bars or spalling concrete due to corrosion of reinforcement of wing walls, and so on.
	Girder and cross-girder	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Fair (CS2)	Good (CS1)/ Fair (CS2)	• Repair/retrofit/replace a damaged or serious settlement, deformed or visible reinforcement bars or spalling concrete due to corrosion of reinforcement of girder and cross girder, and so on.

	Steel members of truss and Bailey bridges	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Fair (CS2)	Good (CS1)/ Fair (CS2)	• Repair/retrofit/replace a damaged or differential settled, defective due to corrosion of steel members/decks or truss of bailey bridges, and so on.
	Deck and walkway	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Fair (CS2)	Good (CS1)/ Fair (CS2)	• Repair/retrofit/replace a damaged or deformed or visible reinforcement bars or spalling concrete due to corrosion of reinforcement of deck and walkway and so on.
Repairing/ Rehabilitation	Embankment slope protection	Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	Good (CS1)/ Fair (CS2)	• Construct/repair/reconstruct approach embankment and protective works (if necessary) of approaches and so on.
	Bridge approaches	Severe (CS4)	Good (CS1)/ Fair (CS2)	Good (CS1)/ Fair (CS2)	• Reconstruct/rehabilitation of settled/eroded approaches and so on.
Repairing/ Reconstruction / New construction	River training works	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	Good (CS1)/ Fair (CS2)	• Repair/reconstruct river bank/slope protection works, construct suitable protective works of exposed piles due to erosion/scour and so on. • Remove accumulated excessive inorganic/combustible materials within 150 meters upstream or downstream of the structure. • Refill, with suitable materials, eroded subsoil close to the abutments or near the abutments or supports and so on.

Note: a. Replace - Only part of the component/element of the structure can be replaced.

Catalogue - C: Rehabilitation (Including Minor and Major Maintenances)					
All Type of Bridges (Except Arch Masonry Bridges, Lightweight Bridges, Iron Bridges, and Wooden Bridges)					
Activities	**Segments/ Component/ Elements**	**Element Condition State (CS)**	**Structure Condition**		**Description of Items**
			Super Structure	**Sub-Structure**	
Repair/ Retrofitting	Pile, Pile Cap, Pier, pier cap, and abutment wall (for carriage width ≥5.5 m)	Poor (CS3)	Good (CS1)/ Fair (CS2)/	Good (CS1)/ Fair (CS2)	• Retrofit/replace a damaged or serious settlement, deformed or visible reinforcement bars or spalling concrete due to corrosion of reinforcement of abutments,

			Poor (CS3)/ Severe (CS4)		supports, pile, pile cap, pier cap/super structures, and so on.
Repairing/ Retrofitting/ Replacement	Girder and crossgirder (for carriage width ≥5.5 m)	Poor (CS3)/ Severe (CS4)	Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	• Retrofit/replace a damaged or serious settlement, deformed or visible reinforcement bars or spalling due to corrosion of reinforcement of girder and cross girder and so on.
Repairing/ Retrofitting/ Replacement	Deck and walkway (for carriage width ≥5.5 m)	Poor (CS3)/ Severe (CS4)	Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	• Retrofit/replace a damaged or deformed or visible reinforcement bars or spalling concrete due to corrosion of reinforcement of deck and walkway and so on.
Repair/ Retrofitting	Pile, Pile Cap, Pier, pier cap, and abutment wall (for carriage width between >3m and <5.5m (If structural review suggests no capacity expansion)	Poor (CS3)	Good (CS1)/ Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	• Retrofit/replace, damaged or serious settlement, deformed or visible reinforcement bars or spalling concrete due to corrosion of reinforcement of abutments, supports, pile, pile cap, pier cap/super structures, and so on.
Repairing/ Retrofitting/ Replacement	Girder and cross-girder (for carriage width between >3m and <5.5m (If structural review suggests no capacity expansion)	Poor (CS3)/ Severe (CS4)	Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	• Retrofit/replace a damaged or serious settlement, deformed or visible reinforcement bars or spalling due to corrosion of reinforcement of girder and cross girder and so on.
Repairing/ Retrofitting/ Replacement	Deck and walkway (for carriage width between >3m and <5.5m (If structural review suggests no capacity expansion)	Poor (CS3)/ Severe (CS4)	Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	• Retrofit/replace, damaged or deformed or visible reinforcement bars or spalling concrete due to corrosion of reinforcement of deck and walkway and so on.
Repair/ Retrofitting	Cap, pier, pier cap, and abutment wall	Good (CS1)/ Fair (CS2)/ Poor (CS3)	Poor (CS3)/	Good (CS1)/ Fair (CS2)	• Retrofit/replace a damaged or serious settlement, deformed or visible reinforcement bars or

	(for carriage width <3 m)		Severe (CS4)		spalling concrete due to corrosion of reinforcement of abutments, supports, pile, pile cap, pier cap/super structures, and so on.
Repairing/ Retrofitting/ Replacement	Girder and crossgirder (for carriage width <3 m)	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	• Retrofit/replace a damaged or serious settlement, deformed or visible reinforcement bars or spalling due to corrosion of reinforcement of girder and cross girder and so on.
Repairing/ Retrofitting/ Replacement	Deck and walkway (for carriage width <3 m)	Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	• Retrofit/replace a damaged or deformed or visible reinforcement bars or spalling concrete due to corrosion of reinforcement of deck and walkway and so on.

Major Scope	Activities	Description of Items
Bailey bridge	Procurement and stacking of Bailey bridges or its parts at all the LGED regional offices.	• To support any emergency situation for maintaining road connectivity such as ➢ Sudden collapse of any bridges or culverts; ➢ One or more elements of the bridge heavily and critically damaged that compromises the safety of the traffic using the bridge; and ➢ Bridge collapse due natural disaster and so on.

Note: Replace - Only part of the component/element of the structure can be replaced

Catalogue - D: Capacity Expansion			
All Type of Bridges (Except Arch Masonry Bridges, Lightweight Bridges, Iron Bridges, and Wooden Bridges)			
Activities	**Existing Structure Condition**		**Description of Items**
	Super Structure	**Sub-Structure**	
Capacity expansion of existing structure **(if carriage width <5.5 meters and structural review suggests capacity expansion)**	Good (CS1)/ Fair (CS2)	Good (CS1)/ Fair (CS2)	• Attaining minimum minor maintenance of existing structure (if required) to comply with Catalogue-A • Attaining minimum major maintenance of existing structure (if required) to comply with Catalogue-B • Capacity expansion of both super and sub structure of existing structure or capacity expansion of only super structure
Capacity expansion of existing structure (if	Good (CS1)/ Fair (CS2)	Good (CS1)/ Fair (CS2)	• Attaining minimum minor maintenance of existing structure (if required) to comply with Catalogue-A

carriage width <5.5 meters and structural review suggests capacity expansion) by including additional new bridge			• Attaining minimum major maintenance of existing structure (if required) to comply with Catalogue-B
construction parallel to existing structure			• Attaining minimum rehabilitation works of existing structure (if required) to comply with Catalogue-C • New construction of bridge (Carriage width ≤3.6 m) without any significant and irreversible social and environmental consequences.

Catalog - E: Replacement

All Type of Bridges

Major Scope	Existing Structure Condition		Description of Items
	Super Structure	Sub-Structure	
Replacement of existing arch masonry, lightweight, iron bridges, and wooden bridges (if Structural review suggests replacement)	n.a	n.a	• Replacement of existing structure with new bridge (Carriage width ≥5.5 m)
Replacement of existing bridge (if carriage width ≥5.5 meters and structural review suggests replacement)	Good (CS1)/ Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Severe (CS4)	• Replacement of existing structure with new bridge (Carriage width ≥5.5 m)
Replacement of existing bridge (if carriage width ≥5.5 meters and structural review suggests no rehabilitation)	Good (CS1)/ Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Poor (CS3)	• Replacement of existing structure with new bridge (Carriage width ≥5.5 m)
Replacement of existing bridge (if carriage width < 5.5 m)	Good (CS1)/ Fair (CS2)/ Poor (CS3)/ Severe (CS4)	Poor (CS3)/ Severe (CS4)	• Replacement of existing structure with new bridge (Carriage width ≥5.5 m)
Replacement of existing bridge (if carriage width <3 meters and structural review suggests no rehabilitation)	Poor (CS3)/ Severe (CS4)	Good (CS1)/ Fair (CS2)	• Replacement of existing structure with new bridge (Carriage width ≥5.5 m)

Appendix-04: Case Study 01

Bridge Maintenance - Epoxy injection work in Gopalpur Bolata Bridge, Tangail

Figure A4.1: Girder Cracks

Figure A4.2: Mixing of Apoxy material

Figure A4.3: Injection of Apoxy to fill the Cracks

Appendix-05: Case Study 02

Bridge Maintenance - Repair of Concrete Surface- Application of Polymer Mortar, Polymer Concrete

(Maintenance of 9.40m long RCC Box Culvert on Itavara RHD-Amin bazar GC road at Ch:6200m [Road ID: 326382003] under upazila keraniganj, Dist: Dhaka.)

Figure A5.1: Detreated (scaled) Abutment Surface

Figure A5.2: Application of Polymer Mortar

Figure A5.3: Culvert repair using Polymer Mortar

Deck Slab Repair - Application of Polymer Concrete

Figure A5.4: Preperation of Concrete Deck for Application of Polymer Concrete

Figure A5.5: Application of Polymer Concrete

Appendix-06: Case Study 03

a. Bridge Maintenance - Repair of Concrete Girder using Carbon Fibre Laminate and Carbon Fiber Wrap:

Figure A6.1: Deteriorated Reinforced Concrete Girder and Repair using Carbon Fibre Laminate

b. Bridge Pier -Maintenance using Carbon Fiber Wrap

Figure A6.2: Deteriorated Reinforced Concrete Pier Column and Repair using Carbon Fibre Wrap

Appendix-07: Case Study 04 (Bridge Rehabilitation)

Rehabilitation of 126-meter RC Girder Bridge at Nakla Upazila, Sherpur under SupRB

Defects and Condition before Rehabilitation

- The back approach abutment scours and pile exposed
- Poor concreting in Piers, pile and girders scalling/spalling of concrete
- Disintegration of piles from pile cap
- Half of the river almost silted i.e, around 55m at front approach side
- Narrowing water flowing area.

Figure A7.1: Scouring at Abutment and disintegrated Pile from Pile Cap

Figure A7.2: Very Poor concreting at the Girder

Figure A7.3: Very Poor concreting at the Pier (Scalling)

Rehabilitation Design

- Micro concreting to the disintegrated pile with permanent casing and affected girder.
- Pier columns were treated by polymer mortar
- Dredging from the silted part of the river and filled by the same dredged sand to repair the scoured abutment.
- laying 250 kg geo bag as riprap in back approach at scoured abutment.

Figure A7.4: Damaged pile surface preparation and Installed Casing

Figure A7.5: Heavy Scour near Abutment

Figure A7.6: Repaired Scour near Abutment

Figure A7.7: Rehabilitated Bridge

Appendix-08: Additional Bridge Repair Items

Surface Deterioration, Honeycombing or concrete Exposure

Surface Deterioration, Honeycombing or concrete exposure can adversely affect the durability, strength, and appearance of the bridge components. It can create pathways for moisture or corrosive substances to infiltrate the concrete, potentially leading to reduced service life, decreased structural integrity, and aesthetic concerns. Proper construction practices, including appropriate concrete mix design, placement, compaction, formwork sealing, curing, and formwork removal, can help minimize the occurrence of these types of defects during bridge construction.

It's important to note that exposed coarse aggregate on the surface of a bridge can affect the appearance, durability, and performance of the bridge. It may require appropriate repair and maintenance measures to address the underlying causes and protect the bridge from further deterioration. Consultation with a qualified engineer or contractor experienced in bridge construction and maintenance is recommended to identify the root causes and determine the appropriate repair and maintenance strategies for addressing exposed coarse aggregate on a bridge surface

It's also important to note that even small cracks, voids, or imperfections on a bridge surface can potentially lead to further deterioration if left unaddressed. Therefore, regular inspection, maintenance, and timely repairs are critical to ensure the long-term durability and safety of bridges. Proper design, construction, and maintenance practices can help minimize the occurrence of cracks or imperfections on the bridge surface and extend its lifespan.

Small cracks, voids, or imperfections can occur on the surface of a bridge due to a variety of reasons, including:

Age and Wear: Bridges are exposed to environmental conditions such as temperature changes, moisture, freeze-thaw cycles, and traffic loads, which can cause the materials to expand, contract, and deteriorate over time. As a result, small cracks, voids, or imperfections may develop on the bridge surface as a natural part of aging and wear.

Structural Movements: Bridges are subjected to various structural movements, including settlement, vibration, and deflection due to traffic loads, thermal expansion/contraction, and other factors. These movements can create stress and strain on the bridge surface, which may result in the formation of small cracks or voids.

Traffic loads: Bridges are designed to carry the weight of vehicles and pedestrians, but heavy traffic loads or overloading can cause stress and strain on the bridge structure, which may result in the development of small cracks or deformations on the surface.

Environmental Factors: Exposure to harsh environmental conditions, such as chemical exposure, saltwater intrusion, or acidic gases, can degrade the bridge surface and cause cracks or voids to form. Additionally, natural disasters such as earthquakes, floods, or severe storms can cause damage to bridges, including surface cracks or imperfections.

Poor Construction or Design: Improper construction practices, such as inadequate compaction of materials, insufficient reinforcement, or improper curing of concrete, can lead to the development of cracks, voids, or imperfections on the bridge surface. Similarly, poor design or detailing, such as lack of expansion joints, can result in stress concentration points that can lead to cracking or other surface defects.

Maintenance or Repair Activities: Some cracks or imperfections on the bridge surface may be the result of previous maintenance or repair activities. For example, cutting, drilling, or coring into the bridge surface during repairs or modifications can create new voids or cracks.

Corrosion: Bridges located in corrosive environments, such as coastal areas or areas with high pollution levels, may be susceptible to corrosion of the reinforcing steel or other bridge components. Corrosion can cause localized damage to the bridge surface, including the formation of cracks or voids.

Seismic activity: Bridges located in earthquake-prone regions may experience seismic forces that can cause small cracks or damage to the bridge surface.

Insufficient concrete cover: Concrete cover refers to the thickness of the protective layer of concrete over the reinforcing steel within the bridge components. If the concrete cover is not designed or constructed to meet the required specifications, it may result in the exposure of the coarse aggregate on the surface of the bridge. Insufficient concrete cover can compromise the durability and performance of the bridge, as it may lead to increased risk of corrosion of the reinforcing steel, which can weaken the structure over time.

Improper formwork installation: Formwork is used to shape and contain the concrete during construction. If the formwork is not properly installed or is not tight enough, it may allow the coarse aggregate to become exposed on the surface of the bridge.

Erosion: Flowing water can erode the surface of concrete over time, especially if the water contains sediment, sand, or other abrasive materials. This erosion can result in loss of surface fines, roughening, and pitting, which can weaken the concrete and reduce its durability.

Chemical attack: Exposure to aggressive chemicals such as acidic substances, alkalis, sulfates, and other corrosive agents can cause chemical attack on the concrete surface, leading to surface deterioration. Chemical attack can result in surface pitting, scaling, and erosion, which can weaken the concrete and reduce its service life.

Incorrect surface finishing: Improper surface finishing during construction, such as inadequate curing, improper use of curing compounds, or inadequate surface protection, can result in weak or porous concrete surfaces that are more susceptible to deterioration from environmental exposure, chemical attack, and abrasion.

Alkali-silica reaction (ASR): Water can also trigger the alkali-silica reaction (ASR) in certain types of aggregates used in concrete, leading to the formation of expansive gel-like substances that can cause cracking and spalling of the concrete surface.

Some pictures of Deteriorated concrete surface showed below:

Figure A.8.1: Honeycomb in concrete surface.

Figure A.8.2: Void and coarse aggregate exposure in concrete surface.

Figure A.8.3: Deteriorated concrete surface

Proper design, construction, and maintenance practices, including adequate concrete mix design, appropriate curing, surface protection, and regular inspection and maintenance, can help prevent or minimize surface deterioration in concrete components of a bridge. It is essential to follow industry best practices, relevant standards, and guidelines to ensure the durability, safety, and longevity of the bridge components. Consultation with qualified engineers or professionals experienced in bridge construction and maintenance is recommended for proper assessment and remediation of surface deterioration in bridge components.

Skim coat: A skim coat for a bridge is a thin layer of material applied to the surface of the bridge to improve its appearance, protect it from weathering, and extend its lifespan. Skim coating is typically done using a specialized type of material, such as a polymer-modified cementitious coating, epoxy coating, or other suitable material, that is designed to adhere well to the bridge surface and provide a smooth, durable finish. Skim coating can also be used to fill in small cracks, voids, or imperfections in the bridge surface, helping to improve its structural integrity and aesthetics.

Materials Selection for skim coat - There are several different types of materials that can be used as skim coat for bridges, depending on the specific requirements of the project, local regulations and codes, and other factors. Some common types of skim coat materials for bridges include:

Polymer-modified cementitious coatings: These coatings are made by blending cement-based materials with polymers, which can enhance their properties such as adhesion, flexibility, and durability. Polymer-modified cementitious coatings are typically used for concrete bridge surfaces and can provide excellent protection against weathering, abrasion, and chemical exposure.

Epoxy coatings: Epoxy coatings are made from epoxy resins, which are highly durable and resistant to chemicals, UV radiation, and abrasion. Epoxy coatings are commonly used for bridge surfaces that require superior protection, such as those exposed to heavy traffic loads, aggressive environments, or frequent chemical exposure.

Acrylic coatings: Acrylic coatings are made from acrylic polymers and are known for their durability, flexibility, and UV resistance. Acrylic coatings are typically used for bridge surfaces that require protection against weathering, UV radiation, and mild chemical exposure, and are often used for aesthetic purposes as they can be tinted or colored to achieve desired finishes.

Silane/siloxane coatings: Silane/siloxane coatings are made from silane or siloxane compounds and are used for their water repellency and ability to penetrate into the surface of the bridge. They can provide protection against water penetration, freeze-thaw cycles, and chloride ion ingress, which can be particularly beneficial for bridges located in harsh environments or exposed to de-icing salts.

Calcium silicate coatings: Calcium silicate coatings are made from calcium silicate compounds and are known for their high temperature resistance, making them suitable for bridges exposed to high temperatures or fire hazards. Calcium silicate coatings can also provide protection against weathering, abrasion, and chemical exposure.

Other specialty coatings: Depending on the specific requirements of the bridge project, other specialty coatings may be used as skim coat materials, such as polyurethane coatings, polyester coatings, or other proprietary coatings that offer unique properties or performance characteristics. It's important to select a skim coat material that is suitable for the specific bridge surface conditions, taking into consideration factors such as the type of bridge, exposure to environmental conditions, expected traffic loads, and desired finish appearance. Consulting with a qualified engineer or contractor experienced in bridge construction and maintenance can help ensure the appropriate skim coat material is selected for a particular bridge project. Yes, the presence of coarse aggregate exposed or honeycombing (voids) on the surface of a bridge can have an impact on the application and effectiveness of a skim coat. Here are some potential effects:

Adhesion: Skim coat materials typically rely on proper adhesion to the underlying substrate for their effectiveness. If the coarse aggregate is exposed, it can create a rough and uneven surface that may reduce the adhesion of the skim coat material, resulting in poor bonding and reduced effectiveness in protecting the bridge surface.

Durability: Coarse aggregate exposed on the surface or honeycombing can create voids or pockets that can trap moisture or allow water to penetrate into the bridge structure, potentially leading to increased moisture-related damage such as freeze-thaw cycles, corrosion of reinforcing steel, or other forms of deterioration. This can compromise the durability of the skim coat and the overall performance of the bridge surface protection.

Aesthetic appearance: If the bridge is intended to have a smooth and uniform appearance, the presence of exposed coarse aggregate or honeycombing can negatively affect the aesthetic appearance of the skim coat. This may not meet the desired finish appearance or aesthetic requirements of the project.

Application thickness: Skim coat materials are typically applied in thin layers, ranging from a few millimeters to several centimeters. If the coarse aggregate is significantly exposed or the honeycombing is extensive, it may require additional preparatory work, such as filling voids or repairing the exposed aggregate, to achieve the desired skim coat thickness, which can add to the complexity and cost of the project.

To address these issues, preparatory work may be needed before applying a skim coat on a bridge surface with exposed coarse aggregate or honeycombing. This may include filling voids, repairing or leveling the surface, and ensuring proper surface preparation to enhance adhesion. It's important to follow recommended surface preparation and application procedures specified by the skim coat material manufacturer, and consult with a qualified engineer or contractor experienced in bridge maintenance and repair to ensure that proper techniques and materials are used for the specific bridge conditions.

Application Procedure:

The process of applying a skim coat to a bridge typically involves the following steps:

Surface Preparation: The bridge surface needs to be thoroughly cleaned and prepared before applying the skim coat. This may involve removing any loose or deteriorated material, cleaning the surface with high-pressure water or other suitable methods, and repairing any significant cracks or defects in the bridge surface.

Material Selection: The appropriate type of skim coat material needs to be selected based on factors such as the bridge's location, exposure to environmental conditions, expected traffic loads, and desired finish appearance. Different types of skim coat materials have varying properties, such as strength, flexibility, and resistance to chemicals, which should be considered in the selection process.

Application: The skim coat material is then applied to the bridge surface using suitable techniques, such as spraying, troweling, or rolling, depending on the type of material and the desired finish. The material is typically applied in thin layers, allowing each layer to cure or dry before applying subsequent layers, until the desired thickness is achieved.

Finishing: Once the skim coat is applied, it can be finished to achieve the desired appearance. This may involve sanding, polishing, or other methods to create a smooth and aesthetically pleasing finish. The skim coat may also be painted or stained to further protect the bridge surface and enhance its appearance.

Curing and Protection: After the skim coat is applied and finished, it needs to cure or dry according to the manufacturer's instructions. During this time, it should be protected from moisture, extreme temperatures, and other damaging factors to ensure proper curing and long-term durability. It's important to note that the specific process and materials used for skim coating a bridge may vary depending on the type of bridge, local regulations and codes, and other factors. It's recommended to consult with a qualified engineer or contractor experienced in bridge construction and maintenance to determine the most appropriate skim coat solution for a particular bridge project.

Figure A.8.4: Surface preparation for Skim coat treatment

Figure A.8.5: Skim coat application in Ceiling or bottom of deck slab

Figure A.8.6: Application of Patching compound

Figure A.8.7: Surface voids repairing

Figure A.8.8: Skim coat application

Figure A.8.9: Figure: Plastering for different concrete surface

Water based cement paint

water-based cement paint is a type of paint that is specifically formulated for use on cementitious surfaces, such as concrete, masonry, and stucco. It is a type of exterior paint that is commonly used for coating and protecting the surfaces of buildings, including bridges, that are constructed with cement-based materials. Water-based cement paint is typically made from a mixture of cement, pigments, additives, and water. It is applied in a liquid form and dries to form a durable and protective coating on the surface of the cementitious substrate. Water-based cement paint is known for its excellent adhesion to cementitious surfaces, as well as its durability, weather resistance, and breathability.

Water-based cement paint is commonly used for exterior painting of bridges, buildings, and other cementitious structures to provide protection against environmental exposure, enhance aesthetics, and extend the service life of the structures. Proper surface preparation, application, and maintenance practices should be followed to ensure the best results and longevity of the paint coating. Consultation with qualified paint professionals or engineers experienced in bridge painting is recommended for proper selection, application, and maintenance of water-based cement paint on bridge components. Some of the key characteristics and benefits of water-based cement paint include:

Protection: One of the primary purposes of using water-based cement paint on bridges is to provide a protective coating that helps to safeguard the underlying cementitious surfaces from environmental exposure. It can protect the bridge components, such as the bridge decks, abutments, piers, and other exposed surfaces, from factors such as UV radiation, moisture, and temperature fluctuations, which can lead to deterioration, such as cracking, spalling, or corrosion of reinforcing steel.

Adhesion: Water-based cement paint has excellent adhesion to cementitious surfaces, providing a strong bond that helps to resist peeling, cracking, or flaking.

Weather resistance: Water-based cement paint is formulated to withstand exposure to harsh weather conditions, including UV radiation, moisture, and temperature fluctuations, without fading, peeling, or deteriorating.

Durability: Water-based cement paint is formulated to be durable and long-lasting, providing a protective barrier that can extend the service life of bridge components. It can help to enhance the durability and performance of cementitious surfaces, reducing the need for frequent repairs or replacements and contributing to the overall longevity of the bridge structure.

Aesthetics: Water-based cement paint is available in a variety of colors and finishes, which allows for customization and can improve the aesthetic appearance of bridges. It can be used to achieve a uniform color or texture, enhance the visual appeal of the bridge, and create a visually pleasing and cohesive look with the surrounding environment.

Breathability: Water-based cement paint is typically breathable, allowing moisture vapor to escape from the underlying cementitious surfaces. This can help to prevent the buildup of moisture within the concrete, reducing the risk of efflorescence, spalling, or other moisture-related issues that can negatively impact the performance and durability of the bridge components.

Environmental considerations: Water-based cement paint is generally considered to be environmentally friendly as it typically contains low levels of VOCs (Volatile Organic Compounds) compared to solvent-based paints. This can help to reduce the emissions of harmful pollutants into the environment during application and improve the air quality around the bridge construction or maintenance sites.

Ease of application: Water-based cement paint is easy to apply using brushes, rollers, or sprayers, and it typically dries quickly, allowing for efficient application and shorter drying times.

Overall, water-based cement paint is used on bridges to provide protection, durability, aesthetics, breathability, and environmental considerations. It is an effective coating solution for cementitious surfaces, helping to extend the service life of bridges and enhance their appearance while minimizing the environmental impact. Proper surface preparation, application, and maintenance practices should be followed to ensure the best results and longevity of the paint coating on bridge components. Consultation with qualified paint professionals or engineers experienced in bridge painting is recommended for proper selection, application, and maintenance of water-based cement paint on bridges.

The procedure for using water-based cement paint on a bridge typically involves the following steps:

Surface preparation: The surface to be painted should be thoroughly cleaned and prepared to ensure proper adhesion of the paint. This may involve removing any loose or peeling paint, dirt, dust, grease, or other contaminants from the surface. In some cases, surface repair or patching may also be necessary to address any cracks, holes, or other imperfections.

Primer application: Applying a suitable primer to the prepared surface can help to improve the adhesion and performance of the water-based cement paint. The type of primer used may depend on the specific condition and composition of the surface being painted, as well as the type of water-based cement paint being applied. Follow the manufacturer's recommendations for primer selection and application.

Paint application: Water-based cement paint can be applied using brushes, rollers, or sprayers, depending on the size and complexity of the bridge component being painted. Follow the manufacturer's instructions for the recommended application method, and apply the paint evenly and uniformly. Multiple coats may be required to achieve the desired coverage and finish.

Drying and curing: Allow the paint to dry and cure according to the manufacturer's instructions. This may involve allowing the paint to air dry or using forced air drying or heat curing methods, as recommended by the manufacturer. Proper drying and curing are crucial to achieving optimal performance and durability of the paint coating.

Inspection and touch-up: Once the paint has fully dried and cured, inspect the painted surface for any missed spots, uneven coverage, or other imperfections. Touch up as necessary to achieve a uniform and visually appealing finish.

Maintenance: Regular maintenance of the water-based cement paint coating is important to ensure its longevity and performance. This may involve periodic cleaning, inspection for any signs of deterioration or damage, and touch-up or repainting as needed. It's important to follow the manufacturer's instructions and recommended guidelines for the specific water-based cement paint being used, as application procedures and drying/curing times may vary. Additionally, consulting with qualified paint professionals or engineers experienced in bridge painting is recommended for proper application techniques and maintenance practices to ensure the best results and longevity of the paint coating on bridge components.

Figure A.8.10: Application of Water based cement paint in the Deck Slab Bottom

Figure A.8.11: Applying water Proofing materials in abutment wall

Figure A.8.12: Fair coats render

Wearing course of bridge

The wearing course, also known as the surface course or the top layer, of a bridge refers to the final layer of pavement or surfacing that is applied to the bridge deck to provide a smooth and durable riding surface for vehicles. The wearing course is typically designed to withstand traffic loads, resist environmental factors, and provide adequate skid resistance for safe vehicular movement. The wearing course of a bridge is subject to various types of wear and deterioration over time, including:

Traffic loads: The wearing course of a bridge is subjected to repeated loads from vehicular traffic, including heavy vehicles, which can cause stress, fatigue, and deformation of the pavement surface. Over time, this can lead to cracks, rutting, and other forms of wear and damage.

Climate conditions: Exposure to various weather conditions, such as freeze-thaw cycles, extreme temperatures, moisture, and UV radiation, can cause the wearing course to degrade. Freeze-thaw cycles, in particular, can lead to the expansion and contraction of water within the pavement, resulting in cracks, potholes, and other forms of distress.

Environmental factors: Bridges and their wearing courses may be exposed to environmental factors such as chemical exposure (e.g., deicing salts), pollution, and other corrosive substances, which can cause the pavement to deteriorate. Chemicals used for deicing purposes, for example, can penetrate the pavement surface and accelerate deterioration.

Aging and wear: Over time, the wearing course of a bridge will naturally wear out due to normal aging and wear. As vehicles traverse the bridge, the pavement surface will be subjected to friction, abrasion, and wear, leading to reduced thickness and performance of the wearing course. Proper design, construction, and maintenance practices are important for ensuring the durability and longevity of the wearing course of a bridge. This may include selecting appropriate materials, providing adequate thickness and drainage, using proper construction techniques, and performing routine inspections, maintenance, and timely repairs. Regular monitoring and timely rehabilitation or replacement of the wearing course can help extend the service life of the bridge and maintain safe and smooth driving conditions for vehicles.

Painting in railing

Painting on railings of bridges can serve various purposes, including aesthetics, protection, and visibility. Some of the reasons for painting railings on bridges may include:

Aesthetics: Painting railings can enhance the appearance of bridges, making them visually appealing and contributing to the overall aesthetics of the structure. Painting can be used to achieve a desired color or finish that complements the surrounding environment or architectural style.

Corrosion protection: Railings on bridges are exposed to harsh environmental conditions, including moisture, UV radiation, and corrosive substances. Painting can provide a protective barrier that helps prevent corrosion and deterioration of the metal or concrete materials used in railings, thereby extending their service life and reducing maintenance costs.

Safety: Painting railings with high-visibility colors can improve their visibility, especially during low light conditions, and make them more easily identifiable by users, including pedestrians, cyclists, and motorists. This can contribute to increased safety by helping to prevent accidents and improve awareness of the presence of the railing.

Identification: Paint can be used to mark specific areas or sections of the railing for identification purposes, such as indicating the beginning or end of a bridge, marking pedestrian walkways or cycle paths, or indicating restricted areas.

Compliance: Painting railings can be used to comply with local regulations or standards, such as using specific colors or markings to indicate the type of railing (e.g., handrail, guardrail) or its designated use (e.g., pedestrian vs. vehicular).

Proper surface preparation, choice of paint materials, and appropriate painting techniques are important for achieving a durable and effective paint job on bridge railings. Factors such as the type of material being painted (metal, concrete, etc.), environmental conditions, and desired lifespan of the paint should be taken into consideration. Regular maintenance and periodic repainting may be required to maintain the appearance and effectiveness of the paint on bridge railings over time. Following relevant industry standards, local regulations, and best practices for painting can help ensure a successful outcome.

Figure A.8.13: Painting on railing

Figure A.8.14: A complete bridge with painting

BRIDGE MAINTENANCE MANUAL

Program for Supporting Rural Bridges (SupRB)
Local Government Engineering Department (LGED)

Sources and References

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4. *Bridge Rehabilitation and Strengthening Manual Part 1 Method, August 2018 Roads and Highways Department, Bangladesh*