Chapter 13 – Table of Contents

Chapter 13 – List of Figures

Chapter 13 - Substructures

13.1 Preventive and Basic Maintenance of Concrete Substructures

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.

What To Look For

Concrete Substructure Components

- Look for cracking and possible movement 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 cracks, greater than 1/8 inch wide.
- Look for impact damage.
- Look for efflorescence, spalling, and scaling of concrete.

Typical areas of concern are shown for concrete abutments and piers in Figure 13.1 and Figure 13.2, respectively.

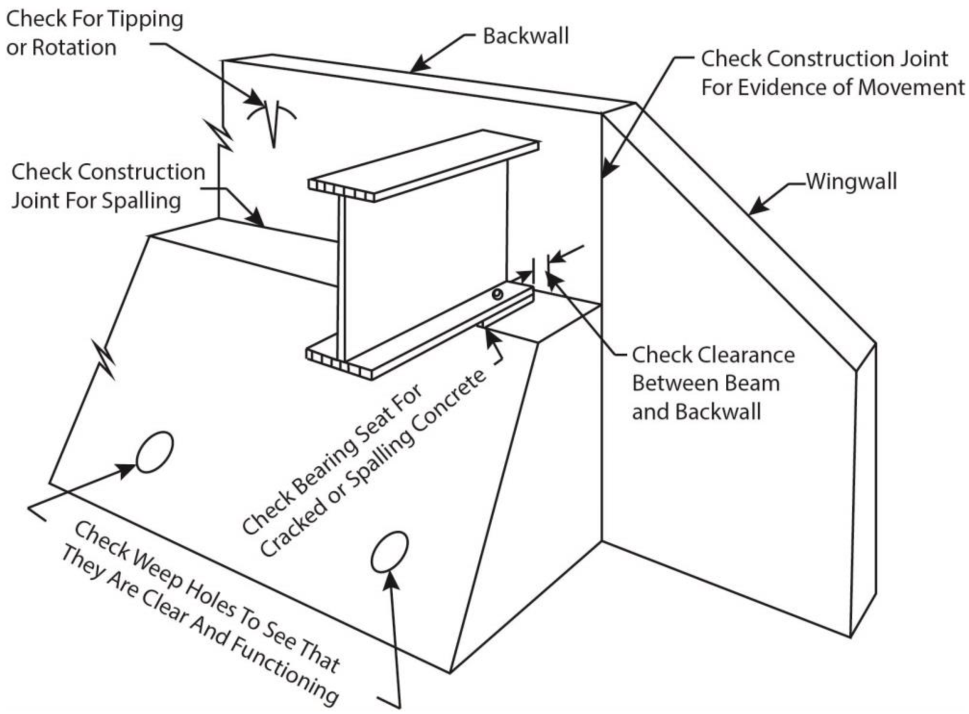


Figure 13.1 Items to Look For at Concrete Abutments

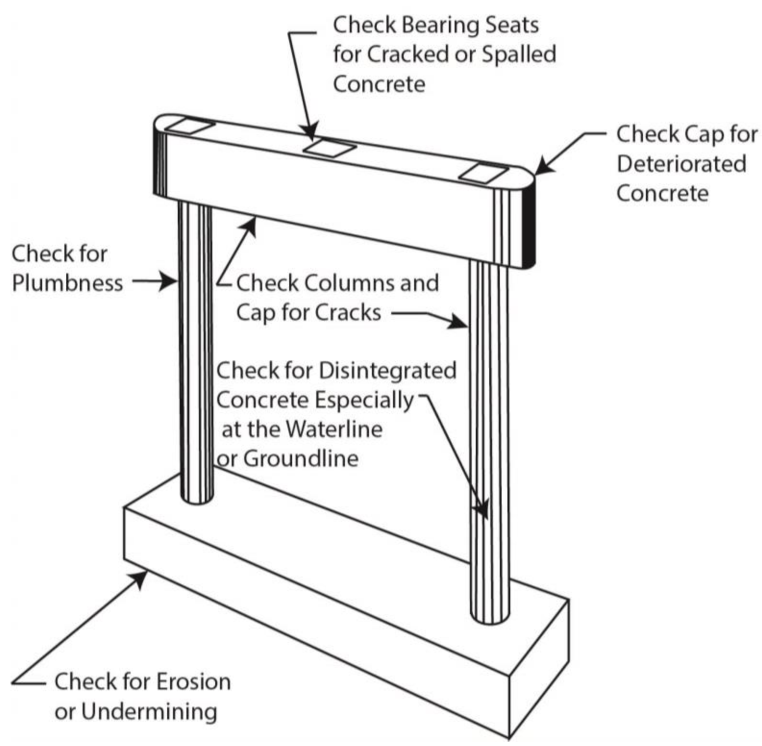


Figure 13.2 Items to Look for at Piers

13.1.1 Cleaning

Debris such as road grit, animal droppings and de-icing salts create a serious problem if not removed. Moisture, deicing salts, and debris that spill through leaking or open joints tend to accumulate and pile up on the seats and the top of the cap. Soon the by-products of corrosion of the rebar cause the concrete to spall. Accumulated debris also hampers inspection efforts.

Birds are common inhabitants on bridges. The wide flanges of steel girders and pier caps are preferred nest and roosting sites. These areas should be thoroughly washed and installation of bird screens would be beneficial. Figure 13.3 shows bird droppings and corrosion of the bearings. Horizontal cracking of the pier cap is also evident, occurring from corrosion of the top mat of reinforcing steel. If bird or nest removal is required, caution should be exercised as there may be restrictions due to federal protection of birds or other species such as bats.

Removal of the droppings should be done while wearing a respirator to avoid inhaling contaminants. Histoplasmosis is an infection of the lungs leading to a cough or flu-like symptoms which is often associated with decaying bat guano and bird droppings. Disruption of the debris can release infectious elements that are inhaled and settle into the lung.

Figure 13.3 Debris on Pedestal and Pier Cap

The bearing seats can also be affected. When the bearings become "frozen" by corrosion, additional stress is introduced into the substructure that can cause spalling or damage to the bearing system. Overloading of the bearing system can result in fracture of the substructure cap and loss of bearing for the beam ends.

Removing the debris must be done before washing. Debris is collected and, if allowed is wasted upland away from the roadway and drainage areas. Some agencies remove debris annually. In some locations, the accumulation occurs so quickly crews remove material monthly. Respirators may be necessary when removing debris.

Debris under the bridge should also be removed. Sometimes the space under the bridge has been used for illegal dumping, drugs, and the homeless. An example is shown in Figure 13.4. Crews should be cautious when encountering unknown materials, syringes, and other hazards left by people seeking shelter within the bridge confines.

Figure 13.4 Bridges Sometimes Become Makeshift Homes

Debris or floating ice that drifts against the substructure can cause premature deterioration and place excessive lateral loads on the whole structure. The techniques available to remove drift are:

- Clear small debris with a pole or hook.
- Pull large pieces of debris clear with a crane or excavator.
- Clear large and small pieces of debris by flushing with large volumes of water.
- Ice jams can either be blasted apart (if permitted) or broken up by flushing with large volumes of water or excavator if the jam can be reached.

Additional information on debris removal can be found in Chapter 15 - Channel and Waterway.

Washing substructures can be done using a volume flush or pressure washing. Flushing requires considerable more water than pressure washing. An example of flushing is shown in Figure 13.5. Tanker trailers, fire trucks and old milk trucks are used to carry water to bridge sites.

Figure 13.5 Flushing with Water

Pressure washing, typically with 2,500 to 3,000 psi pressure uses much less water and, though time consuming, provides for a cleaner surface. In most locations, the amount of pressure that is used depends on the condition of the paint. In some cases, the pressure limitation is stated as "a pressure that does not remove paint". Some states require pressure washing in preparation for the application of a penetrating sealer. Water tanks with baffles can be loaded onto stake racks if crews need to bring water to the site. It may be permissible to pump water from streams for wash water. Crews should check with an environmental coordinator if they are allowed to perform this type of operation.

The bridge expansion joints, drainage pipes, scuppers, downspouts, pier and abutment caps and seats should be cleaned. Access is often a concern, particularly for piers in the water. In some cases, as shown in Figure 13.5, access to the substructure may involve equipment, such as an under bridge unit or scaffolding. Bridge cleaning is typically done in the spring. This minimizes the time that salt is in contact with the bridge and occurs when streams are commonly at their highest levels of flow.

13.1.2 Graffiti Control

Graffiti removal commands a great deal of time and resources for some agencies. Graffiti removal is scheduled by highway route segments for intensive clean-up. Graffiti that was once seen only on walls is now showing up on overhead signs, retaining walls, bridges and bridge columns. With increasing cost for graffiti removal and an increasing need for abatement, new and innovative methods are being explored.

Graffiti vandalism is a crime and for this reason it is recommended that agency retain photographic evidence of incidents of graffiti vandalism. Graffiti is a community-wide problem with both public and private facilities being affected and seriously impairs community appearance and values.

It is recommended that rapid removal is the first strategy adopted in graffiti management. Rapid removal is recognized as best practice because it reduces the level of recognition sought by vandals. Rapid removal also prevents assets from looking neglected. In the case where graffiti is racist or obscene, the graffiti should be removed immediately after taking a photograph.

Urban art projects have provided positive results where a wall with a painted mural is less of a target for graffiti vandalism than a blank wall. There are urban artists who can be contracted to come into the school and take students through a workshop of urban art/mural painting. Several local councils or police stations are equipped to provide graffiti education in schools. In some cases, local high school bridge graffiti was eliminated when students painted "Welcome to Our School" or similar on the bridge.

Concertina wire can be wrapped around columns or end posts as a way of discouraging taggers from gaining access to the overhead signs on heavily targeted areas. Rat Guards, a steel cone personnel barrier, is placed on sign posts to deter taggers from scaling the poles. The guards are used at favorite tagging locations. The guards are made of smooth metal and are disk-shaped, making it difficult to climb on to the overhead signs. Cobra Shields have been used in the last few years. The shields, which vary in length and width, extend over the front and sides of the overhead signs, making it difficult for someone to reach over and deface the signs.

Anti-graffiti coatings are also available. The material is painted on clean surfaces and creates a non-stick surface that repels graffiti from paint, paint spray cans and permanent markers. Graffiti is removed by pressure washing or hand wiping.

13.1.3 Abutment Weepholes

Weepholes are built into abutments to allow water that collects from behind the abutment to drain. The weepholes should be cleaned out and inspected to be sure they are functioning. If water is allowed to collect behind the abutment, it may lead to tilting, settlement, or create problems with the foundations, due to the hydrostatic pressure of water behind the abutment wall placing an additional load on the wall that it was not designed to withstand. Installing rodent guards is often not a bad idea, if there is evidence of rodent habitation. Figure 13.6 shows initial abutment construction with weepholes in place.

Figure 13.6 Weepholes Consisting of PVC Pipe

13.1.4 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

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 13.1.

Table 13.1 Required Drying Time before Sealing (Days)

Ambient Temperature	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 13.7.

Figure 13.7 Hand Sealing the Substructure

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 in Section 13.1.5 is typically recommended.

Some states apply the protective coating to the bearing systems as well as to the substructure 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.

13.1.5 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 13.8. 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 13.8 Protective Coating Applied on the Substructure

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.

13.1.6 Cathodic Protection

Cathodic protection (CP) was first used on bridge decks in the 1970's and on bridge substructures in the 1980's. Since then, it has been employed by a number of state Departments of Transportation on bridges that experienced reinforcing steel corrosion due to deicing salts or marine exposure, or both. While earlier cathodic protection installations on bridges were of the impressed current type, significant advances have been made in the past decade in adapting galvanic systems, which are simpler and more easily maintained, for substructures in particular. Both will be discussed in this section. CP results have been mixed, with some states employing cathodic protection extensively and others only on a limited basis or not at all. The widely differing levels of usage may be due to such factors as:

- Initial and ongoing costs
- The technology, including design, installation, and maintenance, is not understood by many highway personnel
- Instances of inadequate performance
- The absence of a protocol for deciding when to use cathodic protection, considering factors such as type of structural element, nature of exposure, extent of corrosion-induced damage in concrete, desired service life, etc.
- The wide array and evolution of materials and instrumentation available in the marketplace

The Federal Highway Administration has stated that cathodic protection is the only rehabilitation technique that has proven to stop corrosion in salt-contaminated bridge decks regardless of the chloride content in concrete. A more recent evaluation of various types of cathodic protection systems suggests that cathodic protection is effective if designed, installed, and operated in accordance with recommended practice. Although cathodic protection can be applied during new construction, it is most often found in conjunction with rehabilitation of existing concrete structures. However, cathodic protection is not always needed, nor is it applicable on every structure.

The design of the specific cathodic protection system depends upon the type of surface to be protected (horizontal, vertical, soffit, etc.), geometry, reinforcement cover depth, environmental considerations (temperature and moisture), and structural considerations (additional dead load capacity). Titanium-anode-based cathodic protection systems can be expected to last over 50 years under certain circumstances. For this reason specialty firms are usually brought in to perform the design.

Cathodic Protection is a technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell. A simple method of protection connects protected metal to a more easily corroded "sacrificial metal" to act as the anode. The sacrificial metal then corrodes instead of the protected metal.

A cathodic protection system works much like a battery. Batteries have a cathode and anode as show in Figure 13.9. Similarly, a bridge can be turned into a giant battery with the goal of protecting the steel reinforcement.

Figure 13.9 Cathodic Protection requires a Cathode and Anode

When a concrete bridge component is severely contaminated with deicing salts, cathodic protection (CP) may be used over conventional treatments to stop and/or prevent the corrosion process in concrete. This is because, unlike conventional treatments, CP does not require removal and replacement of sound, but nonetheless, contaminated concrete in order to stop and/or prevent the corrosion. Compared with the cost of concrete removal and replacement, CP may be less expensive. The supplier of the system will supply specifications and instructions for installation and maintenance. Substructure units can be protected by cathodic protection.

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 13.10.

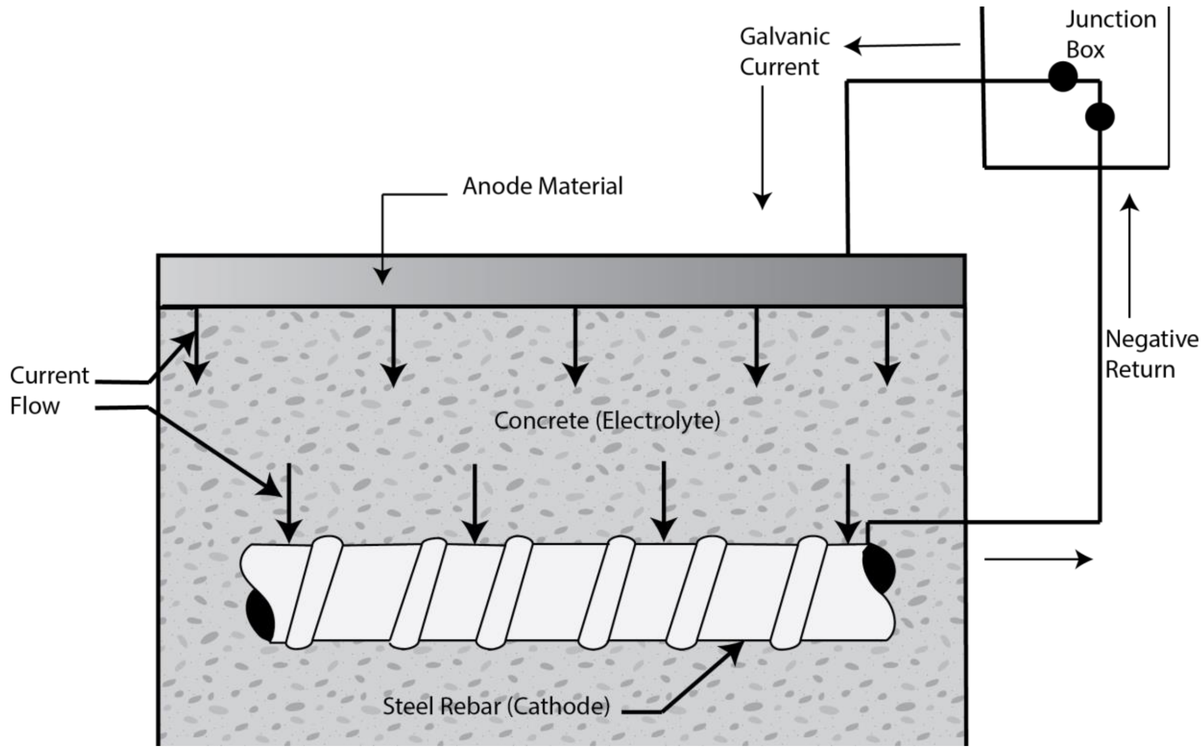


Figure 13.10 Layout of Galvanic (Sacrificial) Anode System of the Reinforcing Steel

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.

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.

Substructure 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 13.11. It is a two piece snap together system.

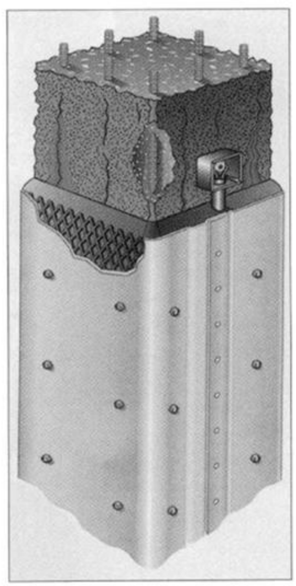


Figure 13.11 Schematic Illustration of a Zinc Mesh Jacket

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 13.12 for a schematic illustration of thermal spray Zn with a Submerged Bulk Anode (SBA) system applied to a pier and Figure 13.13 for an example of thermally sprayed zinc applied to a pier column.

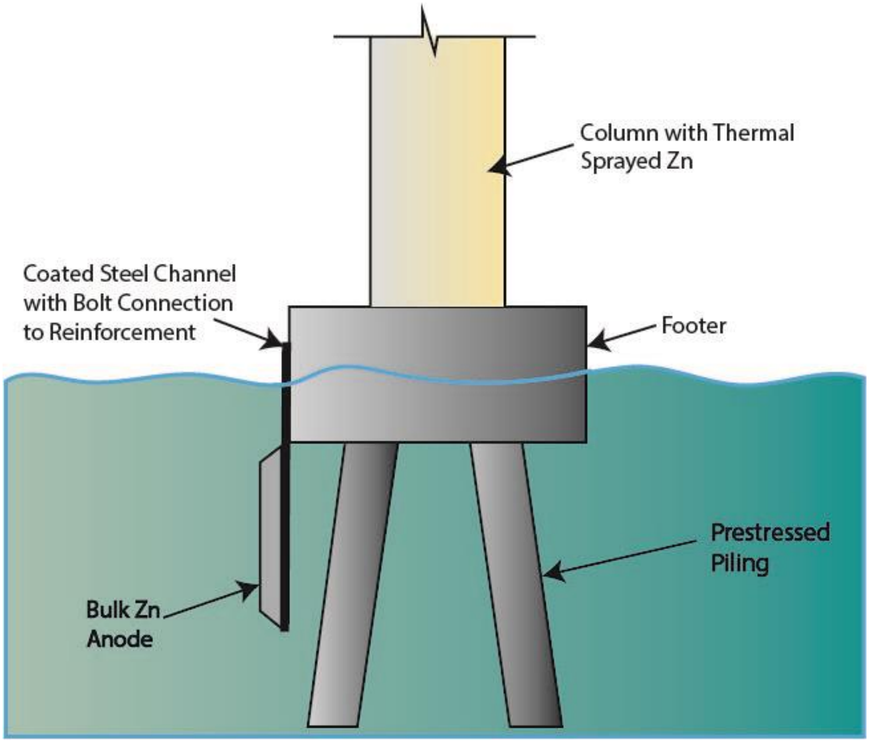


Figure 13.12 Schematic Illustration of Thermal Spray Zn/SBA System of a Substructure

Figure 13.13 Thermally Sprayed Zinc Applied to a Pier Column

The zinc-hydrogel anode system is also a sacrificial anode systems. 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 sprayed zinc system.

Impressed Current System

An impressed-current cathodic protection is achieved by driving a low-voltage direct current (generally less than 50 Volts) from a relatively inert anode material, through the concrete, to the reinforcing bars. Direct current of sufficient magnitude and direction is applied to oppose the natural flow of current resulting from the electrochemical process. The direct current is supplied by an external power source, often a rectifier that converts alternating current to direct current. Recently, solar power and specially designed batteries have been successfully used as external power sources. The direct current is distributed to the reinforcing bars by an anodic material. The uniformity of the current distribution is critical; therefore, an anode is one of the most important components of a cathodic protection system. Current distribution is also a major consideration in the design of cathodic protection systems. A basic layout required for impressed current CP systems is presented in Figure 13.14. Impressed current systems should be monitored periodically to ensure that correct amount of voltage and amperage is applied to the reinforcing steel. Monitoring is done through reference half-cells embedded in concrete in the vicinity of reinforcing steel.

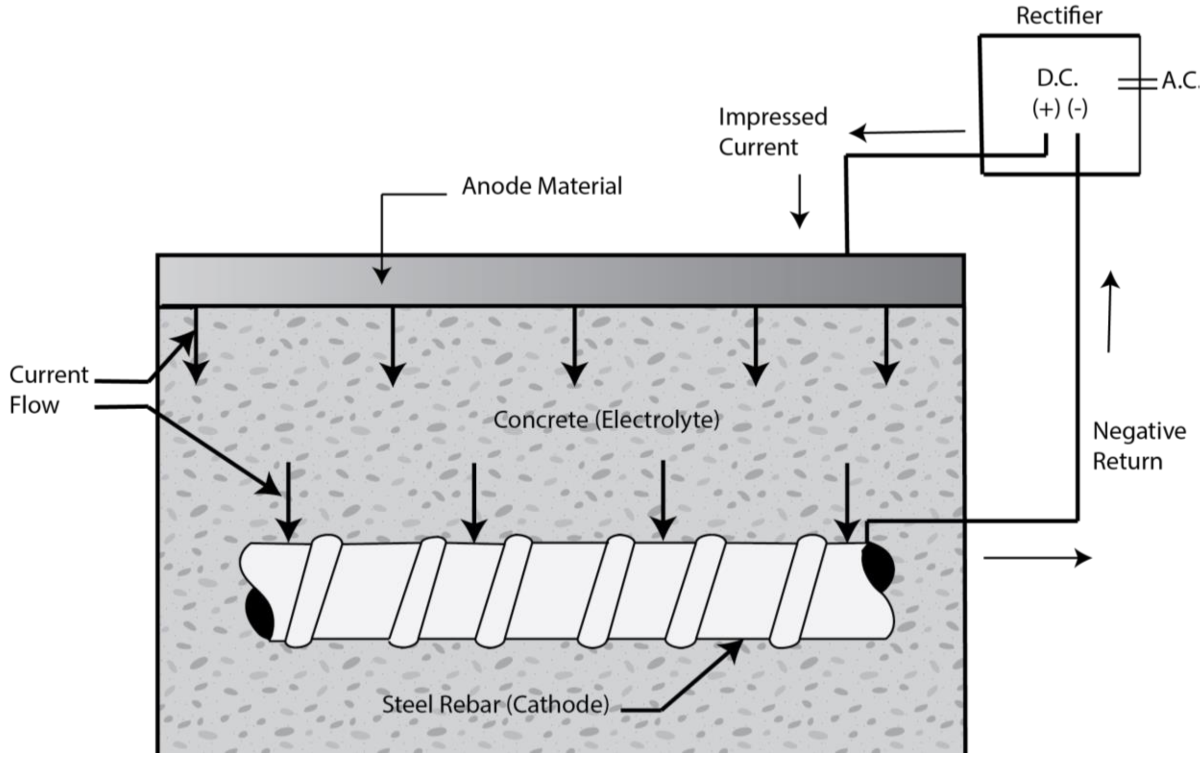


Figure 13.14 Basic Layout of Impressed Current System

Anodes for impressed current systems are available in a variety of shapes and sizes. Common anodes are tubular and solid rod shapes or continuous ribbons of various materials. These include high silicon cast iron, graphite, mixed metal oxide, platinum and niobium coated wire and other materials.

13.1.7 Electrochemical Chloride Extraction

Electrochemical chloride extraction is similar in principle to cathodic protection. However, the total amount of charge (i.e., current with time) is approximately 50 to 500 times that used for cathodic protection. Another important difference is that chloride extraction is a short-term treatment, whereas cathodic protection is normally intended to remain in operation for the life of the structure.

Chloride extraction is particularly suited for structures in which active corrosion is occurring, but only minor concrete damage is present. In addition, the structure must be conventionally reinforced and have an expected remaining service life of at least 5 to 10 years. Chloride extraction is accomplished by applying an anode and electrolyte to the structure's surface and passing direct current between the anode and the reinforcing bars, where the reinforcement acts as a cathode (as shown in the schematic in Figure 13.15). Conduction of direct current through the concrete is accomplished by the movement of charged ions. Since anions (i.e., negatively charged ions) migrate toward the positively charge anode, it is possible to cause chloride ions to migrate away from the reinforcing bars. The speed at which this process is accomplished largely depends on the magnitude of the applied current.

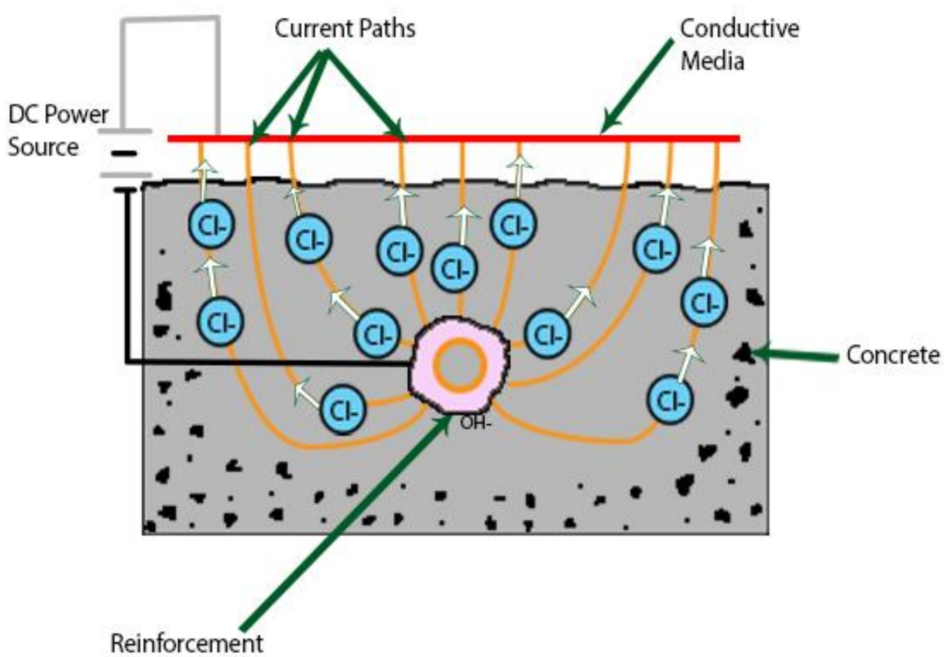


Figure 13.15 Schematic of Chloride Ion Movement in an Electrochemical Extraction

13.2 Preventive and Basic Maintenance of Steel Substructures

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.

What To Look For

Steel Substructure Components

- 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.

13.2.1 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. Coatings are covered extensively in Chapter 18.

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 surrounding areas 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.

13.2.2 Cleaning

Pressure spray or hand cleaning is satisfactory for removing dirt and debris. Good housekeeping is the most effective method of protecting steel from corrosion.

Metal Substructure Cleaning:

- Keep drains open to remove standing water from steel surfaces
- Keep deck joints watertight to prevent water leakage onto steel members
- Keep exposed areas clean by pressure washing
- Spot paint and repaint as necessary

13.2.3 Blast Cleaning

Corrosion or deterioration in steel piling usually occurs at the water or ground line where wet and dry conditions alternate. Damage from impact may also be incurred where piles are near roadways or waterways.

Rust and corrosion should be removed by sandblasting or pneumatic needle scalers. Damaged areas should be straightened when possible (see Section 11.5.4) and the deteriorated areas strengthened by welding or bolting steel plates extending far enough above and below the deteriorated area to restore the full load carrying capacity of the pile. Where deterioration is of a minor nature, plating by adding metal welds may be used. All repaired areas should be cleaned and painted as good preventive maintenance.

13.3 Preventive and Basic Maintenance of Timber Substructures

Preventive maintenance of timber substructures usually involves spotting decay early and taking action. Identifying areas of high moisture content and then removing or diverting the moisture source is critical in protecting a timber bridge from premature deterioration.

A trained bridge maintenance worker who is equipped with a flashlight and probe can accomplish much. Often the greatest challenge is having the time to get to sections of the bridge where decay is most likely. For an example of common timber inspection items, please see Figure 13.16. Pile caps are subject to deterioration if water from the bridge deck is able to seep into checks on the top face of the piling. Decay of wood pilings is most likely to occur immediately below the groundline.

Timber abutments are typically pile bents acting as soldier piles with wales and lagging to retain the fill.

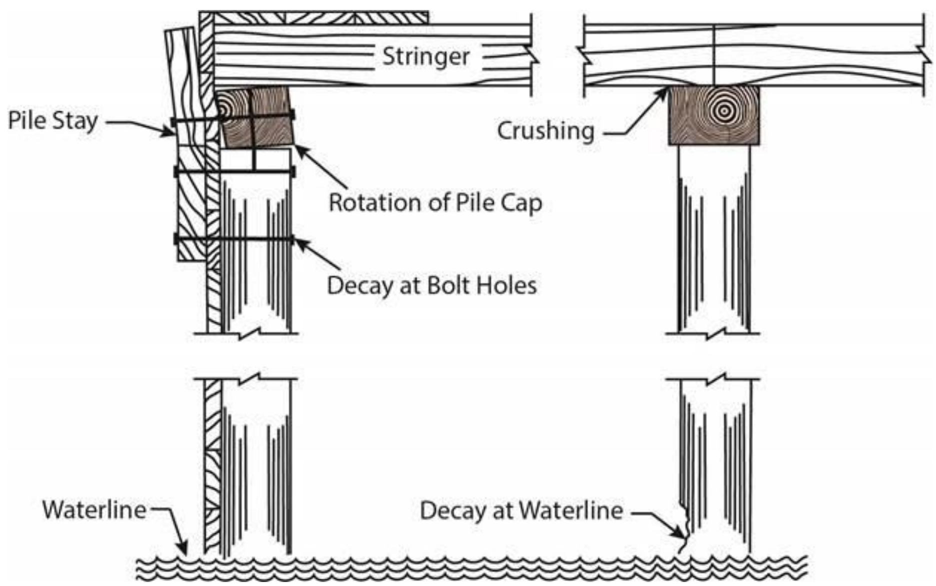


Figure 13.16 Common Timber Inspection Items

Bents are intermediate supports between abutments for multi-span crossings. They consist of timber piles or frames, depending on their height and foundation material. Pile bents are practical if foundation material is suitable and the bent height plus pile penetration is within an acceptable limit. Framed bents may be supported on footings or piles, depending on the quality of the foundation. See Figure 13.17 for a schematic of common timber bent inspection items.

Items to look for in timber substructure components are presented below.

What To Look For

Timber Substructure Components

- Check for decay in the piles, caps, and bracing. Decay may be found by tapping with a hammer or by test boring the timber. In simple terms, active decay makes timber look like mulch.
- Untreated timber will usually rot from the surface in and is normally visible.
- Check particularly at the groundline, waterline, and at joints and splices, since decay usually begins in these areas.
- Check hardware at splices and connections for tightness and corrosion. The acidity associated with corrosion causes cellulose hydrolysis, which severely reduces wood strength. Wood affected by steel corrosion usually looks dark and soft. If the affected area is large relative to the area of the member, refer the condition to a competent engineer, as corrective measures will need to be taken.
- Check the cap where the beams bear directly on it and where the cap bears directly upon the piles. Note particularly any splitting or crushing in these areas. Distinguish between actual crushing, which involves some splintering, and compression resulting from moisture being squeezed out of the cells. Crushing reduces the strength of the member and affects its alignment. Compression only affects the alignment, but does not adversely affect strength.
- Observe caps that are under heavy loads for excessive deflections.
- Check for decayed or damaged timbers in the backwalls of end bents (abutments), especially where such conditions would allow earth to spill upon the caps or stringers.
- Check timber piles in salt water for damage by marine borers. Specifically, pay attention to checks in the wood, bolt holes, laps, or other connections.
- For dolphins, fenders, timber piles and other members, inspect the upper portions lying between the high water and mudline for marine insects and decay. Check the fender pieces exposed to collision forces for signs of wear.

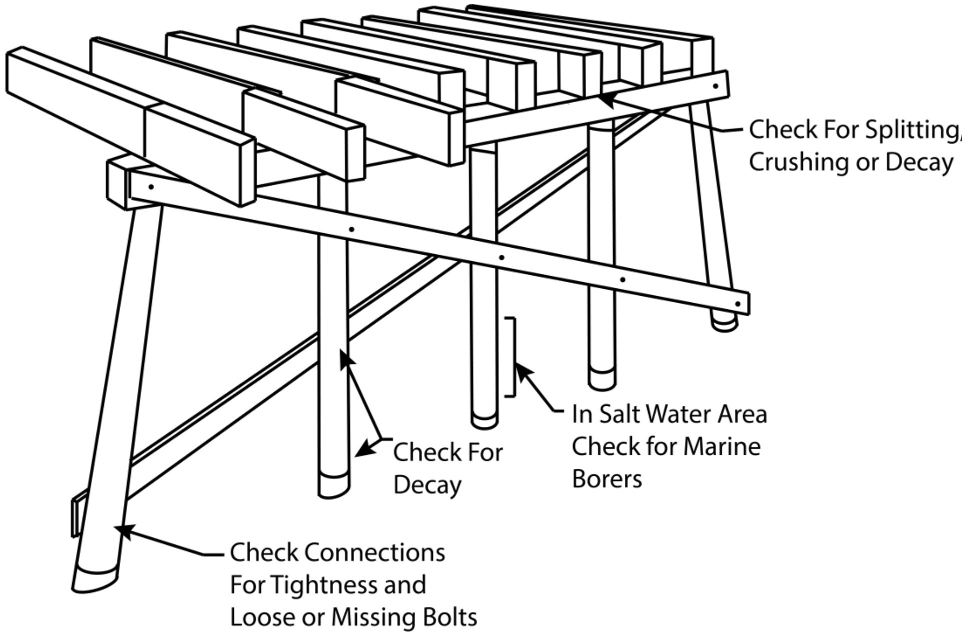


Figure 13.17 Common Timber Bent Inspection Items

It is essential that the area around timber pile bents and abutments is scalped and all weeds and brush removed from the vicinity because of the fire hazard. Where timber pilings are subject to frequent damage from ice, using discarded motor grader blades or other forms of armor should protect them.

Impact and overloading damage will be evident in the form of shattered or injured timbers, sagging or buckled members or timbers with large longitudinal cracks. The inspector should give the location and extent of damage and determine whether immediate remedial action is required.

The presence of water stains and mold/fungus is valuable information for identifying areas of high moisture content. It is also important to visually examine fastener connections as these joints may have undergone fatigue or because they are inherently areas of high moisture content. Piles and other parts of the bridge subject to moving water should be examined for mechanical damage due to water and debris or vessel impacts. The presence of moisture may lead to wood rot, which will degrade the strength of the wood. As moisture contents may vary seasonally, it is important that the appearance of water stains be used to identify potential sites of decay.

A chipping hammer, an ice pick, and an increment borer are the primary tools used for assessment of wood deterioration. The soundness of all timbers should be first checked by tapping with the hammer. Hammer sounding has been done for centuries and is still used today. The procedure is to hit a structural wood member with a hammer and determine from the quality of the sound if the component is sound. A dull or hollow sound indicates problems and the need for further investigation whereas a ringing, clear sound indicates the wood is good. The accuracy of "hammering" depends on judgment, experience and hearing. Decay has to be extensive and/or near the surface for this method to be effective. Wood that splinters is usually good. Wood that breaks abruptly is usually decayed. An ice pick can be used to probe for soft spots.

Coring and boring are the most widely used destructive methods for detecting internal decay. It is very important that coring and borings are done with sharp instruments. If extensive damage is suspected, an increment borer should be used to take a test boring and fully define the extent of deterioration. The increment borer is a specialized tool used to extract a section of wood tissue from a timber element with relatively minor damage to the element. The tool consists of a handle, an auger bit, and a small, half circular, metal tray (core extractor) that fits into the auger bit. The auger bit is usually manufactured from carbide steel. The tool breaks down and the auger bit and extractor fit into the handle. This makes it highly compact and easy to carry. Boring permits direct examination of a sample of the inside of a member. Since decay starts on the interior of a treated timber member, this test is needed to determine if a member should be removed as part of a repair. It is important to clean bore drills after use so that they do not transfer decay organisms. Borings should be taken very selectively to not further weaken the already damaged timber, and borings should not be made at all if no deterioration is evidenced. Once the boring has been made, save the boring sample and make sure that plugs treated with the same treatment as the timber are inserted into the hole made by the borer.

Moisture meters measure the moisture content of timber members. Moisture meters give qualitative readings above 30 percent. These hand-held meters provide a rapid means of sampling moisture content of wood. The measurements must be compared against a calibration curve to obtain an indirect measure of moisture content. Preservatives such as creosote and adhesives for glue lam products affect readings significantly. Two types of meters are available: conductance meters and dielectric meters.

The shigometer measures electrical resistance to detect decay in wood. The device is inserted into drilled holes at various depths to measure resistance. Wood should have a uniform resistance throughout its cross-section. This device requires frequent calibration. Since it also requires drilling holes, it may be simpler to merely take bore samples or to use a shell thickness rod. Shigometers allow the user to detect the initial breakdown of wood by fungi. The wood being inspected has to have moisture content above 30 percent for this device to work.

A pilodyn is used to measure the soundness of wood surfaces. The tool has a spring-loaded probe that measures the shock resistance of wood. The depth of penetration of the probe into the wood is an indication of its soundness.

Impact-echo detects low-density regions inside timber. Low-density regions are most likely decayed. The test is useful on Douglas fir and western red cedar but is not useful for southern pine.

Infrared thermography (IR) can be used, in the right circumstances to determine if wood has an excessive amount of moisture within it. The limitation to IR thermography is that the equipment is expensive, the operator must be well-trained and the conditions must be just right for the temperature difference to occur. Another limitation is that IR thermography provides only an inference about the moisture content of the wood, rather than a direct measure of either wood rot or residual strength.

In-place strength of timber members can be determined by ultrasonic testing. The load carrying capacity of a member is related to the wave velocity normal to the grain and its weight. This test should only be performed by experienced personnel.

Insect damage is evident by observing the damage to the timber. Insects that may cause damage include:

- Termites: All damage is inside the surfaces of the wood; hence, it is not visible. White mud, shelter tubes or runways extending up from the earth to the wood and on the side of masonry substructures are the only visible signs of infestation. If the timber members sag excessively, check for termite damage with an ice pick or an increment borer.
- Powder-post Beetles: The outer surface is poked with small holes. Often a powdery dust is dislodged from the holes. The inside may be completely excavated.
- Carpenter Ants: Accumulation of sawdust on the ground at the base of the timber is an indicator. The large, black ants may be seen in the vicinity of the infested wood.
- Marine Borers: Marine borers commonly enter the wood through bruises, breaks, or unplugged bolt holes. The area of infestation generally runs from the mudline to the water level at high tide.
- Mollusk Borers (Shipworms): The shipworm is one of the most serious enemies of marine timber installations. The most common species of shipworms is the teredo. This shipworm enters the timber in the early stage of life and remains there for the rest of its life. Teredos reach a length of 15 inches and a diameter of 3/8 inch, although some species of shipworm grow to a length of 6 feet. The teredo maintains a small opening in the surface of the wood to obtain nourishment from the seawater.
- Crustacean Borer: The most commonly encountered crustacean borer is the limnoria or wood louse. It bores into the surface of the wood to a shallow depth. Wave action or floating debris breaks down the thin shell of timber outside the borers' burrows, causing the limnoria to burrow deeper. The continuous burrowing results in a progressive deterioration of the timber pile cross line. In such cases, there are often no outside evidences of borer attack.

The most common treatment for dry land insects is to pressure treat the wood with a proper material, and/or replace damaged member with new pressure treated member, and keep careful watch for reinfestation.

The best method of control of marine borers is prevention of infestation: 1) prevent bruises by installing buttresses to protect the structural members from damage by wave action, current flow, or floating debris, and 2) treat damaged wood by plugging or coating all holes, bruises, and freshly sawed ends with heavy creosote.

Fungi usually require some moisture to exist. As a rule, fungus decay can be avoided only by excellent preservative treatment. Fungus decay is classified as follows:

- Mild fungus decay appears as a stain or discoloration. It is hard to detect and even harder to distinguish between decay fungi and staining fungi.
- Advanced. Wood darkens further and shows signs of definite disintegration, with the surface becoming soft and spongy, stringy, or crumbly, depending upon the type of decay or fungus. Fruiting bodies of fungi, similar to those seen on old stumps, may develop. The inspector should note the location, depth of penetration, and size of the areas of decay. Where decay occurs at a joint or splice, the effect on the strength of the connection should be indicated. A knife, icepick, or an increment borer can be used to test for decayed wood.

13.3.1 Cleaning

Cleaning dirt and debris from the deck surface, drains, and other horizontal components also reduces moisture and improves air circulation. Accumulated debris should be removed from any timber surface. Debris holds moisture that will penetrate into the timber member. The bark of native logs should be removed if it is not removed during construction. This prevents moisture from being trapped between the wood and bark.

Pre-treated timber will deteriorate after about 5 years if it is not maintained. Pressure washing and sealing exposed timber elements should be done on a routine basis. The maintenance interval should be selected in accordance with the manufacturer's instructions.

13.3.2 Moisture Protection

Moisture content of wood is one of the most significant factors regarding wood decay because a considerable amount of water is required for fungus growth and in many instances, the moisture content of wood in service is subject to control. Moisture control was the only method used for protecting many covered bridges constructed of untreated timber, some of which have provided service lives of 100 years or more. Moisture control is the simplest, most economical method of reducing or preventing decay in timber bridges. When exposure to wetting is reduced, members can dry to moisture contents below that which will support most fungal and insect growth (approximately 25 percent).

Not only does the amount of water in wood directly control the possibility of fungus infection and growth, but it also is significant to the decay process in less direct ways. Prolonged or repeated wettings contribute to leaching and a consequent loss of natural decay resistance. Further, during the seasoning of large timbers, the loss of water is accompanied by shrinkage that normally results in the development of seasoning checks. Such checks may expose untreated parts of preservative-treated timbers and may also form water-trapping pockets that can become infection sites for decay fungi.

Decay is very likely to occur at connections, splices, support points, around bolt holes, and at the ends of field cut members (such as beams, pile tops, or chords). This can be attributed to the tendency of such areas to collect and retain moisture. Unless these surfaces are protected, decay is very likely. Although modem timber bridges are protected with preservatives, decay can still occur in areas where the preservative layer is shallow or broken. Many times pressure treated lumber may be field cut exposing the interior of the members to a decay entry point. This damage is the major cause of deterioration in timber bridges.

Moisture control involves a common sense approach of identifying areas with visibly high moisture contents, locating the source of water, and taking corrective action to eliminate the source. For example, drainage patterns on approach roadways can be rerouted to channel water away from the bridge rather than onto the bridge. New cuts and bolt holes in treated timber should be thoroughly coated with preservative materials to prevent moisture from entering the wood and causing decay.

Whenever repair or rehabilitation of a timber structure is done, all effort should be made to include field-treatment of holes and cuts made as part of the work performed.

Some attempts at moisture control such as the use of roll roofing material as stringer covers under decking or as piling top covers under caps or sheet metal as water-diverting cover or caps may contribute to increased wetting. As roofing material ages, it becomes permeable to water and the material will inhibit the drying.

If a drift pin is used to install metal sheeting over the pile, a slight depression in sheet metal is formed and a less than watertight seal is created. This results in an avenue for water to infiltrate the timber. Nails through the metal into the pile top function similarly. As a result, banding is preferred.

13.3.3 Preservation Treatments

Most untreated wood will decompose when the four conditions required for decay and insect attack occur:

- High moisture
- Favorable temperature
- Oxygen
- Food source (wood fiber)

If any one of these conditions is removed, infestation and decomposition cannot occur. Eliminating wood fiber as a food source by using pressure-treated wood products is an easy and practical solution. Research has shown that wood can be expected to last for many decades when properly treated and installed for its intended use. The map in Figure 13.18 indicates, by region, the degree of potential wood deterioration. Because deterioration zones range from moderate to severe across most of the country, it is important to understand the types of wood treatments available for use in timber structures.

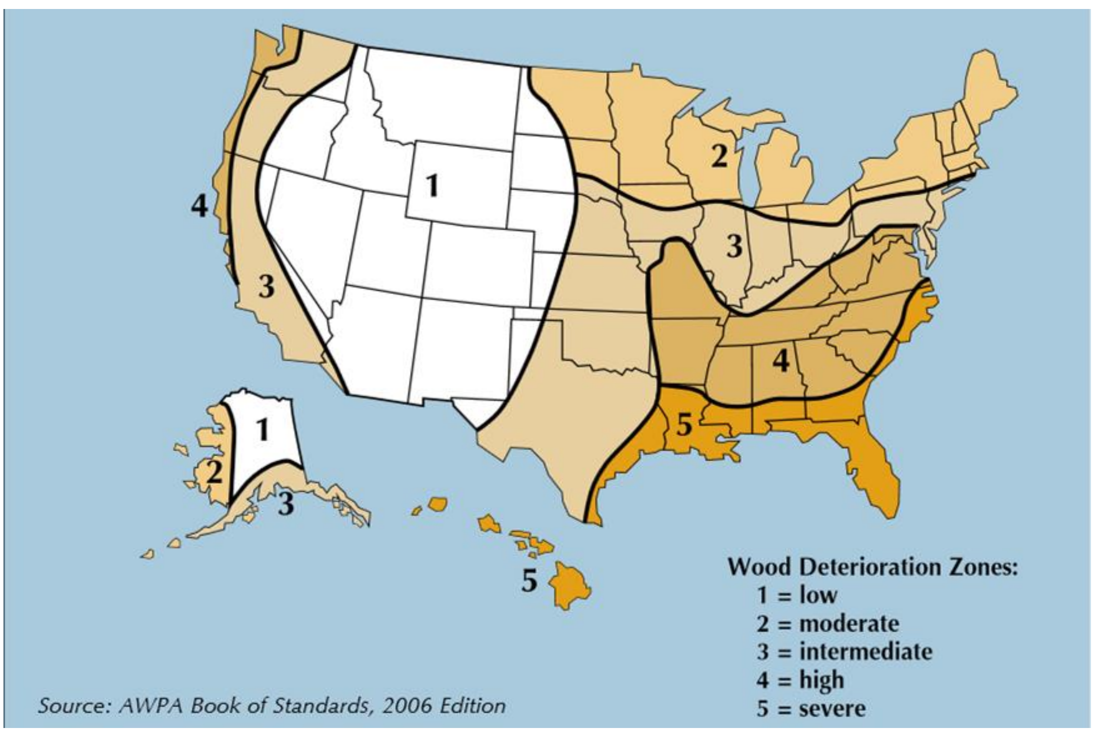


Figure 13.18 Potential for Wood Deterioration Throughout the United States

Types of wood preservation to be discussed in this section include:

- Surface treatments (bridge element replacement)

- Pressure treatments (at the plant)
- In-Place treatments (in the field, includes surface treatments, internal treatments, and wrapping)

Timber bridges use pressure treated wood since it provides the best long term protection. The additional life obtained by pressure treatment over that of untreated wood will be affected greatly by the level of penetration and retention of preservative in the wood and conditions of service. For most pressure treated wood, whether used above or in ground contact applications, data indicates that when properly installed and maintained, the expected service life could be in excess of 30 years for most applications.

When the pressure treated wood is brought out to the bridge site, it may have to be cut to size and drilled through during installation. Figure 13.19 shows an existing timber deck being replaced. Cutting and drilling through the pressure treated wood exposes internal areas of the wood where the treatment may not have penetrated. For this reason, surface treatments are applied in the field.

Figure 13.19 New Bridge Replacement Elements Need Surface Treatment

The effectiveness of surface treatments depends on the thoroughness of application, wood species, size, and moisture content at the time of treatment. Wet wood absorbs less preservative than does dry wood. This factor is significant in timber bridges because many areas requiring treatment are subject to wetting. Tests indicate that improved treatment of wet wood was obtained by using preservatives at double the normal 3- to 5-percent concentration. Although field tests show that surface treatments in above ground locations can prevent decay infections for up to 20 years or more, it is recommended that treatments used for bridge applications be systematically reapplied at intervals of 3 to 5 years to ensure adequate protection from decay.

The American Wood Protection Association (AWPA) is the principal standards-writing body for wood preservation in the United States. The AWPA Book of Standards establishes what preservatives and chemical formulations are appropriate for common applications; sets treating procedures; establishes wood species requirements and testing procedures; and provides guidance on quality control and inspection.

13.3.3.1 Surface Treatment (Bridge Element Replacement)

If a timber bridge element needs to be replaced, its removal can potentially expose untreated surfaces of existing timber elements. Surface treatments are not generally as satisfactory as those of pressure treatment in achieving optimum protection and extended service life. The processes do serve a useful purpose when more thorough treatments are impractical or exposure conditions are such that little preservative protection is required. Non-pressure methods, in general, consist of (a) surface application of preservatives by brushing or brief dipping,(b) soaking in preservative oils or steeping in solutions of waterborne preservatives, (c) diffusion processes with water-borne preservatives, (d) vacuum treatment, and (e) a variety of miscellaneous processes. Surface treatments are applied to these existing bridge members to protect newly exposed, untreated wood from decay or to supplement the initial treatment some years after installation. They can be applied in liquid, power, or solid form. This type of treatment is most effective when applied before decay begins and is commonly used for treating checks, splits, delaminations, mechanical damage, or areas that were field-fabricated during construction. The ease of application and effectiveness of surface treatments as barrier make them useful in preventive maintenance. However, the shallow penetration limits their effectiveness.

During timber element replacement anchor bolts, drift pins, and lag bolts create holes where decay and deterioration often begins. These holes should be protected from moisture penetration by swabbing with hot asphalt or treating with a preservative using a pressure bolt hole technique. This technique uses a preapproved device called a bolt treater to apply a pressure to the circumference of the bolt hole while applying the preservative. Unplugged holes such as those left by test borings, nails, bolts, and the like, also permit entrance of pests. Their location and extent should be noted and recommendations should be made for their repair.

The natural opening in the grain of timber ends allows easier water penetration. If the end is cut, it should be painted with a preservative or swabbed with hot asphalt. The ends of the exposed members should be capped with a thin sheet of aluminum, tin, or similar material.

Figure 13.20 shows a timber bridge deck being replaced. Note the drills and saws that cut through the pressure treated lumber.

Figure 13.20 Timber Bridge Deck Being Replaced

13.3.3.2 Pressure Treatment (at the Plant)

In commercial practice, wood is most often treated by immersing it in a preservative in a high pressure apparatus and applying pressure to drive the preservative into the wood. The chemical preservatives react with the wood fiber to form a treated wood product resistant to attack by insects, decay, fungus and marine borers. Reaction of the chemical preservative within the wood's fiber begins during the treating cycle. The time needed to maximize fixation or stabilization of the preservative in the wood fibers can range from several hours to several days, depending on ambient temperatures and humidity that vary greatly with locale and seasonal conditions and/or various post treatment processes that might be employed by the treating facility

Treated wood products in compliance with AWPA standards are labeled with a plastic tag, called a quality mark, usually stapled on the end to the timber. The mark indicates a third party inspection has been completed, adhering to the AWPA standards of quality. Information on the quality mark includes the AWPA recommendations on the use, exposure categories for the timber, and identifies the preservative used and the moisture content after treatment. This is useful information for preservation and maintenance actions involving pressure treated wood. An example quality mark and definitions are shown in Figure 13.21 below.

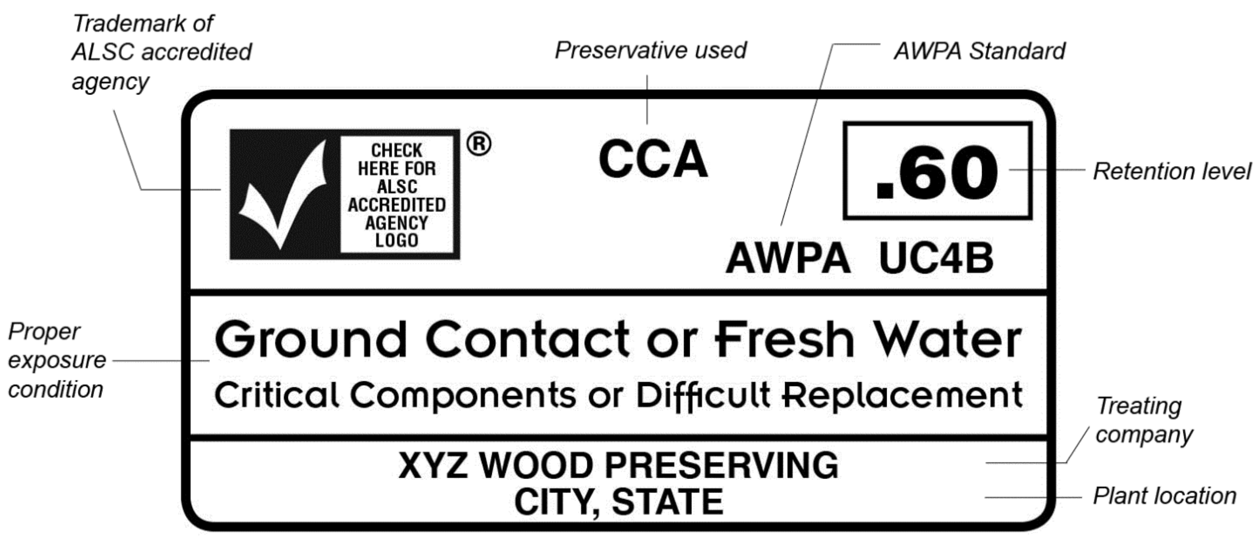


Figure 13.21 Interpreting a Quality Mark for Timber

There are three broad classes of preservatives used for the pressure treatment of wood products:

1. Waterborne preservatives, where water is the carrier for the preservative chemicals, serve a wide variety of uses. These include residential, commercial, marine, agricultural, recreational and industrial applications.
2. Oil-type preservatives are used primarily for industrial applications including utility poles, piling, posts, glulam beams and timbers.
3. Creosote preservatives, including creosote/coal-tar mixtures, protect railroad ties, marine pilings and utility poles.

For decades, treatments for industrial products were dominated by Chromated Copper Arsenate (CCA), creosote and pentachlorophenol. Although these traditional preservatives continue to be widely used, newer alternative treatments are becoming increasingly available.

Waterborne preservatives are commonly specified for most residential, commercial and marine building applications, including timber bridges. Waterborne treatments are clean in appearance, odorless and paintable.
They are also EPA-registered for both interior and exterior use without a sealer.

Incising can be done for wood species that do not allow preservation treatments to consistently and uniformly penetrate into the fibers. Incising is a mechanical process wherein numerous longitudinal incisions are made with chisel-type or knife-type teeth into the wood surfaces, parallel to the grain direction. Incising increases preservative retention and penetration during the treating process by increasing the amount of exposed, easily penetrated end-grain and by increasing the side-grain surface area.

While preservative treatment increases durability, the incising process is known to reduce certain strength values of structural lumber caused by the crushing of wood fibers. The type and amount of strength reduction is dependent on the depth of incision. Research results found the depth of incision to be the critical factor on determining the reduction of mechanical properties.

Treated wood must meet minimum preservative penetration and retention requirements for use in a particular service condition. Penetration refers to the depth a preservative must permeate into the wood fiber. The amount of preservative that remains in the wood after the pressure-treating process is complete is called retention. Retention levels are expressed in pounds of preservative per cubic foot (pcf) of wood fiber and the higher the retention, the harsher the service condition the wood may be exposed to.

Creosote pressure treatment is the most effective method of protection for bridge timbers. But its use is also highly restricted by environmental laws. Pentachlorophenol (penta-oil treatment) is a heavy oil solvent applied using pressure methods. Inorganic salt solutions are applied using pressure and provide less water repelling than other treatments. The salt solution can corrode any hardware used to construct the bridge. For more information on hardware, see Section 13.3.3.3 Connections in Preservative Treated Lumber.

13.3.3.3 Connections in Preservative Treated Timber

Fasteners and connectors for preservative-treated wood need to be hot-dipped galvanized in accordance with ASTM A-153, silicon bronze, copper or 304 or 316 stainless steel. Stainless steel fasteners should be used below grade and are recommended for use with treated wood in other corrosive exposures such as in or near salt water.

Hot-dipped galvanized or stainless steel fasteners and connectors are recommended for use when lumber is treated with a copper-based preservative. Copper-based formulations include CCA, ACZA, ACQ, or CA-C and may be used in interior or exterior applications. Hot-dipped galvanized fasteners and connectors are generally acceptable for above-grade applications. Fasteners and connectors used together must be of the same metallic composition to avoid galvanic corrosion (e.g., use hot-dipped nails with hot-dipped joist hangers). Type 304 or 316 stainless steel is recommended for maximum corrosion resistance in more severe exterior applications including, salt-water exposure and below-grade applications. Stainless steel is also a recommended option for use with CCA, ACZA, ACQ, or CA-C treated wood at retention levels greater than required for ground contact.

Standard carbon-steel or aluminum products should never be used in direct contact when lumber is treated with a copper-based preservative. Electroplated galvanized metal products generally have a thinner layer of protection compared to hot-dipped galvanized and are typically not accepted by the building codes for use in exterior applications. When aluminum or electroplated products such as flashing or termite shields are used, spacers or other physical barriers are necessary to prevent direct contact from copper-based treated wood. These barriers should provide complete separation and remain intact for the intended service life of the metal.

13.3.3.4 In-Place Preservative Treatment (Surface Treatments and Internal Treatments)

In-place treating can provide a safe, effective, and economical method for extending the service life of timber bridges. Most of the techniques and treatments were developed for use on railroads or utility poles, for which they have been used effectively for many years. A large number of timber bridges have been treated in-place, extending service life by as much as 20 years or more.

Surface Treatments

To further protect in-service wood timbers, sealants can be applied to prevent infection of exposed wood. The use of bituminous or asphaltic mastics as sealants or bedding compounds can be effective sealants. Copper naphthenate-based solutions may be used for field treatment of materials originally treated with pentachlorophenol, creosote or waterborne preservatives as specified in AWPA Standard M4. The preservative concentration should contain no less than 2 percent copper metal. Newly exposed surfaces resulting from field fabrication and/or handling abuse should be field treated by brushing, dipping or soaking. The application should be done in a manner that the preservative does not drip or spill into the surrounding soil.

Internal Treatments

Internal treatments usually involve either water-diffusible or fumigants. The most popular and recommended water-diffusible treatment are boron based and are discussed in detail in Section 11.3.3.1 of this manual. Fumigants are discussed below but are being used less for timber bridge preservation.

If decay is already occurring, fumigants are used. Fumigants are preservative chemicals available in liquid or solid form that can be used to control internal decay from fungi and insects. Fumigants are placed in prebored holes to arrest internal decay. Over a period of time, the fumigants volatilize into toxic gases that move through the wood, eliminating decay fungi and insects. Fumigants can diffuse in the direction of the wood grain for 8 feet or more from the point of application in vertical members, such as poles. In horizontal members, the distance of movement is approximately 2 to 4 feet from the point of application.

The three chemicals most commonly used as liquid fumigants are Vapam (33-percent sodium N-methyldithiocarbamate), Vorlex (20-percent methylisothiocyanate, 80-percent chlorinated

C3 hydrocarbons), and chloropicrin (trichloronitromethane). Solid fumigants are available in capsules of methylisothiocyanate (MIT), which is the active ingredient of Vapam and Vorlex.

Solid fumigants provide increased safety, reduce the risk of environmental contamination, and permit fumigant use in previously restricted applications. Borate has become the treatment of choice for internal solids, see Section 11.3.3.1 for more information.

To be most effective, fumigants must be applied to sound wood. When applied in very porous wood or close to surfaces, some of the fumigant is lost by diffusion to the atmosphere. Before applying fumigants, the condition of the member should be carefully assessed to identify the optimal boring pattern that avoids fasteners, seasoning checks, badly decayed entire structure, it is advisable to contract the project to specialists in the field.

Protection of Piles by Wrapping

Additional protection should be applied to timber bridge piles at the groundline since this is where the deterioration will occur first. Installation of a PVC barrier is a typical protection measure.

A suggested procedure for pile protection follows and is illustrated in Figure 13.22:

Suggested Procedure

Pile Protection

1. Piles should be protected 1 foot below the mudline and 1 foot above high tide.
2. A flexible PVC barrier can be installed when a pile loses approximately 10 to 15 percent of its cross- sectional area.
3. Sheath the pile with a 30-mil PVC sheet. A half-round wood pole piece is attached to the vertical edge of the PVC sheet to help in the wrapping process. (Note: A pile with creosote bleeding from its surface must first be wrapped with a sheet of polyethylene film prior to installing the PVC wrap to prevent a reaction between the PVC and the preservative.)
4. Staple lengths of polyethylene foam, ½ by 3 inches, about 1 inch from the upper and lower horizontal edges of the sheet.
5. Fit the pole pieces together with one inserted into a pocket attached to the bottom of the other pole.
6. Roll the excess material onto the combined pole pieces and tighten around the pile with a special wrench.
7. Secure the wrap and poles with aluminum alloy rails.
8. Nail rigid plastic bands at the top and bottom directly over where the polyethylene foam is located under the wrap.
9. Install additional bands on equal distance centers between the top and bottom bands.

For timber elements other than piles, wrapping with PVC sheeting is an effective preservation action. Examples include braces or other timber elements with slight damage or to prevent damage from occurring. Remove the bolt which secures the brace to the pile. Wrap the freed end with 20-mil flexible PVC sheeting. Drive the bolt through the wrapping and existing hole. Rebolt the brace to the pile. Wrap the remainder of the brace in the sheeting.

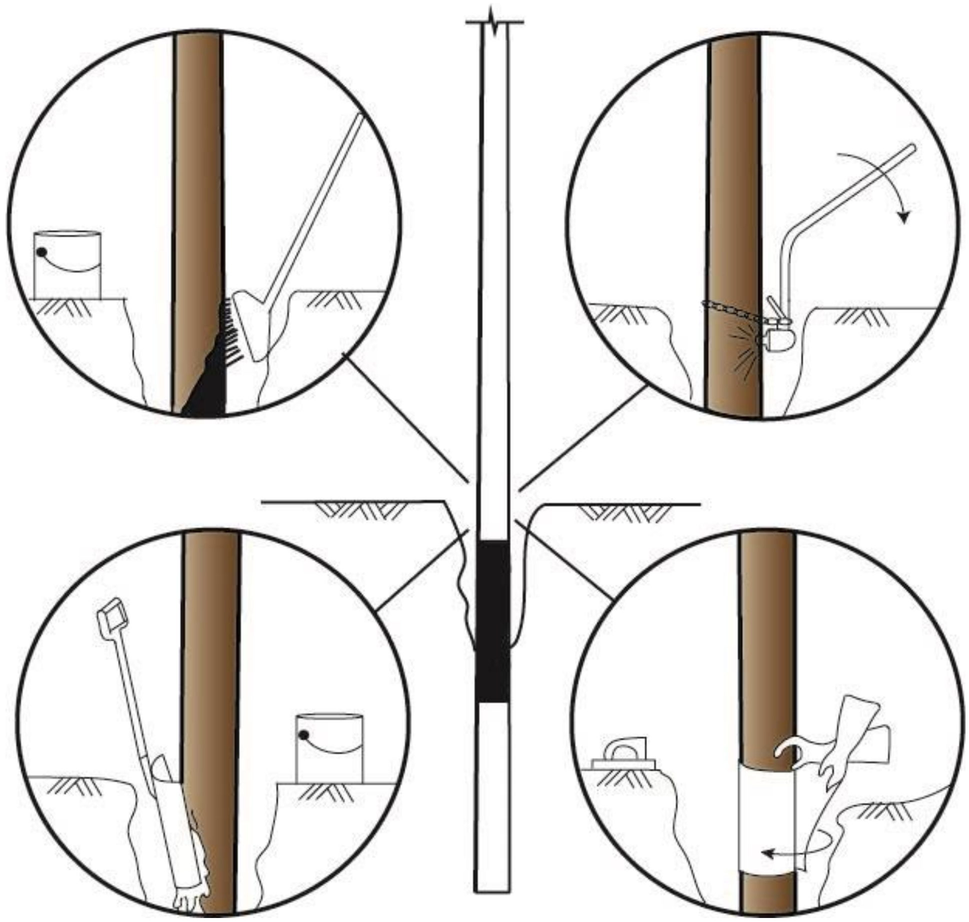


Figure 13.22 Methods of Applying Groundline Treatment to Bridge Pile Bents

Protection of Piles Tops

As bridge pile bents are initially constructed or replaced they need to be cut to the correct elevation for the cap. When this happens the top of the freshly cut pile is susceptible to deterioration if not treated.

Two options exist for treatment of pile ends: (1) Drill 3/4-inch holes evenly spaced into the pile top 1½ inches deep, fill holes with a preservative, and cap with aluminum sheeting. (2) Clamp an iron ring around the top of the pile, pour a preservative into the ring, and allow the pile to absorb the preservative, remove the ring, and cap the pile. Rounding the top of the pile helps to shed water off the horizontal surface.

Preservative is injected into the pole at the groundline with a special tool or applied on the pole surface as a paste or bandage.

13.3.3.5 Handling and Disposal of Treated Wood

When applying use of pressure-treated wood, do not use where the wood will be in frequent or prolonged contact with bare skin or under circumstances where preservative may become a component of food for either humans or animals. Examples include sites using mulch from recycled treated wood, cutting boards, counter tops, animal bedding and structures for storing human or animal food. Treated wood should not be used where it may come into contact or indirect contact with public drinking water except for uses such as docks and bridges. Wood treated with Pentachlorophenol or Creosote should not be used where it may come into contact with drinking water for domestic animals or livestock. Waterborne preservatives are approved for this use.

Recommendation

When handling pressure treated wood, take proper safety precautions.

When handling treated wood, wear protective clothing such as long-sleeved shirts and long pants and use gloves. After working with the treated material, wash any exposed area before eating, drinking, going to the toilet, or using tobacco products. When sawing and machining the treated material, wear goggles to protect eyes from flying particles. Wear a dust mask and, if possible, work outdoors to avoid inhalation of sawdust.

Under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), wood preservative systems containing chemical pesticides are fully regulated by the U.S. Environmental Protection Agency (EPA) and are required to undergo a rigorous registration and re-registration process. The EPA considers wood preservative systems as antimicrobial pesticides and requires that the pesticides be supported with thorough scientific review and analysis, as well as show they can be used in wood preservative products without causing undue adverse effect to human health or the environment. Further, under federal law, preserved wood products themselves are not considered to be a pesticide and therefore are not regulated by FIFRA. Further, under the Resource Conservation and Recovery Act (RCRA), which regulates waste disposal, treated wood is not listed as a federal hazardous waste. Treated wood is also exempt from state hazardous waste regulations. Being a non-hazardous waste allows material deemed to be waste treated wood to be disposed in an approved state solid waste landfill or properly permitted combustion facility. Treated wood would only be regulated as a “hazardous waste” if (1) it was to become listed in the RCRA regulations, or (2) the material exhibited a hazardous waste characteristic. Studies have determined that treated wood does not exhibit a federal hazardous waste characteristic.

If material removed from service is not designated as waste treated wood, the preferred option for handling is to reuse the material in a manner consistent with the use of similar treated wood products. Material originally used for structural applications can often either be used for structural purposes if found to still be sound or for non-structural purposes such as landscaping timbers or parking bumpers, or posts. Treated wood should NEVER be burned in open fires of any kind, stoves, fireplaces, or residential boilers.

Treated wood can be used in an industrial biofuel burner, if it is a permitted facility meeting state and federal air quality standards. Treated wood is also considered biomass in some states and may be combusted for generation of energy and/or be eligible for renewable energy credits. For example, creosote treated timber products have a long history of being used as a renewable resource for the generation of energy through combustion. As a last resort, all treated wood waste, whether it is generated from commercial, industrial, or residential uses, can be disposed of as non-hazardous material in an approved solid waste landfill, provided it is disposed in conformance with federal, state, and local regulations.

Recommendation

Treated wood is not considered a federal hazardous waste, but one should dispose of all treated wood waste in an approved solid waste landfill.

During construction or installation of treated wood products, it is important to collect all scraps, sawdust, and curing debris and remove for appropriate disposal, especially when the area is readily accessible to the public or near and over bodies of water.

13.4 Repair and Rehabilitation of Concrete Substructures

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 supported by 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.

When to Call the Engineer

Call the Engineer if temporary support of loads or raising of the superstructure is required to perform the repair.

13.4.1 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 13.23 was performed under loading as the repairs were only to the superficial concrete covering the rebars.

Figure 13.23 Non-Structural Repair of a Column

Substructure concrete will deteriorate from the effects of water, deicing chemicals, freeze cracking, settlement cracking, structural cracking, or impact by debris. The deterioration leads to 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.

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:

Suggested Procedure

Non-Structural Repair for Concrete Substructure 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 adequate strength.
7. Apply a bonding agent to the surface (if owner allows)* and fill the form with concrete.

* Not all agencies authorize the use of bonding agents.

Effective bonding of the new concrete to the old is usually accomplished with a bonding material 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 the concrete.

Before and after photos of surface repair of a retaining wall are shown in Figure 13.24 and Figure 13.25.

Figure 13.24 Preparation for Repair of Retaining Wall

Figure 13.25 Retaining Wall After Repairs

13.4.2 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:

Suggested Procedure

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 formwork.
6. Set reinforcing steel and forms.
7. Apply epoxy-bonding agent (if owner 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 substructure concrete elements is shown in Figure 13.26.

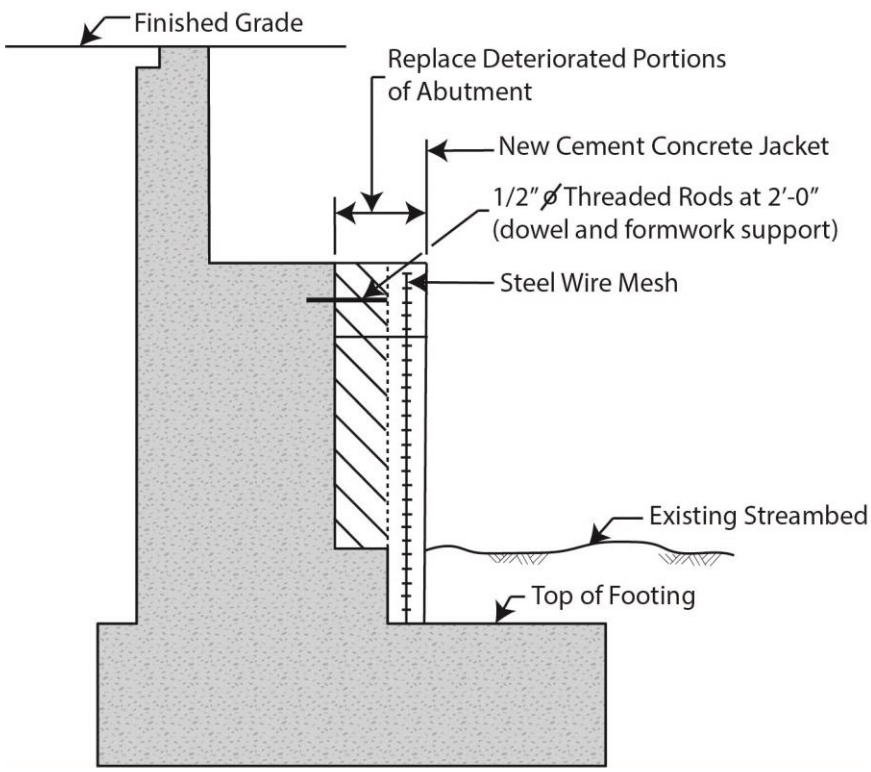


Figure 13.26 Repair of Abutment Face

Portions of an otherwise sound concrete may be broken off by frost heave, ice that forms in voids 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.

Wingwalls

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

Suggested Procedure

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 sound concrete and set with non-shrink grout, 18 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 Figure 13.27.

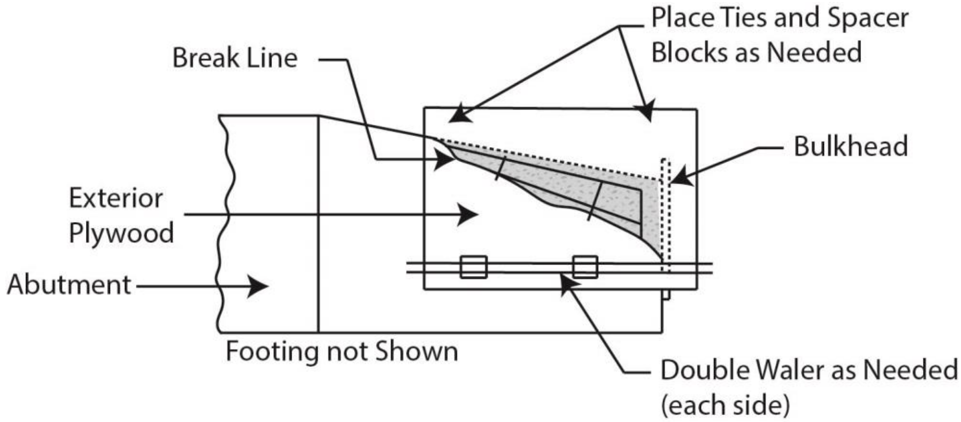


Figure 13.27 Reconstruction of Wingwall

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.

Suggested Procedure

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 or by drilling and grouting.
5. Place forms for concrete. 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. Place and cure concrete. Insure 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.

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 see a 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.

When to Call the Engineer

Call the Engineer if pier cap has vertical cracks at midspan between columns, emanating from bottom of cap, or shear cracks in cantilever areas of hammer head pier caps.

Figure 13.28 Pier Cap and Column in Need of Structural Rehabilitation

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:

Suggested Procedure

Footing Repair

1. Water must be kept clear of work area by means of diversion channels, cofferdams, sandbags, or sheet piling if 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 extend the footing to cover a larger area and extend the sides downward 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 becomes excessive.

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.

13.4.3 Jacketing of Concrete Substructure 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 of a 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 premolded fiberglass; however, it could be steel or fabric. Old drainpipes have been used as jacket liners. Figure 13.29 shows a standard concrete pile jacket with steel reinforcing cage.

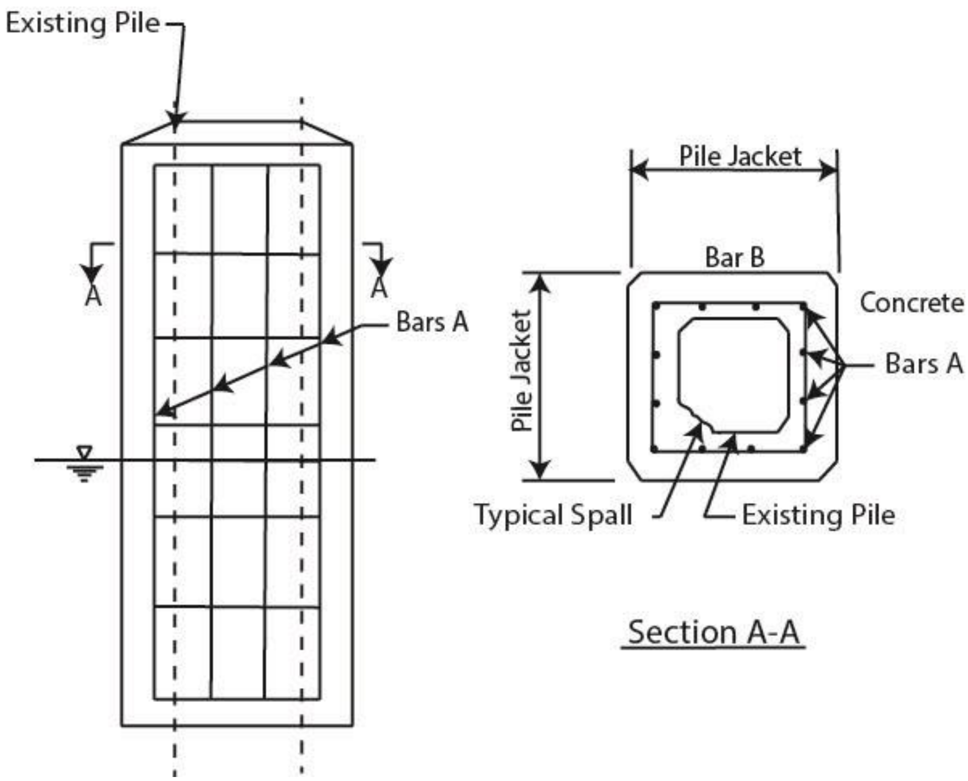


Figure 13.29 Concrete Pile Jacket with Steel Reinforcing Cage

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.

When to Call the Engineer

Call the Engineer before any concrete removal of prestressed piles.

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.

Suggested Procedure

Concrete-Filled Pile Jacket Installation

1. Scrape surface of the pile clean, removing deteriorated concrete or wood.
2. Sandblasting may be used to clean the exposed reinforcement in concrete piles above the waterline. 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 pile 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 13.30.

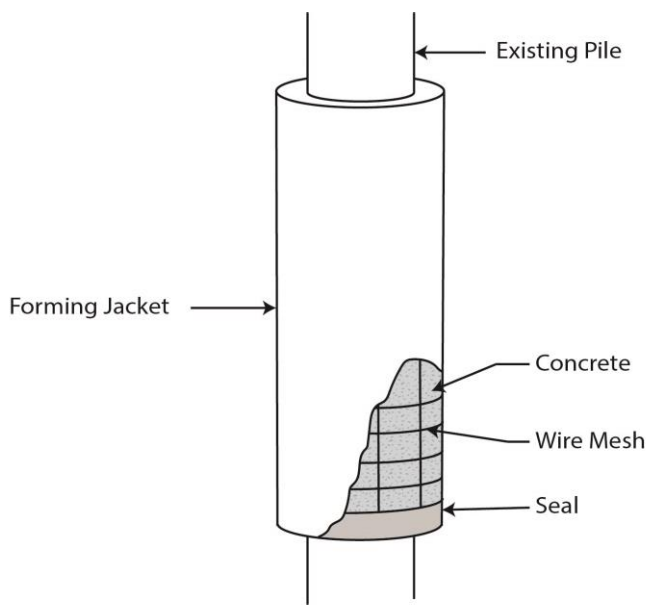


Figure 13.30 Concrete Pile Jacket Installation

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 new concrete. 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 13.31. 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.

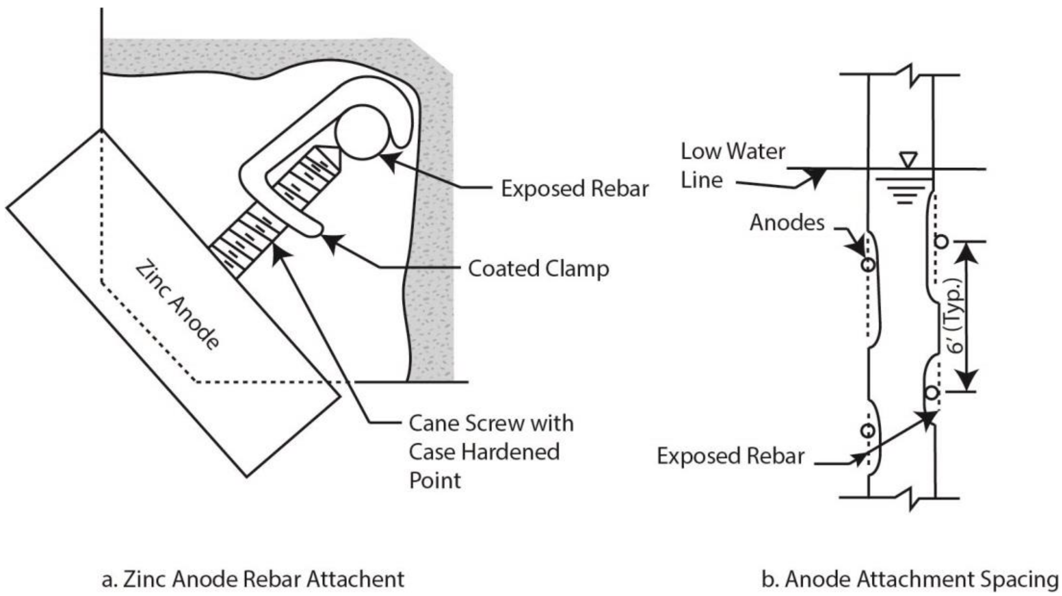


Figure 13.31 Galvanic Cathodic Protection of Concrete Piles (Underwater)

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.

Suggested Procedure

Cast-In-Place Pile Repair

1. Erect a 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. Ensurethe 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.

13.4.4 Shotcrete for Substructure 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 13.32. 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 an materials 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.

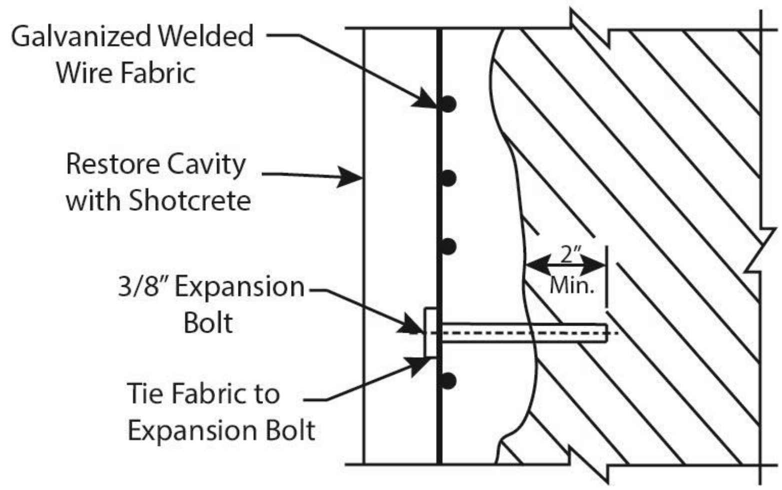


Figure 13.32 Welded Fire Fabric Anchorage for Shotcrete

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

13.4.5 Crack Repairs

Sealing cracks in substructure elements typically involves vertical or horizontal application of the 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 it should 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 are 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. Chapter 5 has procedures for crack repair.

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.

Epoxy Injection

The most effective method of repairing substructure vertical cracks is epoxy injection. An example of the installation ports is shown in Figure 13.33. 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 13.34.

Figure 13.33 Installation of Epoxy Injection Ports (Courtesy of MDOT)

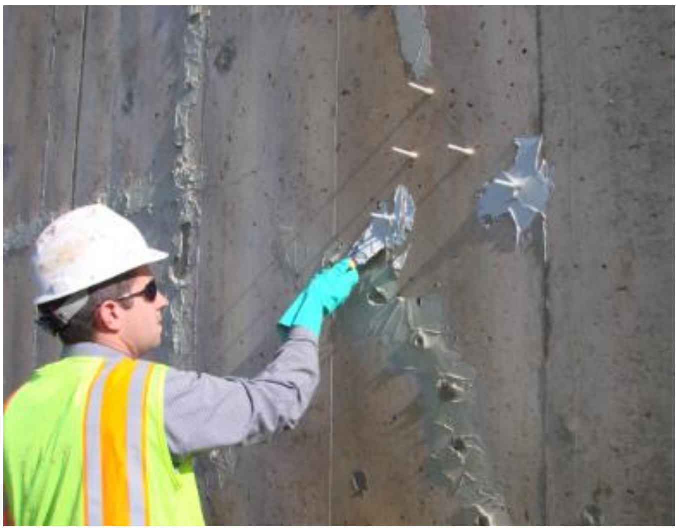


Figure 13.34 Application of Epoxy Resin over Cracks Prior to Injecting (Courtesy of MDOT)

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 the pressure needed to apply the epoxy and should result in greater crack-filling penetration.

The injection progresses from port to port, normally starting at the lowest point, and continuing until 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.

Chapter 5 covers epoxy injection repair procedures in greater detail.

13.4.6 Mechanisms that Move Substructures

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 stresses greater 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 tremendous lateral loads when an ice jam occurs at the bridge.

Thermal forces: On structures without expansion bearings, or where the expansion bearings fail to operate, thermal forces may tip the substructure units. Pavement thrust is another force that will 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.

13.4.7 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.

13.4.7.1 Sensitivity of Bridges to Settlement

The types or settlement are categorized as:

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.

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:

- *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.
- *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:

- 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.
- Settlement (vertical movement) - Any type of substructure not founded on solid rock may be 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
- 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 13.35.

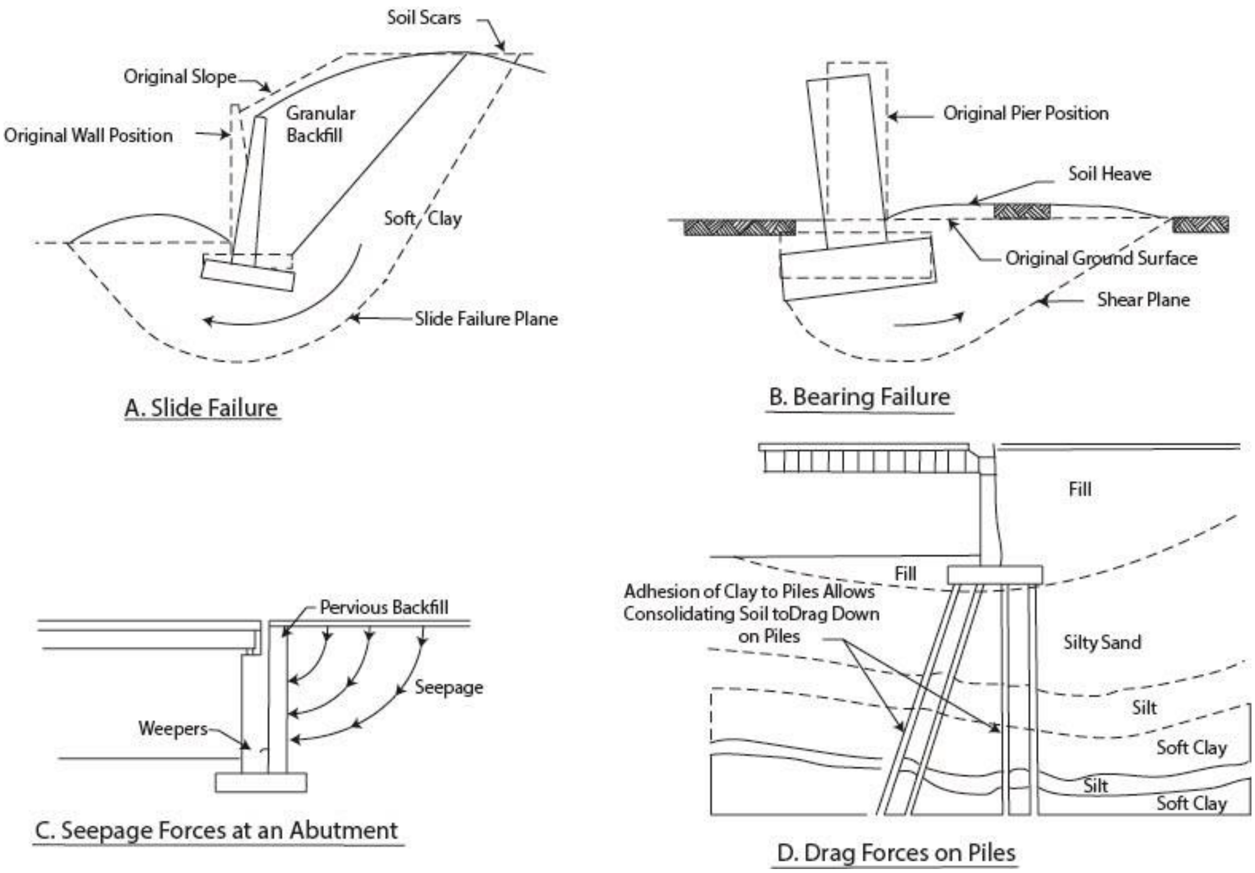


Figure 13.35 Common Causes of Foundation Failure

13.4.7.2 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.

When to Call the Engineer

Call the Engineer when planning to correct differential settlement.

Resource requirements are:

- Diving equipment
- Work boat

- Concrete drilling equipment
- Steel dowels
- Concrete pumping equipment
- High strength pretailored grout bags
- Reinforcing steel
- Jacks for bringing the superstructure to grade

A procedure for correcting underwater differential settlement follows:

Suggested Procedure

Correction of Underwater Differential Settlement

1. Remove traffic.
2. Install turbidity curtain and other devices to maintain water quality. Alternately, a cofferdam could be used, and repairs constructed in the dry.
3. Install concrete leveling sill to ensure pier stability during excavation. The sill 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 subject to environmental water quality requirements.
6. Install 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 the 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 into existing stem and footing to anchor new work to old.

Figure 13.36 shows a procedure for correcting differential settlement.

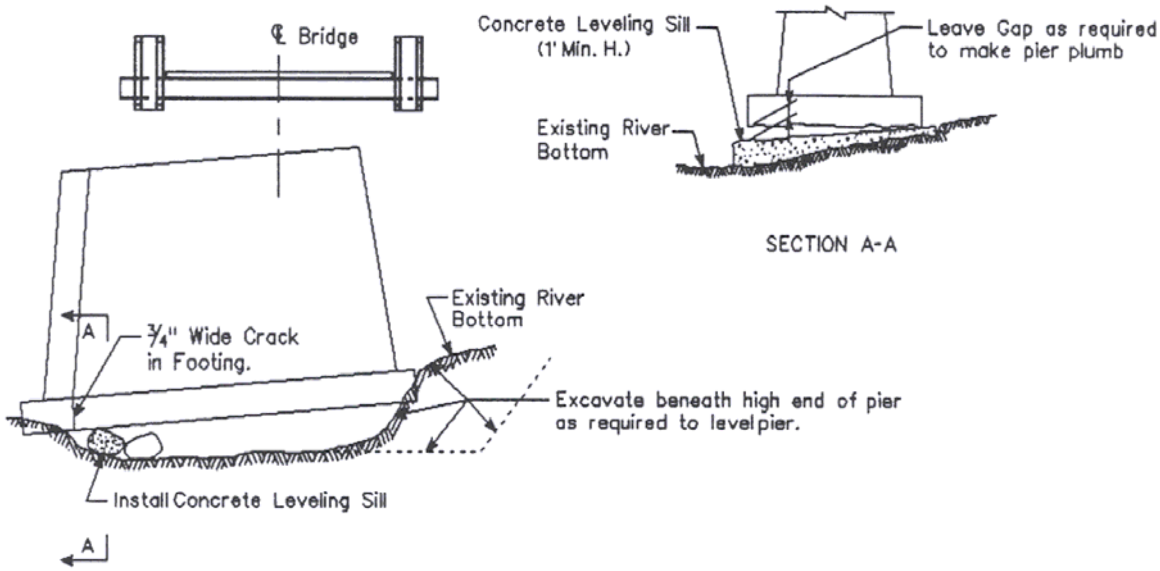


Figure 13.36 Pier Settlement Stabilization

When to Call the Engineer

Call the Engineer for any pier settlement stabilization repair.

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.

Suggested Procedure

<u>Pier Settlement Stabilization Repair</u>

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 13.37 shows how additional piles could be added to the footing and the footing widened and thickened.

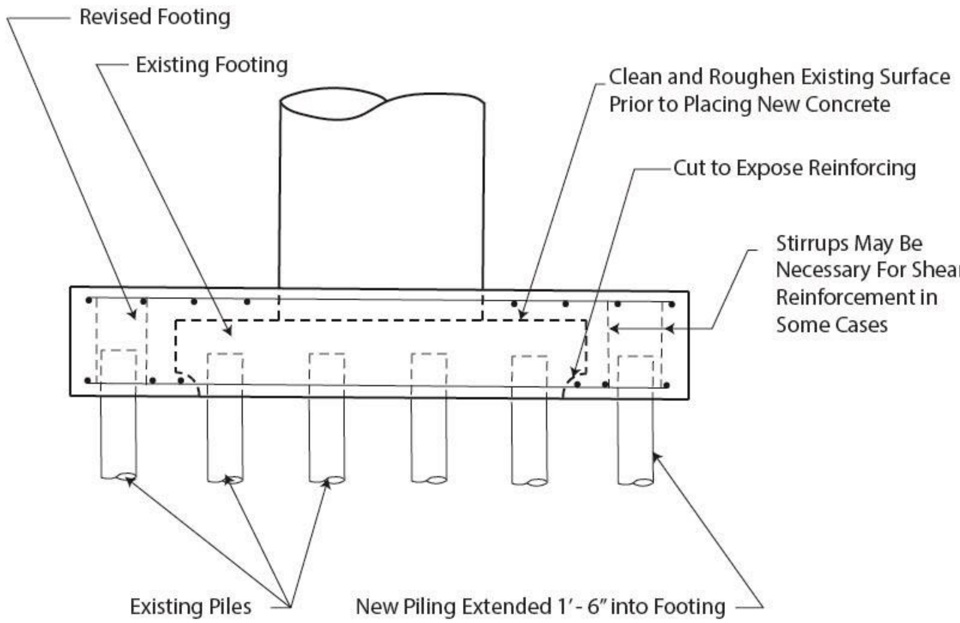


Figure 13.37 Increasing Live Load Capacity of Existing Footing

13.4.8 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 13.38, 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 13.39.

(a)

(b)

(c)

(d)

(e)

(f)

Figure 13.38 Undermining Repair Sequence

Figure 13.39 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 tremie hopper 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.

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 13.40. 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 13.40 Grout Bags Used to Prevent Undermining

13.4.8.1 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 13.41.

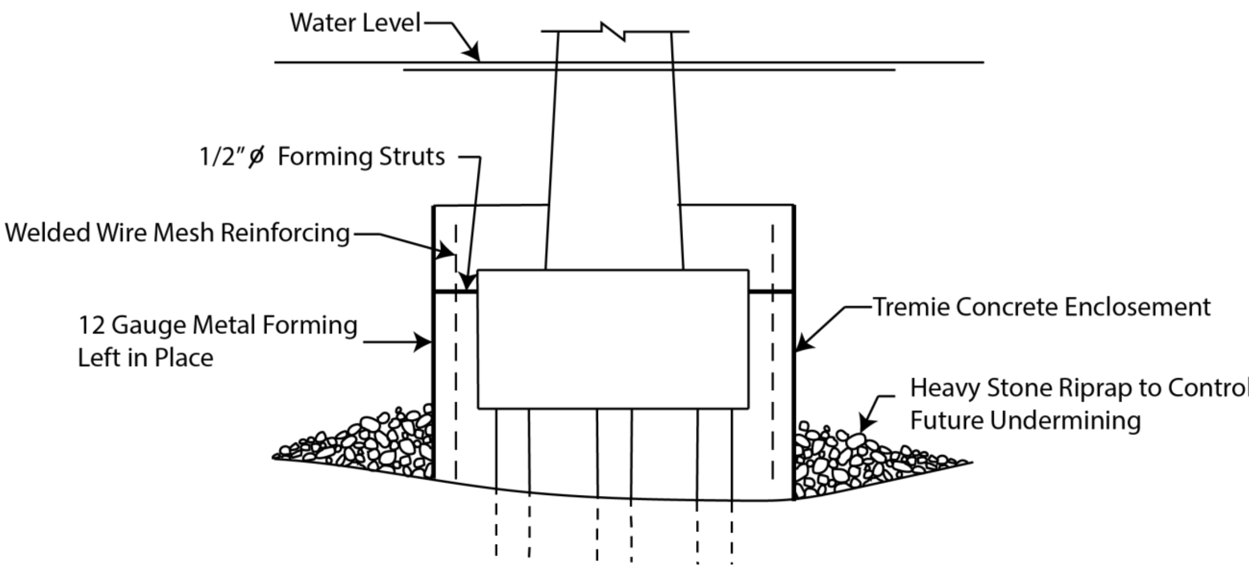


Figure 13.41 Tremie Concrete Scour Repair

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.

When to Call the Engineer

Call the Engineer when planning any tremie concrete scour repair.

The following will be needed:

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

Suggested Procedure

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 for the steel forms, as shown in Figure 13.42 below.

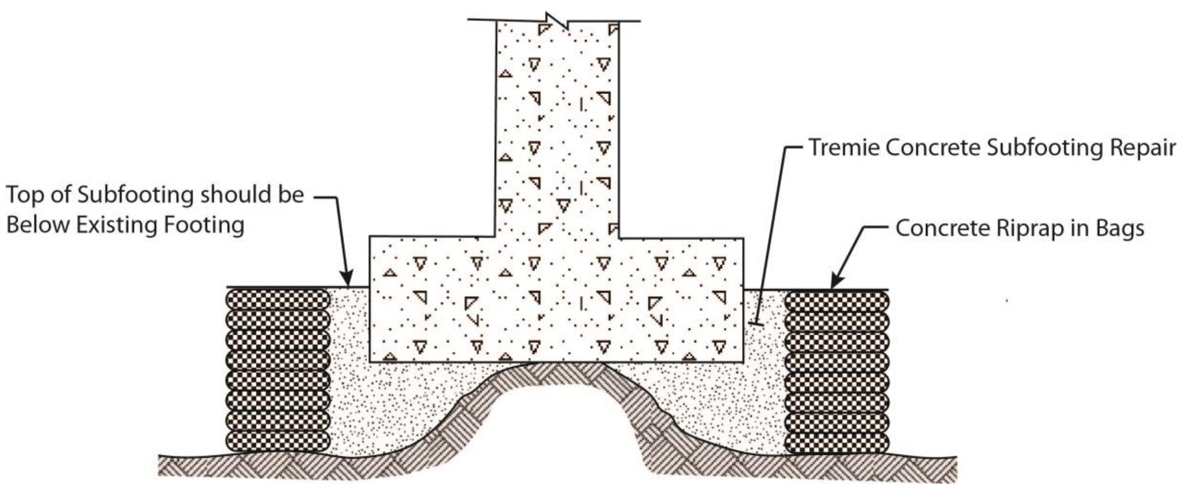


Figure 13.42 Bagged Riprap Scour Repair

13.4.8.2 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 13.43 for an example of tremie repair using fabric tubes.

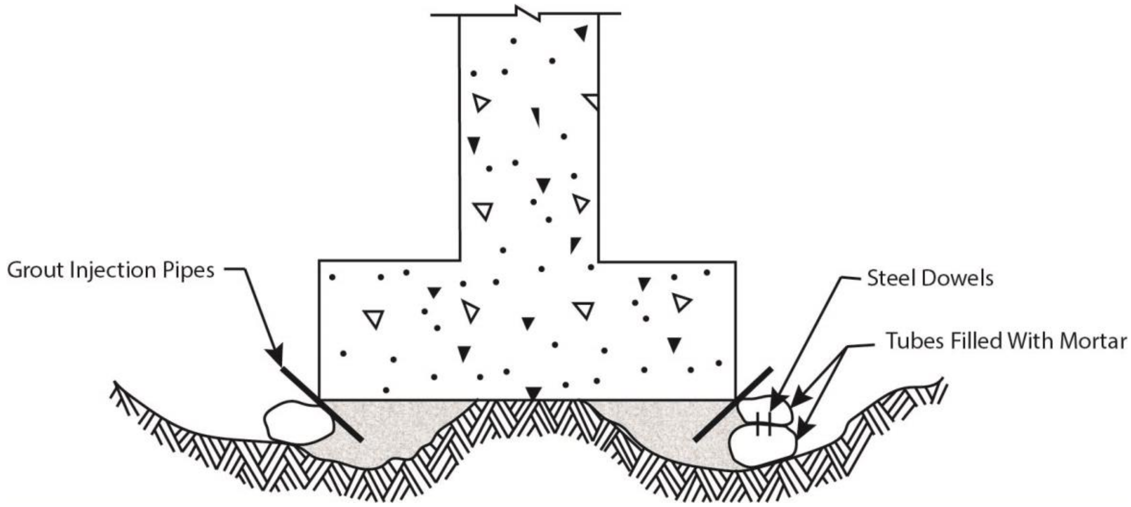


Figure 13.43 Mortar Filled Tube Scour Repair

13.4.8.3 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 deadmen that may have been provided to resist the loads, should be ascertained in evaluating safe conditions during repair. See Figure 13.44 for an example of eroded scour repair.

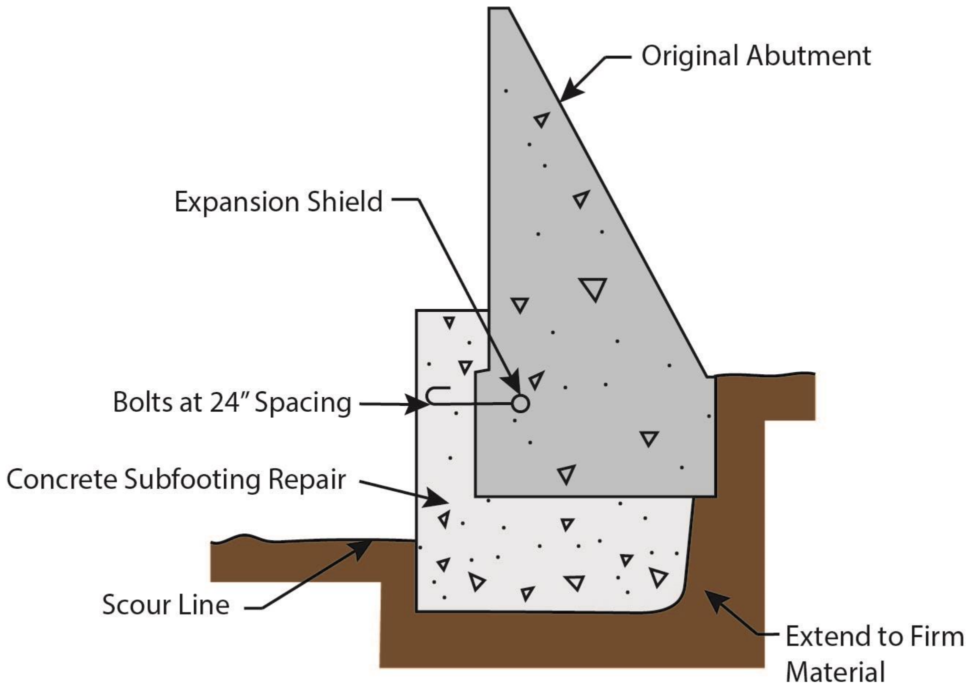


Figure 13.44 Eroded Scour Repair

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.

When to Call the Engineer

Call the Engineer when planning any eroded scour repair.

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

Suggested Procedure

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 reached design strength, remove the forms and add stone riprap. Hint: See what size rock is not getting washed downstream. Use riprap equal to this size or larger.

13.4.8.4 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 procedure also 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 13.45.

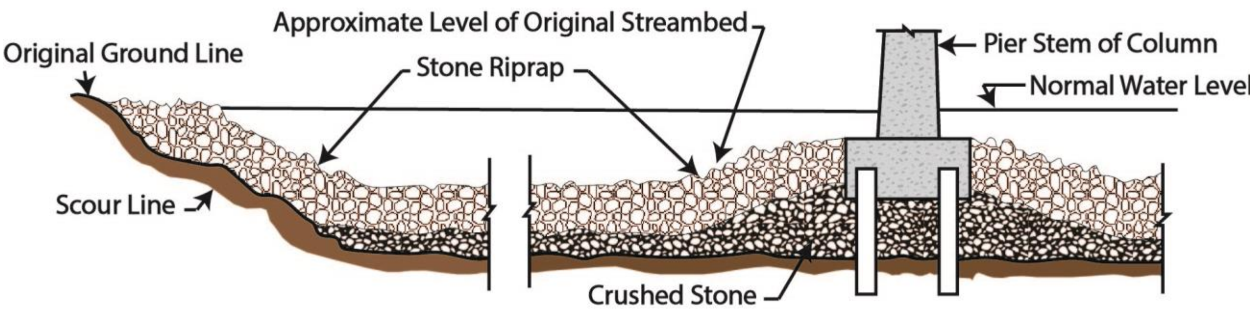


Figure 13.45 Streambed Paving Repair

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.

When to Call the Engineer

Call the Engineer when planning any streambed paving repair.

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

Suggested Procedure

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 extend above the high water line at both sides of the channel.

13.4.8.5 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.

13.4.9 Miscellaneous Abutment Repairs

Abutments vary in type and design and each has special considerations. Integral and to a lesser extent, semi-integral abutment structures have performed successfully for a number of years. This substructure type is defined in Chapter 3. For abutments on steel piles, deterioration at the soil line is a major concern. Wingwalls and Mechanically Stabilized Earth (MSE) can become unstable when steel ties to the wall face deteriorate and earth pressures behind the wall force it to rotate. The same repairs for steel substructures can be used in the repair of integral or semi-integral abutments constructed with steel sheeting.

13.4.9.1 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 13.46 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

When to Call the Engineer

Call the Engineer when planning to install deadmen for abutment stabilization.

Suggested Procedure

Deadman Installation

1. Excavate the area where the deadmen are to be placed and provide a trench for the restraining rods.
2. Drive piles for the deadmen, if required.
3. Place formwork and concrete for the deadmen. Note that the side of the deadmen 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 deadmen.
6. Place the waler beams and tighten the rods (see Figure 13.46).
7. Grout holes in backwall. Back fill.

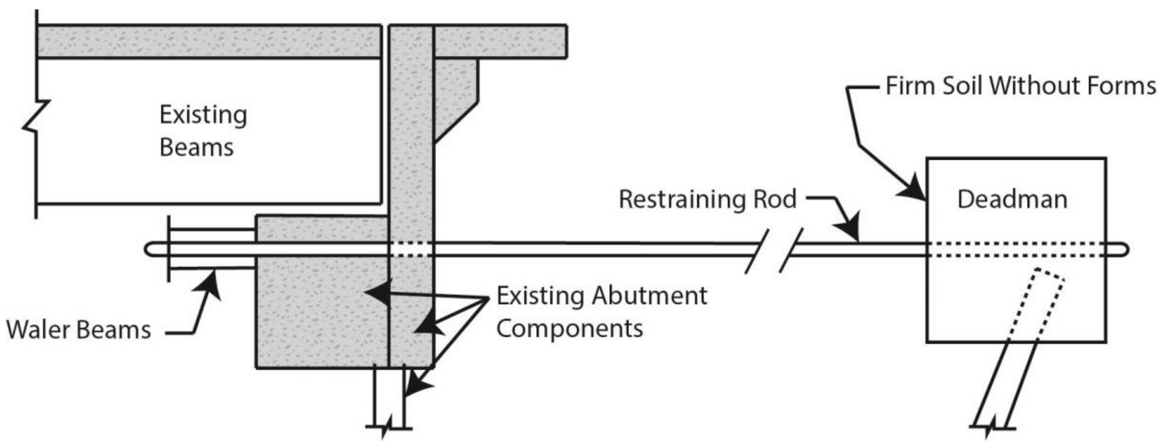


Figure 13.46 Installation of a Deadman Anchor

13.4.9.2 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.

Suggested Procedure

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. (See Section 12.3.2 Jacking of the Superstructure).
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 (see Figure 13.24). 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 no detergents or bond inhibiting chemicals. Where reinforcing steel has corrosion, it shall be sandblasted to a white metal finish. If it is found that the 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 unreinforced bearing seats is not confined by the rebar.

13.4.10 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 for any evidence that sound concrete may be critically contaminated with chlorides. If chlorides are present 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 may be 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 of the 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 ^{o}F to 95 ^{o}F 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

Suggested Procedure

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 topcoat is applied to the 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 repairs 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 13.47 Alternatively, the fiber sheet may be separately impregnated using a resin-impregnating machine before placement on the concrete surface.

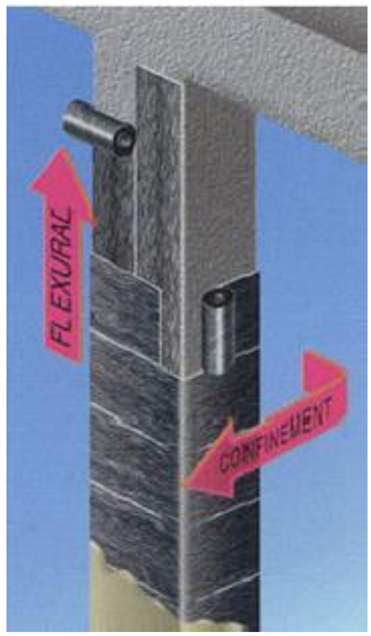


Figure 13.47 Advantages of Multi-Ply FRP Application

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 3/4 inch radius (see Figure 13.48). 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.

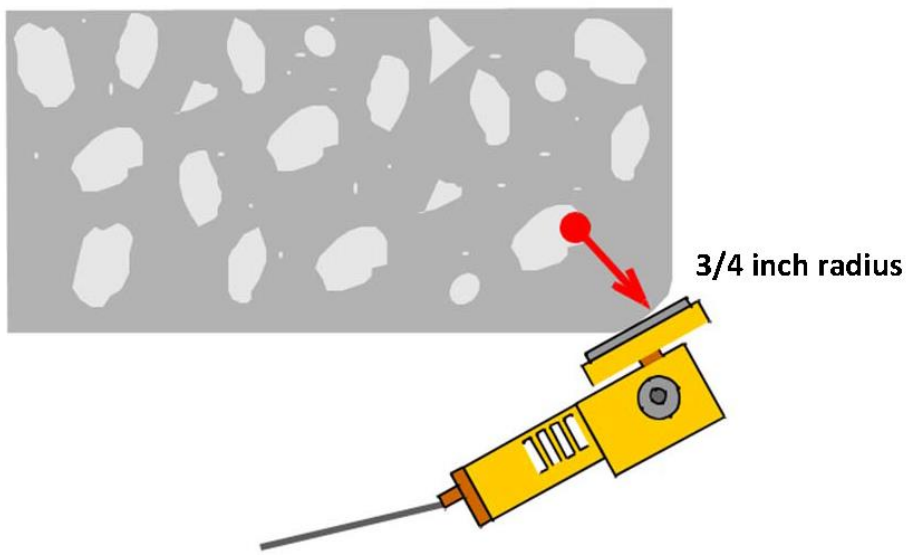


Figure 13.48 Grind Sharp Corners to 3/4 Inch Radius (Courtesy of MDOT)

Various applications for the use of FRP in the repair and rehabilitation of concrete substructures are shown in Figure 13.49 through Figure 13.51.

Figure 13.49 Strengthening a Spandrel Arch with FRP

Figure 13.50 Pedestal Repair with FRP

Figure 13.51 Completed Column Repair with FRP

13.4.11 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.

When to Call the Engineer

Call the Engineer when planning external post-tensioning repairs.

Suggested Procedure

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 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 13.52.

Figure 13.52 External Post-Tensioning Rods used in Pier Containment

13.5 Repair and Rehabilitation of Steel Substructures

Steel substructures can consist of piling, pile bents, frames and towers. Examples are included in Chapter 3. Most steel substructures utilize bolting or welding in the original design and these connection types must be considered in repair and rehabilitation.

13.5.1 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.

When to Call the Engineer

Call the Engineer when evaluating section loss and any welding.

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.

13.5.2 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. This may save having to go back to the same location after the next inspection to replace additional rivets.

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 13.53 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.

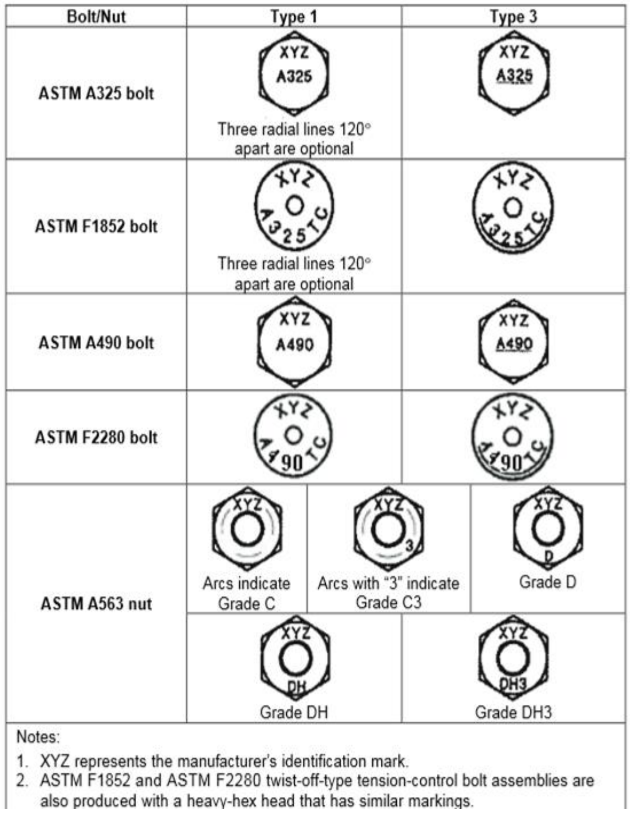


Figure 13.53 ASTM Heavy-Hex Nuts Marking Standards
(Courtesy of The Research Council on Structural Connections)

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 diameter so 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 pretensioning methods such as the calibrated wrench pretensioning method and twist-off-type tension-control bolt pretensioning 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.

Suggested Procedure

Turn of the Nut

1. Snug 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 the appropriate bolting pattern, apply the required turns as shown in Table 13.2. The amount of turn past snug tight is based on the ratio between the bolt length and diameter, as well as the slope disposition of the outer steel plies.

Table 13.2 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 less than or equal to 8D	1/2 Turn	2/3 Turn	5/6 Turn
More than 8D and less than 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 13.54. 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.

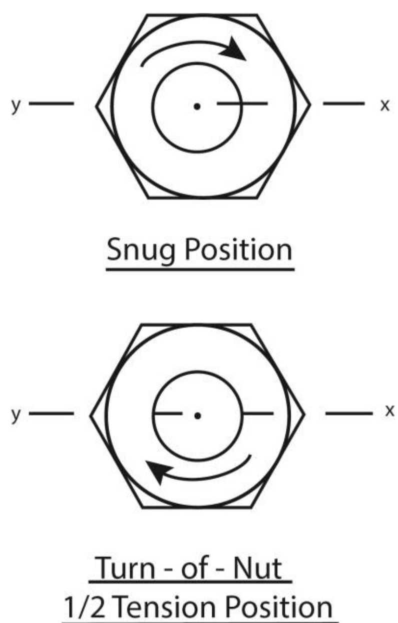


Figure 13.54 Turn of the Nut Method

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.

13.5.3 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.

When to Call the Engineer

If splicing new steel sections to damaged steel, contact the Engineer to determine the appropriate size, number, and spacing of the bolts.

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

Suggested Procedure

Steel Pile Strengthening by Splicing

1. Clean damaged pile.
2. Locate extreme limits of deteriorated section.
3. Channel section should be 18 inches longer than the distance between these limits.
4. Thoroughly 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 13.55.

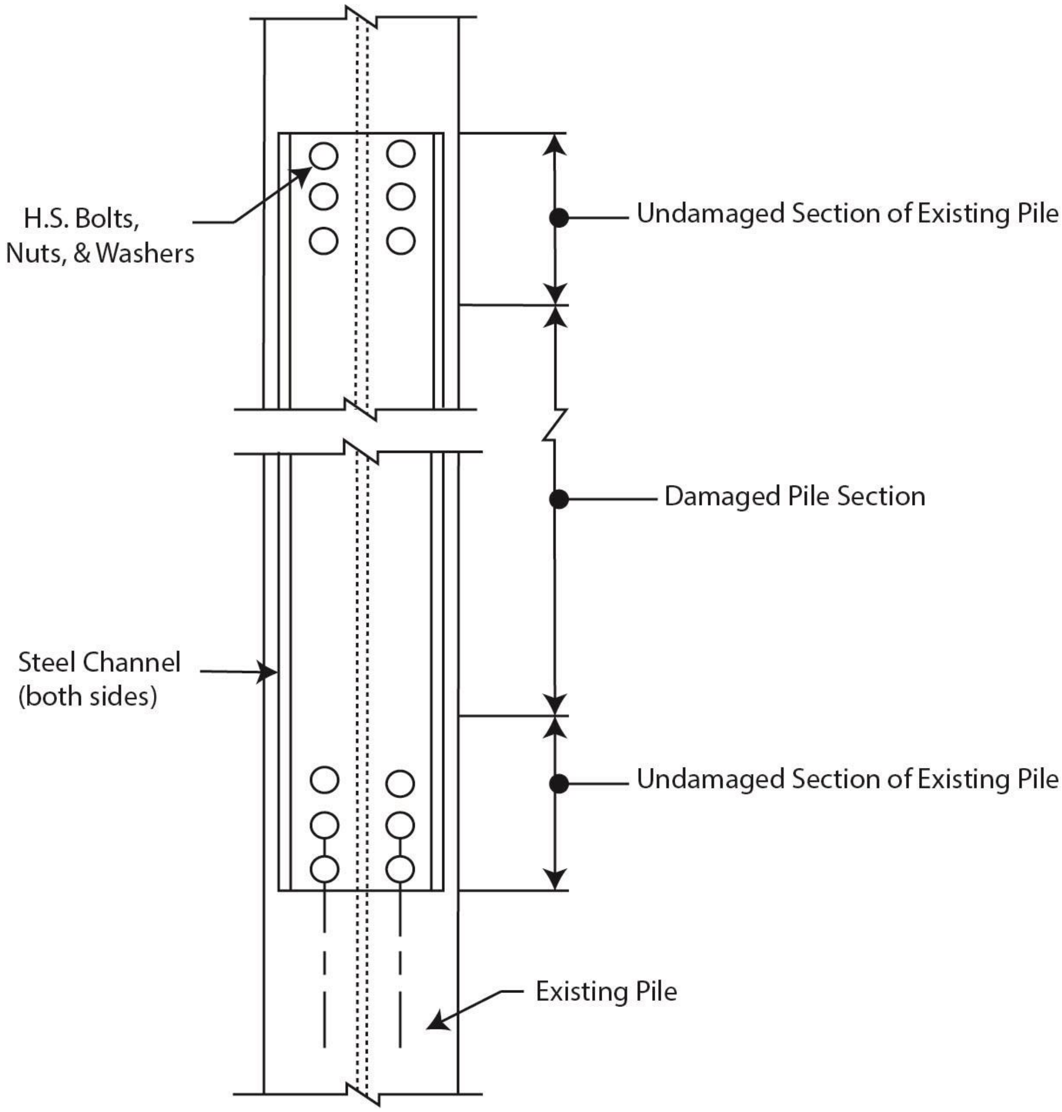


Figure 13.55 Steel Pile Strengthening

13.5.4 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 13.56 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.

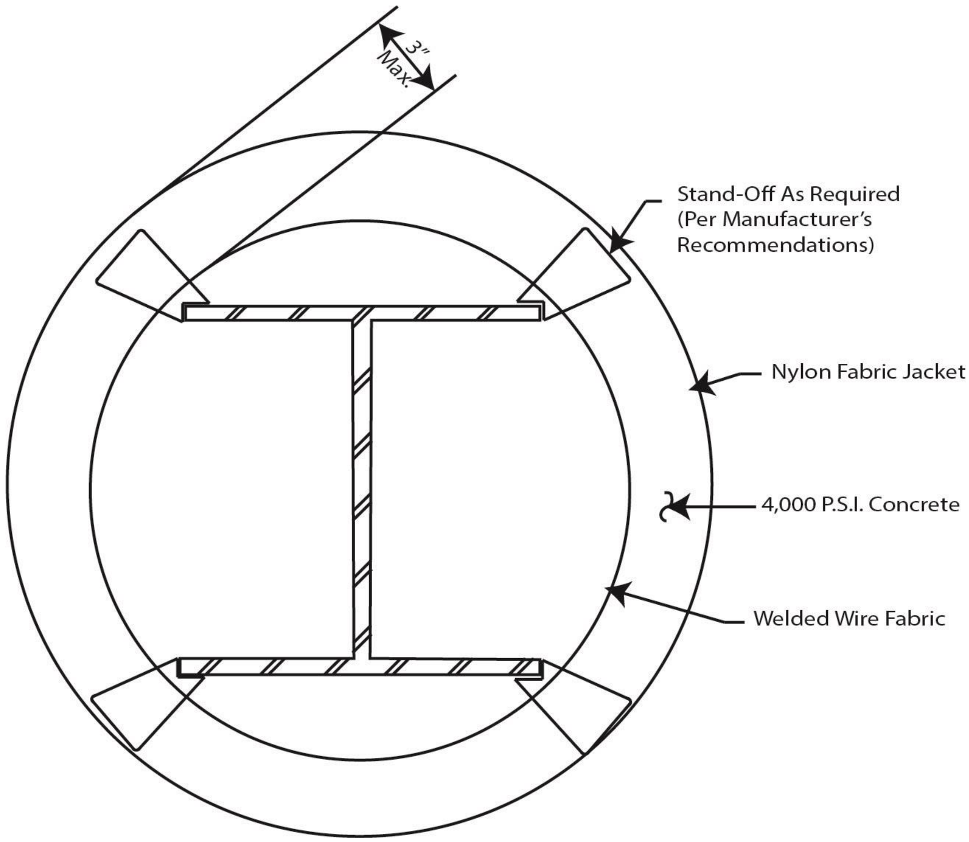


Figure 13.56 Flexible Formed Pile Jacket

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 and below 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.

Suggested Procedure

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 the 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 to 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 13.57.

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.

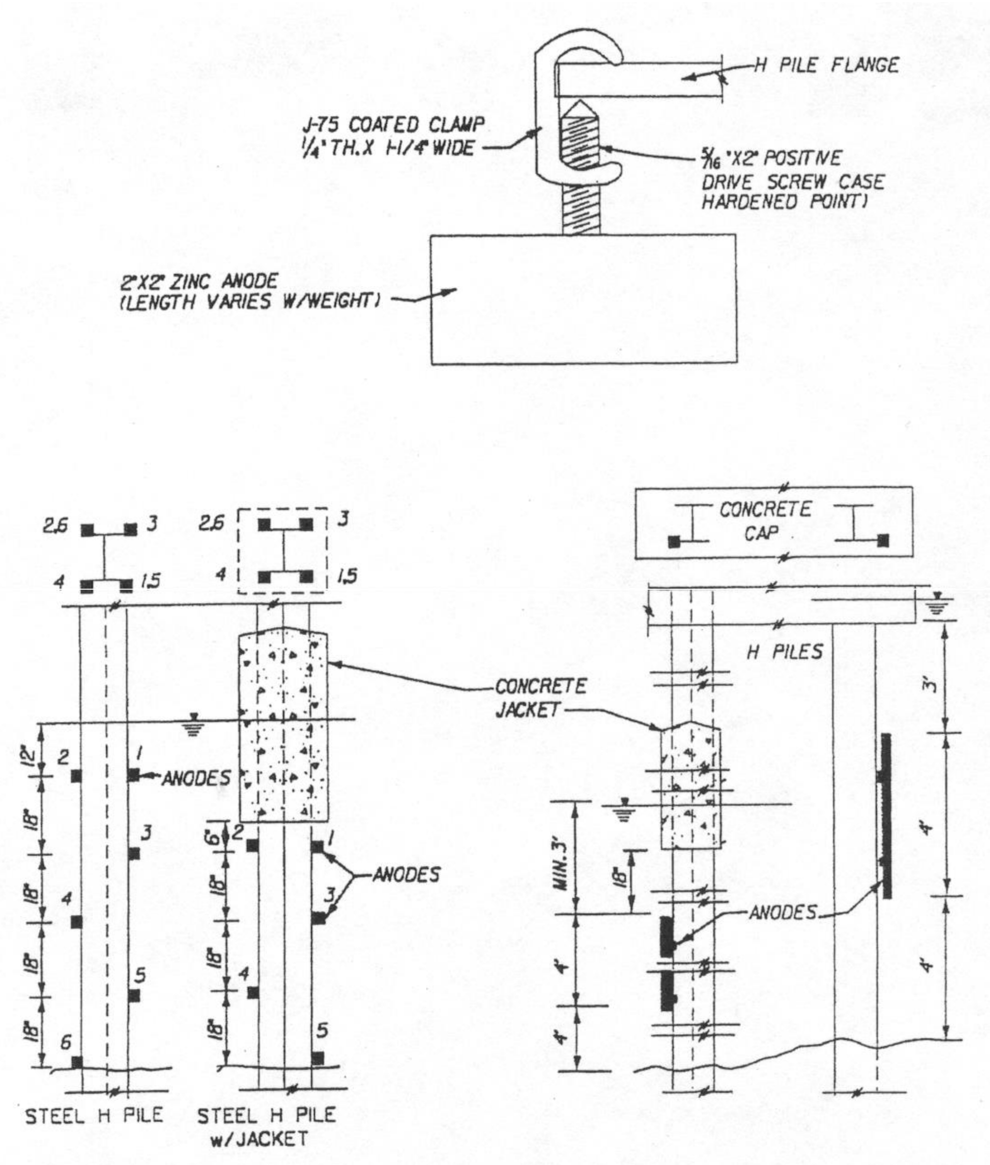


Figure 13.57 Corrosion Protection of H Pile by Zinc Anodes

13.5.5 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.

13.5.6 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 13.58.

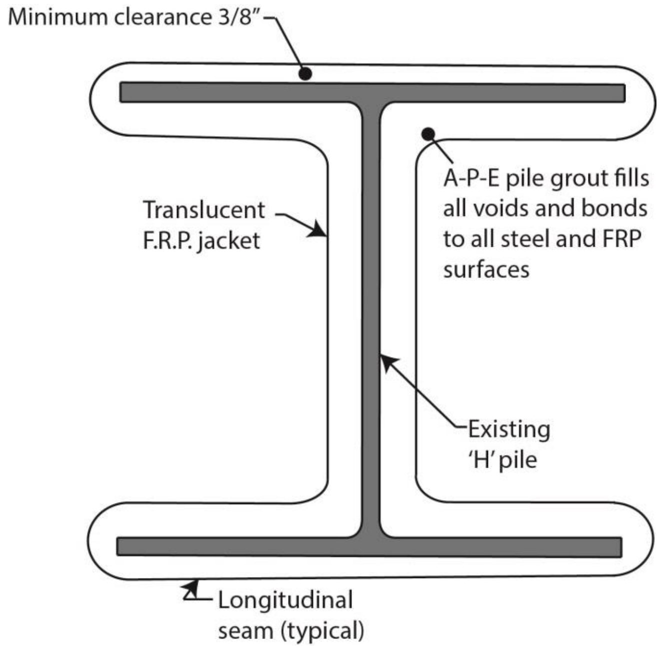


Figure 13.58 FRP Jacket for Strengthening Steel Piles

13.6 Repair and Rehabilitation of Timber Substructures

A review of the causes of deterioration in timber members should be conducted before starting the repair operation. Otherwise, new timber members will be exposed to the same conditions that caused the original problems. The conditions should be evaluated and steps taken to prevent the same damage from occurring to the new member. The new member should be treated with preservative when an extended service life is required. Adjacent and contacting members should also be treated with preservative when an extended service life is required. And all adjacent and contacting members should be checked for possible decay infections. Such areas, if confirmed or questionable, should be replaced, treated in place, or the new member protected from them.

The repair or replacement of timber caps on either abutments or intermediate timber bents is a common repair procedure in the maintenance of timber substructures.

The conditions which result in a cap failure can be decay from a buildup of dirt on the cap. But, in a surprising number of instances, the cap fails as the abutment transfers earth pressure into the superstructure. This can be first observed as a twisting of the end of the cap. Many times this is mis-diagnosed as merely warping and twisting of the timber cap. Unfortunately, what is happening is that the cap is being restrained at the top by the superstructure and is being subjected to a large lateral load at the bottom of the cap by the piling. The pilings are being pushed by the earth pressure behind the abutment. As the cap starts to twist from these opposite forces it will start to crack. This will let moisture into the center of the member and decay will follow.

When inadequate residual strength remains in a member, replacement or reinforcement is necessary. This can be accomplished by replacing the entire member, replacing a portion of the member, or adding a sister member or reinforcing element to carry the load. Obviously, these operations require a thorough structural evaluation to ensure the bridge is properly supported during the repair or rehabilitation procedures and that the new elements are adequate.

It may be more practical to remove only the defective part of a member. In such cases, the recommendations above for replacing the member also apply. Additionally, it is important to remove an adequate length of the defective member to ensure elimination of the source of the problem. The undetectable extensions of the infection fungi may reach 6 to 12 inches in the grain direction beyond the apparent limits of decay. A safe rule in removing decayed parts of members is to include visible decay plus an additional 2 feet of the adjacent wood in the grain direction. All newly exposed, cut-off timber faces should be treated with a wood preservative.

The decayed top of a wood bearing pile can be repaired by cutting off the damaged portion and fumigating the exposed cut-off to destroy any remaining affected material. A section of sound timber is installed and secured with epoxy cement or drift pins and fish plates to build the pile to the proper height. An example of pile top replacement is shown in Figure 13.59.

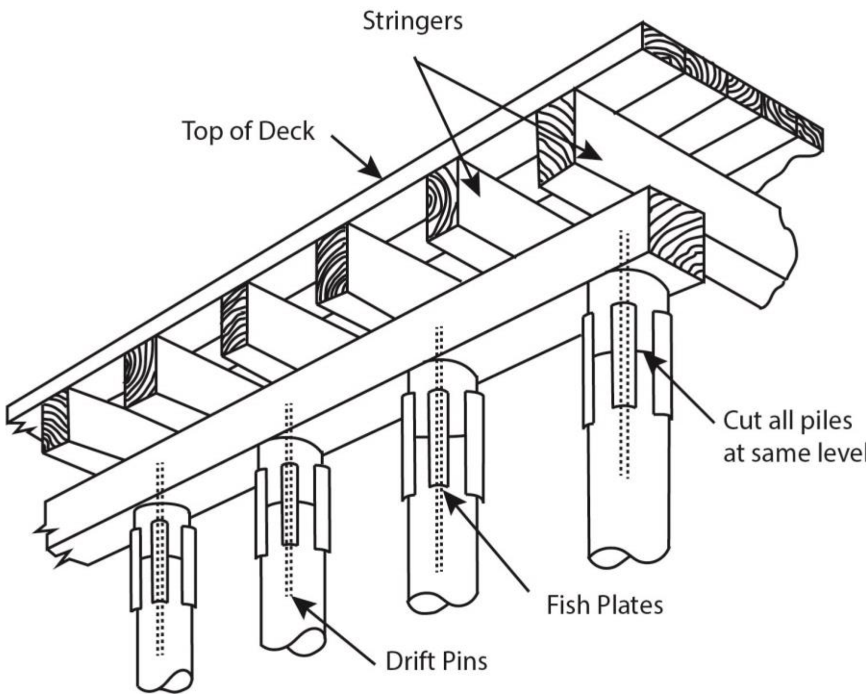


Figure 13.59 Replacing Tops of Piles

13.6.1 Jacketing

Jacketing is a common preventive maintenance technique for timber piles that can also be used in the repair of moderately damaged piles. In general, the equipment and techniques for jacketing timber piles is similar to jacketing concrete or metal piles.

A jacket is placed around the pile as shown in Figure 13.60. Reinforcing steel is placed and the jacket is filled with concrete. The reinforced concrete acts to increase the pile strength if designed properly.

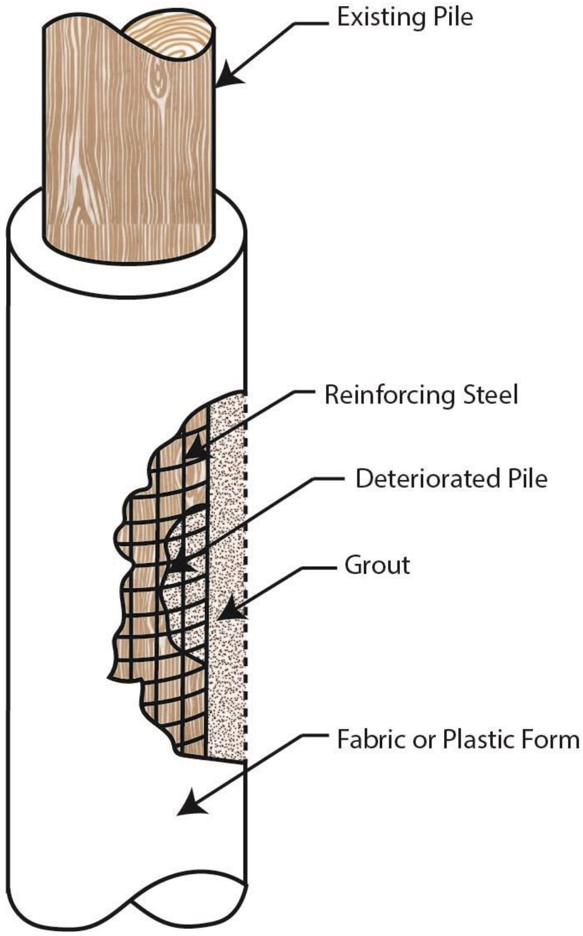


Figure 13.60 Timber Pile Jacketing

13.6.2 Scabbing and Splicing

Timber repairs usually involve the addition of steel or wood to strengthen deficient members. Scabbing refers to techniques to add effective section to reinforce deteriorated or deficient timber bridge members. The material, steel or timber, is generally attached by bolts to the defective area to transfer a load around that defective member over a substantial length. Splicing refers to similar techniques for repair over a shorter length. Details are shown in Figure 13.61.

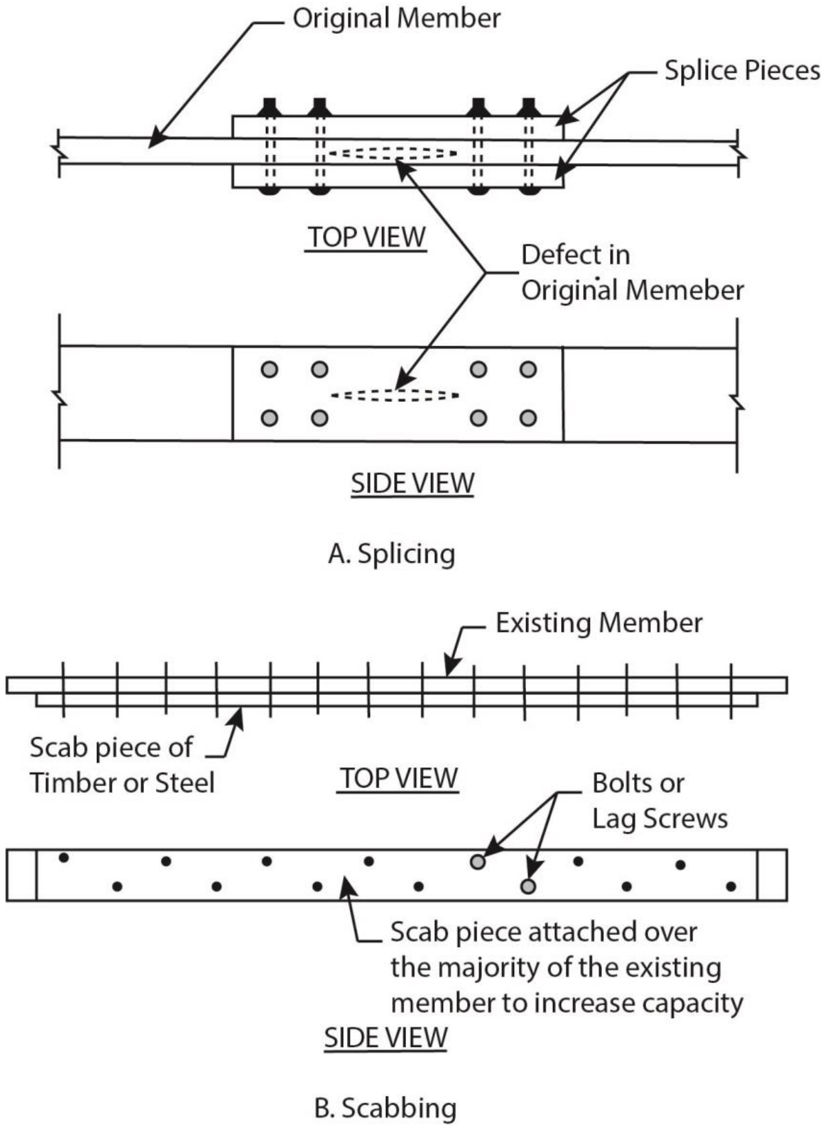


Figure 13.61 A. Splicing (top) and B. Scabbing (bottom)

13.6.3 Clamping and Stitching

Clamping and stitching are used to correct longitudinal splits that form in timber. The purpose of this maintenance operation is not to close the split or check, but rather to prevent further development by drawing the two parts together. Examples of clamping and stitching are shown in Figure 13.62.

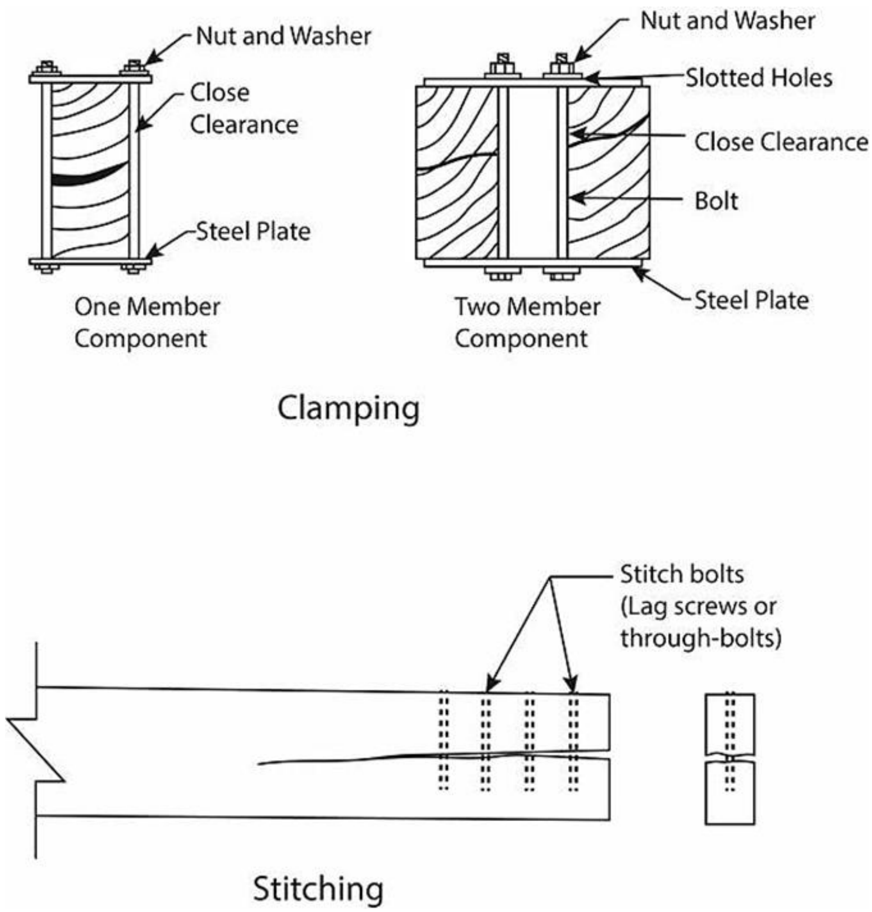


Figure 13.62 Clamping (top) and Stitching (bottom)

In clamping, plates are placed on the narrow cross sectional sides of the member. External bolts draw the plates together, clamping the member. Clamping has the advantage over stitching in that the cross section of the member is not reduced. An example of clamping is shown in Figure 13.63.

Figure 13.63 Repair to Split Timber Pile Using Steel Clamps (Courtesy of Washington DOT)

Stitching consists of placing stitch bolts which can either be lag screws or through bolts through a member spanning the split. As the screw or bolt is drawn tight, the split is drawn together.

Bolts should only be tightened to a point where they take tension. Stitch bolts should be no larger than the maximum nut size permitted in the structural grade.

13.6.4 Timber Cap Repair and Replacement

The need to increase the load capacity of a bridge may arise due to improper sizes or defects in a particular member. An example is wood pier caps that have developed large lengthwise shrinkage cracks or many splits in the vicinity of bolt fasteners. A structural analysis may indicate such caps rate significantly lower than other members because of such defects.

Provided the original cap is still in good structural condition and no decay is evident, strengthening the cap is often easier and cheaper than replacement. In some cases replacement may be very difficult due to access limitations or other factors and strengthening is the only logical alternative.

During the preliminary planning stage, necessary procedures should be determined. These procedures should be based on assurances that the existing cap and columns are in good condition and a determination the required new section will meet the needs.

In the following procedure for timber cap strengthening, the new members will help to support live load only, since the original cap remains in place to carry the dead load.

The resources which will be needed should be ascertained. They may include:

- Access to pile cap
- Light lifting equipment
- Wrenches
- Heavy duty drilling equipment
- Small hand tools

Suggested Procedure

Timber Cap Strengthening

1. Construct scaffolding, as required, around existing bent.
2. If pile diameter is wider than existing cap, notch existing piles or columns to accommodate new timber cap members.
3. Place new members snug against existing cap and stringers; temporarily clamp in place.
4. Drill bolt holes 1/16 inch larger than the bolts being used.
5. Place bolts, tighten, and remove clamps.
6. Remove scaffolding.

A schematic for timber cap strengthening is shown in Figure 13.64.

When to Call the Engineer

Call the Engineer to determine size, number, and spacing of bolts when attaching new cap strengthening timbers.

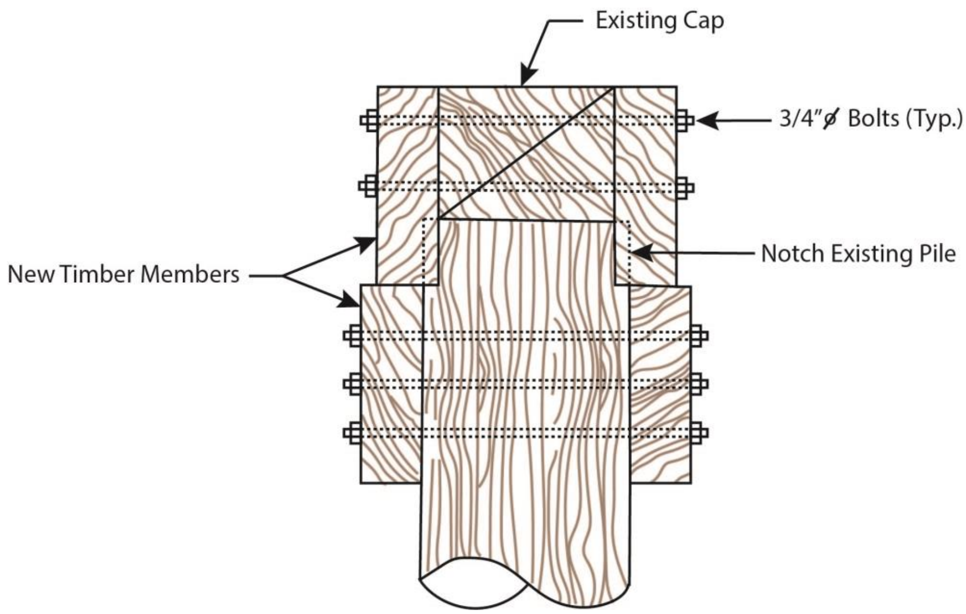


Figure 13.64 Timber Cap Strengthening

Decay on the bearing ends of timber stringers can be repaired by increasing the width of bearing provided by the cap. This decay is generally the result of dirt allowed to build up on the cap between the stringers.

Suggested Procedure

Scabbing Timber Cap to Increase Bearing Area

1. Scab a 6 inch by 12 inch to each side of an existing timber cap using split ring connectors and bolts.
2. The existing cap must be sound timber.
3. Raise the scab members into position and clamp to cap or use bolts to temporarily hold in position.
4. Drill through the scabs and the cap.
5. Remove the scab members and cut grooves for the split rings.
6. Put the scab members back into place and place bolts and washers to complete the repair.
7. The primary resistance to the imposed load is the split-rings.

An example of a scabbed timber cap with split rings is shown in Figure 13.65.

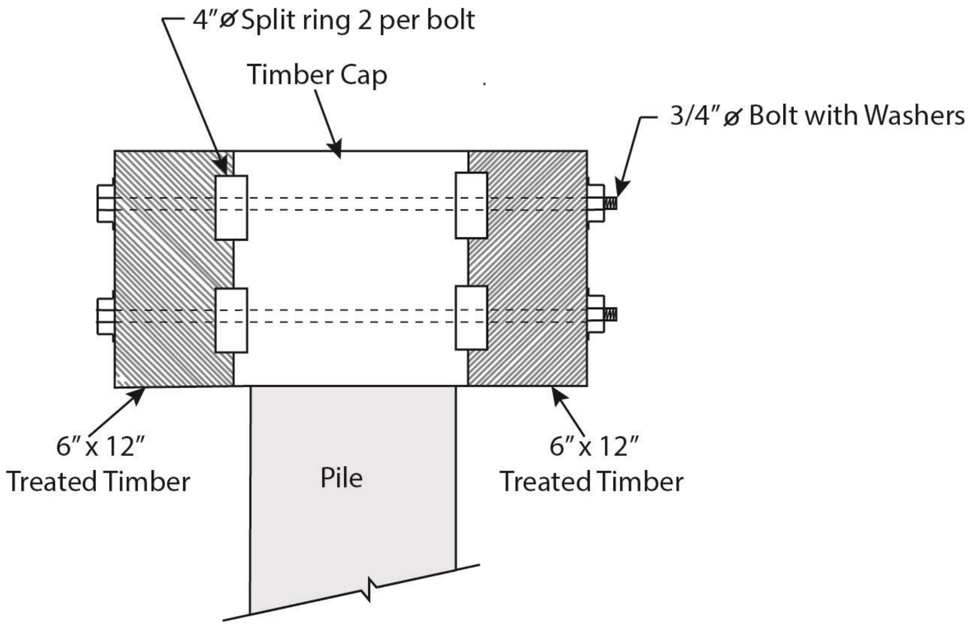
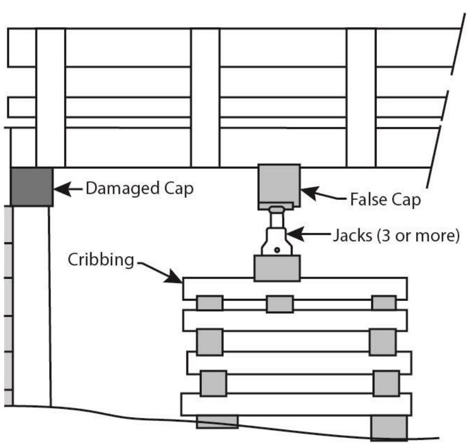


Figure 13.65 Scabbed Timber Cap with Split Rings

There are two different methods to be used for removing load from the existing cap. These are jacking from cribbing and jacking from the bent piles.

For replacement of abutment caps, place cribbing in front of the abutment, leaving room for the removal of the old cap and replacement of the new cap, as shown in Figure 13.66. For timber spans use a false cap to jack against. Spans with steel stringers jack against the bottom flange of the beams. Jack up the span about 1 to 2 inches. Cut off the drift pins connecting the cap to the piles. Slide the old cap off the piling and move the new cap into position. Lower the jacks. Connect the cap to the piles with steel straps and drift pins.



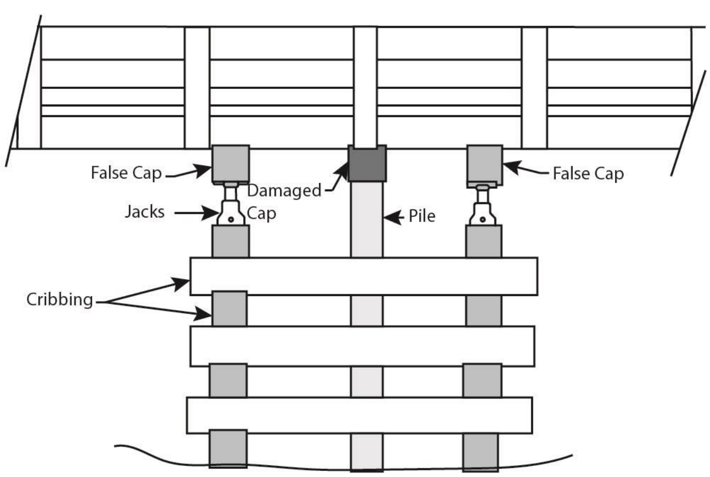


Figure 13.66 Jacking at Abutment (left) and at Pile Bents (right) using Cribbing

Timber Cap Replacement

A common maintenance problem with pile caps is decay followed by longitudinal cracks and crushing caused by the load on the cap. The pile cap must be replaced when any of these problems arise. The superstructure is jacked from both sides of the existing structure or from a temporary bent. The decayed cap is removed and a new cap is secured in position. Figure 13.67 shows an example of jacking the superstructure so that a deteriorated timber cap can be replaced.

Figure 13.67 Timber Cap Replacement (Courtesy of Virginia DOT)

To avoid future decay, timber pile caps that have deteriorated may be replaced by steel beam caps. Stiffeners may be welded between the flanges directly over the piling. The steel cap is secured to the piling with a piece of flat stock bent to encircle the top of the pile and welded to the bottom of the cap. A schematic example of a steel replacement cap for a timber pile is shown in **Figure** 13**.**68.

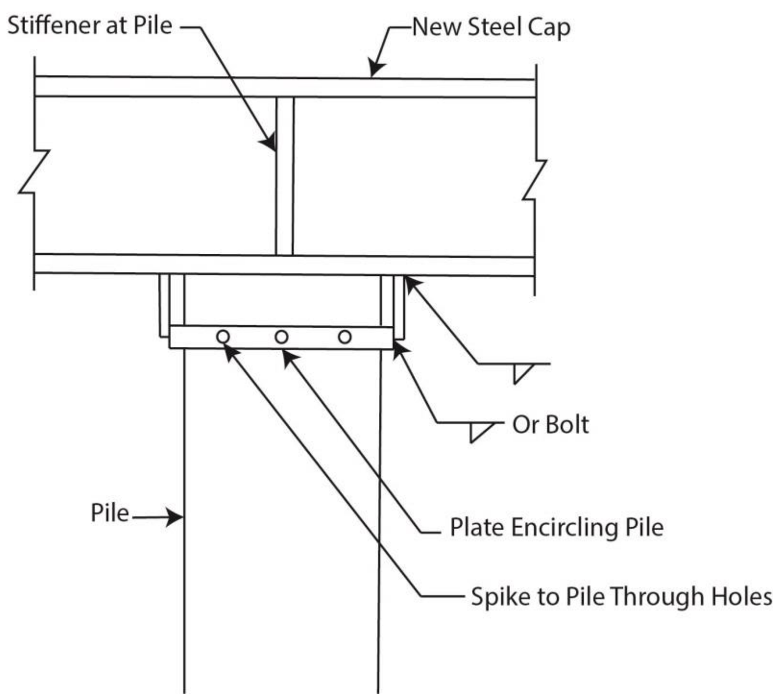


Figure 13.68 Steel Replacement Cap for Timber Pile

Figure 13.69 shows the steel cladding used to repair a deteriorated timber cap. The entire load is carried by the steel once the repair is completed. The existing cap is raised up about 1/2 inch. Steel angles are placed between the pile top and the cap. The modular sections of the cladding are put up and bolted together at the midpoint between piles. When the members are assembled, straps are welded above and below the cap. A cross member is welded between the support angles and a vertical strap with holes predrilled is welded to the strap. Lag screws attach the strap to the timber post.

Figure 13.69 Steel Cladding Used to Repair Deteriorated Timber Cap (Courtesy of Washington DOT)

When replacing a timber cap, it is important not to overload any single pile during the jacking process. The photo in Figure 13.70 shows the use of pile jack stands used to lift the timber caps off the piles. The jack stands are clamped to the piling. The stands have the advantage of not damaging the piles and can lift a span that is over water or on a steep hillside. In the position shown the jacks are positioned so the ears that stick out from the jack stands are under the cap. Force can then be applied to raise the cap enough to either insert angles between the cap and pile for the steel cladding on the cap, or cut off the drift pins before removal of the deteriorated cap. After the drift pins are cut, the jack stands can be loosened and rotated 90 degrees and then retightened against the piles. Steel jack beams can be located up against the timber stringers (beams), and over the ears of the projections from the jack stands. Jacks can then be placed and the superstructure lifted off of the cap. The deteriorated cap can then be removed and replaced.

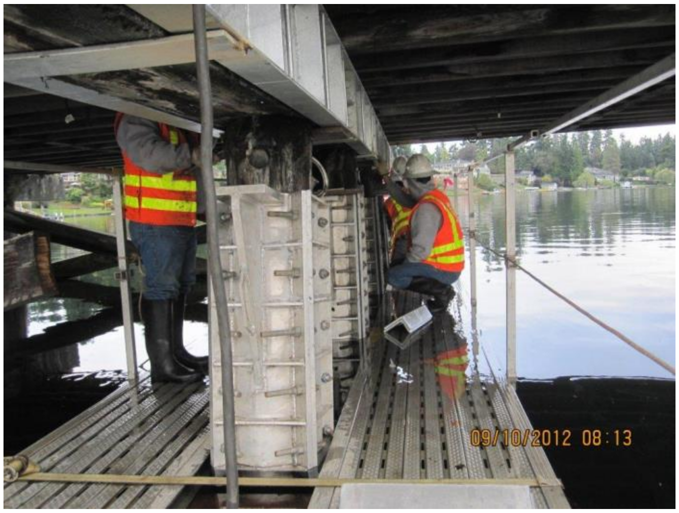


Figure 13.70 Use of Jack Stands to Ensure Adequate Load Transfer for Pile Splices (Courtesy of Washington DOT)

13.6.5 Post Splicing

The service life of deteriorated marine wood piles can be prolonged in some instances by repairing the piles. Repair methods include encasing the damaged wood pile with some type of jacket or sheeting (e.g., plastic, steel, or concrete) or removing the damaged portion and replacing it with a new piece that is spliced with the old wood pile. For example, damaged creosote-treated wood piles can be repaired using a wire-mesh reinforced shotcrete jacket, as shown Figure 13.60. Ground repair of wood poles involves screwing a metal sleeve around the base of the pole and filling the space between the sleeve and the pole with aggregates and resin as discussed earlier in Section 13.3.3.

The preliminary planning for post splicing includes:

- Determine extent of pile damage
- Design and fabricate pile steel splice sleeve
- Prepare to keep traffic off side of bridge being repaired
- Interacting with engineer as to extent of cutting and splicing

The resource requirements include:

- Timber cutting and drilling equipment
- Light lifting equipment
- Staging of traffic to reduce load over repair area

Suggested Procedure

Post-Splicing Timber Pile Repair

1. Move traffic from side of bridge being repaired.
2. Remove cross bracing as necessary to install new pile.
3. Install supplemental member to support cap.
4. Remove deteriorated portion of existing pile, cutting end off level. If the deterioration is due to rot, treat the raw end of the pile to be left in place with a fumigant. Fumigants come in a paste that can be applied to the raw wood. It would also be good to drill in and place solid fumigants according to the manufacturer specifications 6 to 8 feet along the pile to be left in place. The raw end of the pile should be covered with waterproof material after the paste fumigant is applied.
5. Install new treated timber pile and pile-splice sleeve.
6. Drive shims or other method to ensure load transfer.
7. Re-install cross bracing.
8. Restore traffic.

A schematic of timber pile repair by post-splicing is shown in Figure 13.71, and an elevation view photo is presented in Figure 13.72.

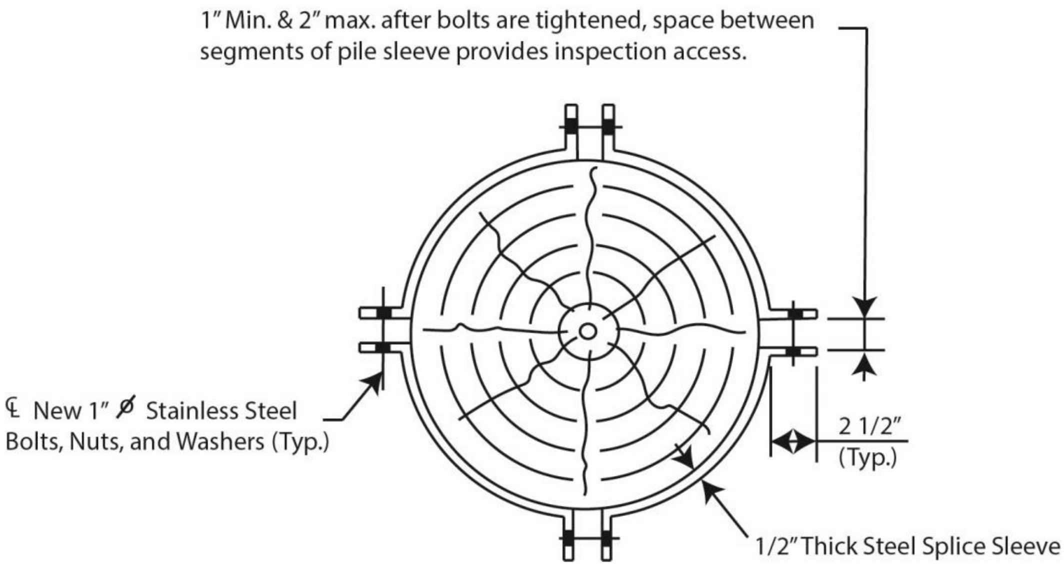


Figure 13.71 Timber Pile Repair Schematic

Figure 13.72 Timber Pile Repair - Elevation View (Courtesy of Washington DOT)

When the portion below the ground is still sound, treated timber piles that have decayed or have been damaged by fire or impact can be repaired without the need for driving a new pile.

Suggested Procedure

Treated Timber Pile Repair Procedure (Sound Pile Below Ground)

1. After the required auxiliary support is in place, the old pile is cut off below the decayed or damaged area.
2. A new section of pile is cut about 6 inches shorter than the section removed. Plates are placed on top of the pile in place and on the bottom of the new section of piling. A drift pin can be used to keep the plate from sliding off the existing pile.
3. A 3/4-inch bolt with a nut is welded to the bottom plate and extends through a hole in the top plate. By adjusting the nut on the bolt, the new section of pile can be raised until it is securely seated against the bent cap. Care must be taken to raise the new section of piling far enough to secure the piling that receives the loading from the bent cap.
4. After the new section is in place, 1/4-inch thick angles are welded between the plates at each corner.
5. Used girder plates or flat stock are then bolted to the timber pile and extend down on the original pile about 12 inches. The top of the pile is secured to the bent cap using straps.
6. A 3 by 3 by 2 foot block of dense concrete is poured around the pile.
7. Any falsework may be removed after the concrete is poured and cured.

Timber pilings that have decayed, been weakened by insects or marine organisms, or been structurally damaged by collision or overloading may be replaced by steel columns

The following items should be considered as part of the planning process when replacing timber pilings with steel columns:

- Condition of existing piles below surface and existing cap

- Need for cofferdam to dewater work area
- Method of temporary support for superstructure during repairs
- Provisions to restrict traffic from work area during repairs

The equipment and tools needed are as follows:

- Wood cutting tools
- Light lifting equipment
- Welding and steel cutting equipment
- Wrenches and other small hand tools

Suggested Procedure

Timber Pile Replacement with Steel Column

1. Determine all cutoff points on the existing piles and the column length needed for the repair.
2. Construct temporary support for the superstructure before beginning the repair.
3. Construct cofferdam, if necessary, and dewater.
4. Excavate so that the top of the new footing will be a minimum of approximately 9 inches below the ground line.
5. Cut existing piles off so that they will project at least 12 inches into the new footing.
6. Separate the old sections of piling from the pier cap.
7. Form and pour concrete footings over the existing pile stubs.
8. Place the anchor bolts in the footing concrete prior to initial set.
9. Cut the steel columns to the proper length and weld on the base plates.
10. Provide load transfer through shimming or other methods.
11. After concrete has reached required strength, attach new steel columns to footings with nuts and washers.
12. Attach the top of the new columns to the existing pier caps with lag screws.
13. Remove all temporary supports, backfill where necessary, and remove the cofferdam if one was used.

A schematic showing replacement of timber piles with steel columns is shown in Figure 13.73.

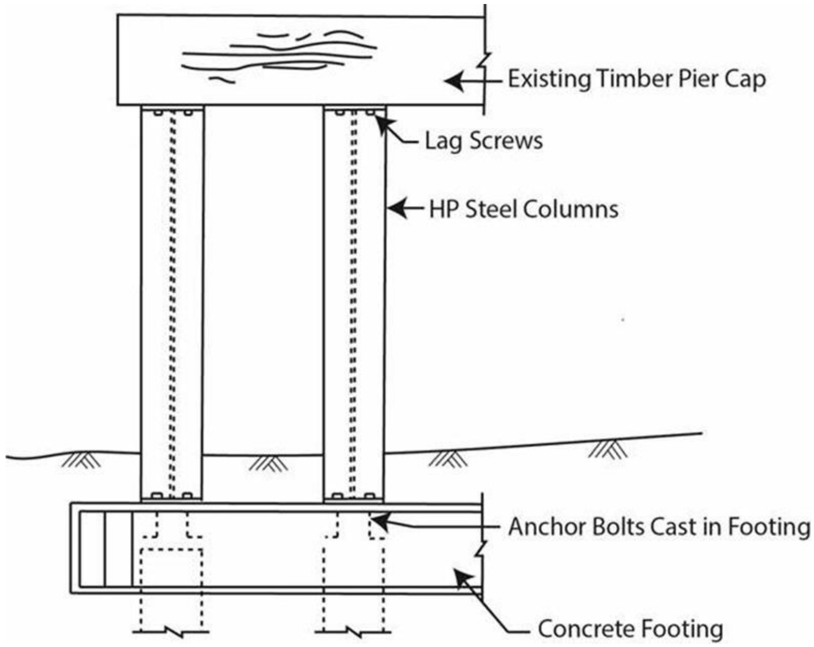


Figure 13.73 Timber Piles Replaced with Steel Columns

When using a post splice repair method a challenge can be to restore the load in the pile when a new piece is spliced into place. It can be as simple as shimming the pile to ensure adequate bearing but load transfer might not fully occur.

The construction procedure for the proper shimming between pile top and cap is not well understood by many repair crews. There is a misunderstanding that when shims are used the surfaces of the pile tops are cut to match the bevel of the wedge. This is not correct. The correct construction procedure requires the use of sets of “matching wedges”, as shown in Figure 13.74. The wedges should be cut from good structural timber such as Douglas Fir. They should be pressure treated with copper naphthenate after cutting. The repair of bridges requires some forethought to have the right parts for repair. Having several different sizes of wedges available prior to starting the bridge work is advisable.

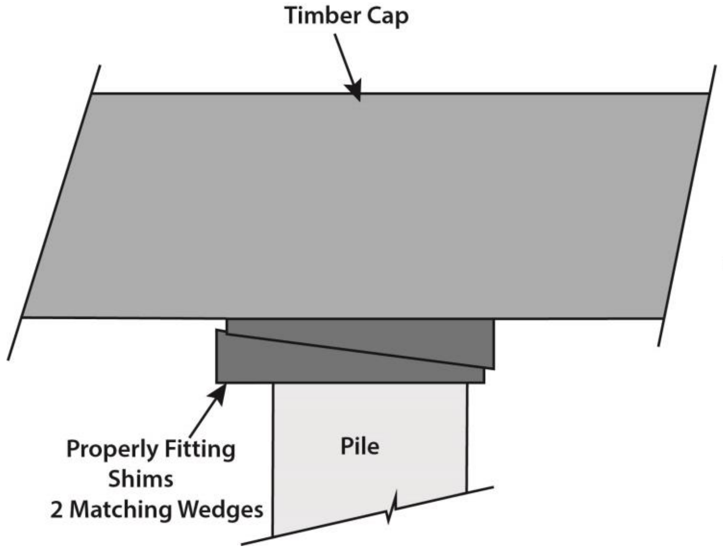


Figure 13.74 Matching Wedges for Uniform Bearing

With wedges you cannot be sure if the load has been restored to the pile or if you are overloading the pile. Wedges can also work loose over time. An alternative to wedges is jacking boxes.

Some bridge owners have developed in-place jacking boxes when replacing a timber pile with steel. Figure 13.75 shows a photo of two piles that were replaced with steel. The right pile has the jack box at the top of the pile. The left pile shows the jack box just above the pier protection. After the pile is in position a hydraulic jack is placed in the jack box. The force on the pile is then jacked to the as built pile load. The gap between the two halves of the jack box is measured and plates cut to that dimension. The plates are then welded into place. The welds and plates are then touched up with galvanic spray paint.

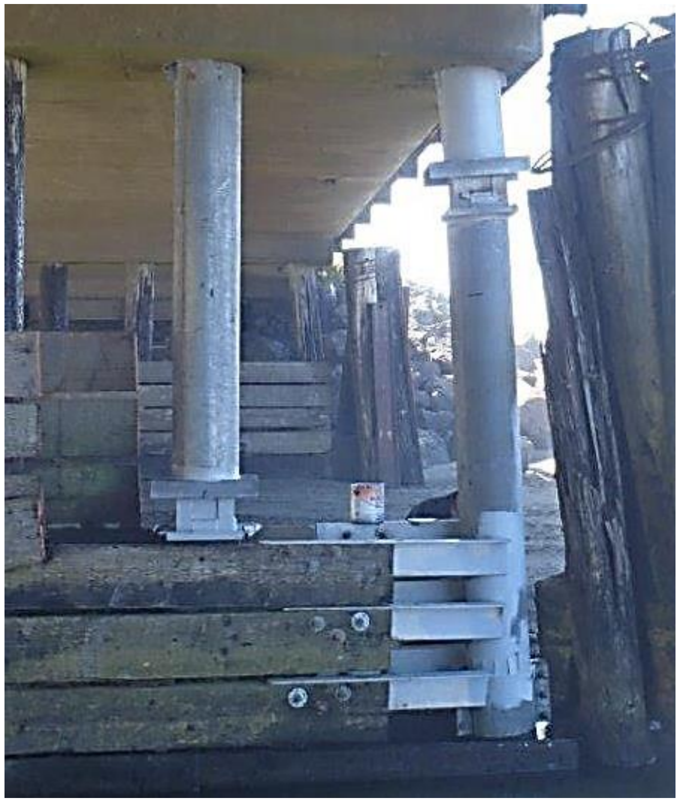


Figure 13.75 Two Steel Pile Replacements showing Alternate Jack Box Locations

The spliced pile can be loaded to design requirements, welded into place, and welded areas sprayed with a cold galvanic paint for corrosion protection.

The timber splice method previously described is not to be used when replacing piling in the abutments or end bents, because it will not provide sufficient resistance to the overturning moment produced by the force of the fill against the back wall.

Suggested Procedure

Abutment Pile Top Repair

1. Place falsework.
2. Cut the pile off below the decayed or damaged area.
3. A cylindrical steel pile shell, long enough to extend from the bottom of the cap down about 2 feet on the remaining pile, is split lengthwise and placed around the pile.
4. After the steel shell pile is pulled tight around the pile and welded, it is filled with concrete.
5. The falsework may be removed after the concrete has set.

When to Call the Engineer

Call the Engineer to determine the maximum section length that can be cut off when performing an abutment pile top repair.

Where it is not practical to repair the piling as described above, a new section of pile can be spliced to the old section using steel pipe or a band to hold the two butt ends together.

When timber pile abutments are pushed forward by the retained fill so that the pile cap is rotating, it indicates that the pile stays are broken or the abutment was constructed without stays. Abutments that are too high can also cause this problem. This defect is corrected by the following procedure:

Suggested Procedure

Installation or Repair of Pile Stays

1. Remove all soil from behind the abutment.
2. Pull the piles and caps back into position.
3. Repair or install pile stays.
4. Bury or drive deadmen behind the abutment and fasten and tighten cables, of the size specified by an engineer, to the piles with eyebolts. See “settlement repairs” above for deadman installation.

An existing substructure unit that is not capable of supporting the required load may be augmented with a timber helper bent. One example is a concrete bridge pier in which the seat damage is so deteriorated that the bearings are affected and the beams may lose bearing support. In this case, a timber helper bent adjacent to the pier would support the load and preclude bridge failure, if bearing failure did occur. The timber helper may also be used to reduce the span length and increase bridge capacity in a situation when the beams are weakened or were not designed for current loads.

When to Call the Engineer

Call the Engineer to determine size and location of the helper bent.

A structural engineer should determine the size and location of the helper bent, whether the bridge can support a pile driving rig, or if the equipment can be located off the deck. A hydraulic engineer should determine if the additional restriction is acceptable. And provisions should be made to maintain traffic safely away from work area.

The following equipment may be needed:

- Pile driving equipment

- Deck cutting equipment
- Lifting equipment
- Scaffolding, if necessary

Suggested Procedure

Helper Bent Installation

1. Locate piles so that the deck beams will not interfere with driving.
2. Cut holes in only one lane of traffic at a time.
3. For timber deck, remove sufficient amount of timber decking to permit pile to go through hole. For reinforced concrete deck, remove sufficient amount of concrete in a square pattern to permit pile to go through hole. Cut reinforcing steel at center of hole and bend back out of way of pile.
4. Set piling and drive to required bearing.
5. Cut off piling approximately 1/4 inch above bottom of existing cap. If existing cap has settled, allowance must be made for grade differential.
6. Place cover plates over deck holes, open lane to traffic, and move to adjacent lane, repeating operation.
7. After all piles have been driven and cut off, jack up superstructure approximately 1/2 inch using existing pile bent.
8. Place timber cap over both rows of piling. For end bents, only one row of piles and cap is required.
9. Lower superstructure onto new caps and strap cap to piling. Shimming may be required to obtain bearing between superstructure and timber cap.
10. Remove deck plates and reconstruct deck. If deck is reinforced concrete, splice cut bars. Replace deck in one lane at a time. Concrete deck repair may be reopened to traffic if protected by steel plates.
11. Erect cross bracing on new pile bent. For intermediate bents, cross bracing between the two new bents is also required.

An example of a helper bent installation is shown in Figure 13.76.

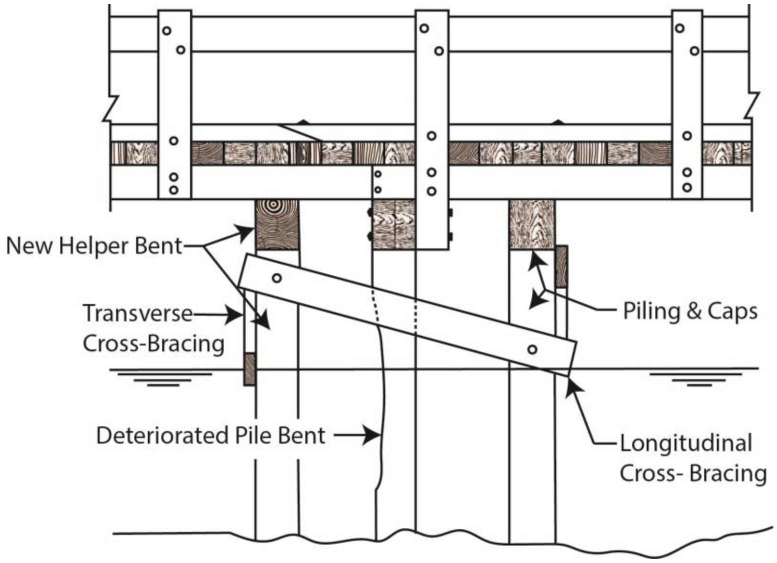


Figure 13.76 Helper Bent

Figure 13.77 shows pile driving through the deck to build a helper bent. Since piles are driven from the deck, the deck must be capable of supporting the necessary pile driving equipment. Dry land or floating pile driving rig may be used, if possible.

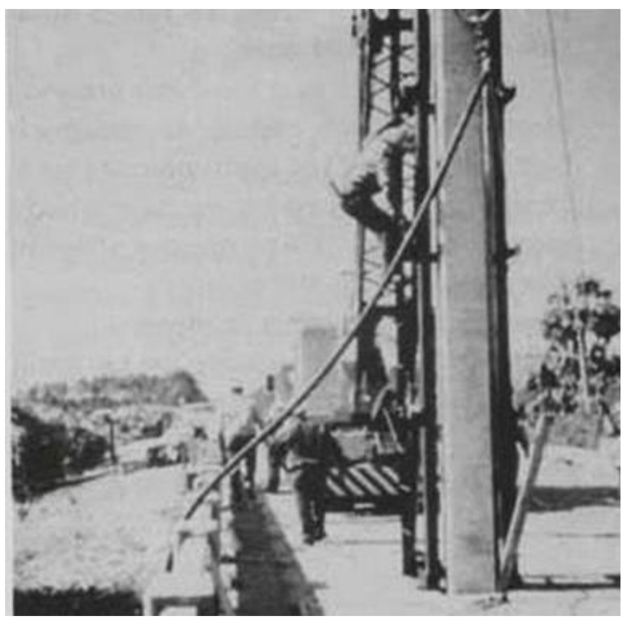


Figure 13.77 Driving Piles through Deck

13.6.6 Installation of Timber Piles

Timber piles need to be installed with special care as they are susceptible to brooming and damage. Any sudden decrease in driving resistance should be investigated since it may indicate that the pile has been split or broken. If splicing of timber piles is needed, the following guidance is recommended.

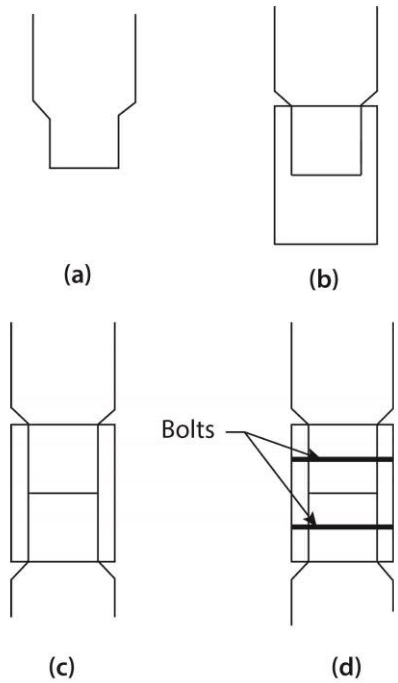


Figure 13.78 Splicing of Timber Piles

Usually, timber piles are tapered prior to splicing. The sleeve (or the pipe section) is inserted then the bottom pile is inserted. The pipe section is bolted to the piles. Sleeve joints are approximately 3 to 4 feet in length. The bending strength of the joint is much lower than the pile. Splice strength can be increased by increasing the length of the sleeve. A splice should not be installed along areas of the pile subject to high moment. This is typically at or near the ground line. An engineer can assist in calculating the bending stresses.

When to Call the Engineer

Call the Engineer to calculate bending stresses.

Precautions:

- Sleeves larger than the pile may get torn and damaged during driving and should be avoided. If this type of sleeve is to be used, the engineer should be certain that the pile sleeve is not driven through hard strata.
- Timber pile splices are extremely vulnerable to uplift (tensile) forces and should be avoided. Most timber piles are in compression, exceptions are seismic and buoyancy, or a continuous pile bent.

13.6.7 FRP Repairs

Epoxy repairs of FRP components can be classified as grouting, splicing, and pile rehabilitation. Epoxy grout is used for filling checks, splits, delaminations, and voids created by insects and decay. The epoxy prevents infiltration of water and debris. Epoxy acts to bond split sections together. Surface damage may also be repaired with epoxy gel.

Splicing involves adding pieces to span over a split or deteriorated area which are epoxy bonded in place. Epoxy is preferred over other wood adhesives because of high strength and short curing time. Epoxy bonding is not recommended for exterior use with fluctuating moisture content or for wood treated with oil type preservatives due to poor bond.

13.6.8 Pile Rehabilitation

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

13.6.8.1 Pile Posting

Pile posting involves the complete removal and replacement of a damaged section of pile with a new 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 Figure 13.79.

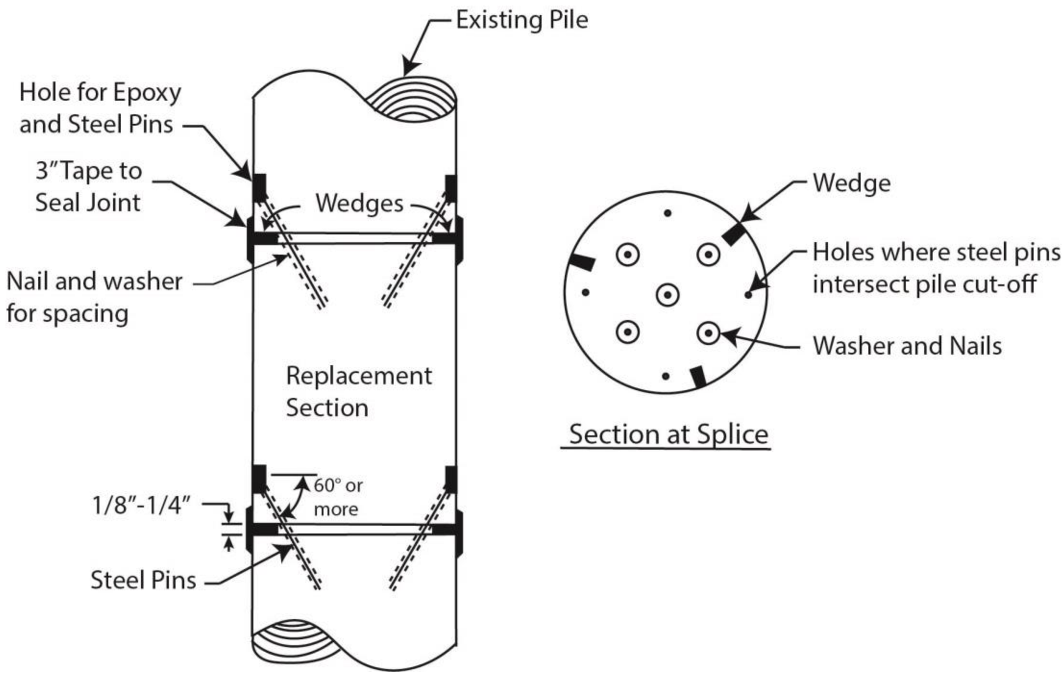


Figure 13.79 Pile Posting

13.6.8.2 Pile Restoration

Pile restoration involves the removal and replacement of a vertical wedge-shaped section of piling rather than the entire cross section. In this method the deteriorated localized section in an otherwise sound pile is removed. A similar shaped wedge is fabricated from new treated material. This replacement section is slightly smaller than the void in the existing section. Both old and new sections are covered with epoxy gel. The new section is installed and held with banding while the epoxy cures. This method is economical only where limited access prevents the use of pile posting.

The primary steps for pile wedge restoration include:

- Member preparation
- Port setting
- Joint sealing
- Epoxy injection
- Finishing

Preparation begins with removing decayed wood from a member, removing the visible decay plus an additional 2 feet of adjacent wood in the direction of the grain. This gets rid of the infecting fungi extensions. Wet wood should be dried before repairs are made. Surface that will be bonded with epoxy should be thoroughly cleaned of dirt and debris.

Ports are then installed and the epoxy is applied through one injection port at a time. As the epoxy begins to emanate through the adjacent injection port the previous port is sealed. A maximum pressure of 40 psi is recommended. Epoxy cures in a few minutes to a few hours. Injection ports may be removed and sanded or painted to meet aesthetic requirements.

The repair of wood piles with prefabricated FRP composite has a dual function of marine borer protection and structural restoration. Using prefabricated forms is environmentally friendly since no new wood preservative chemicals are introduced to the surrounding marine environment. The encasement with the FRP composite shield can reduce further leaching of chemicals from treated wood piles. Restoring structural integrity through FRP can be a cost competitive option compared to damaged pile extraction and new pile installation.

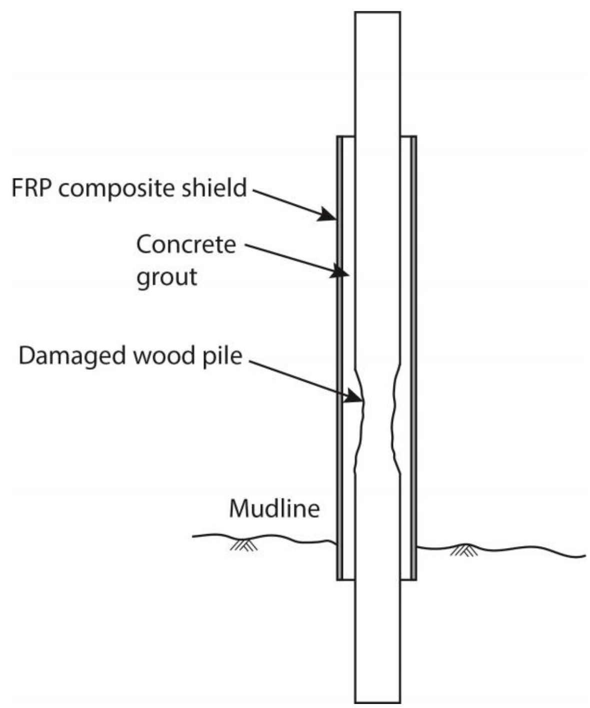


Figure 13.80 Grout-Filled FRP Composite Shield

13.7 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 workers and 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 of lifting a support column in shown in Figure 13.81.

Figure 13.81 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 13.82.
- 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.

When to Call the Engineer

Call the Engineer whenever shoring systems are going to be used.

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.

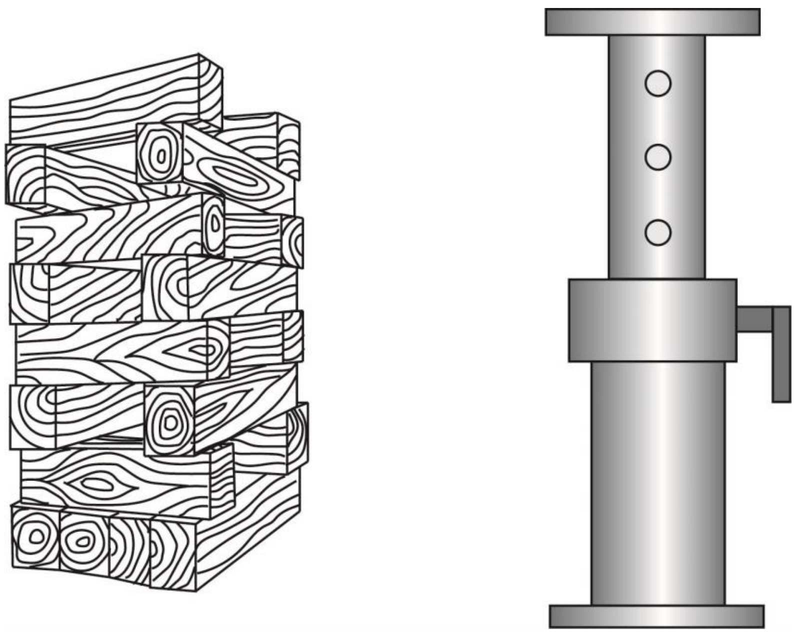


Figure 13.82 Timber Cribbing (left) and Pipe Jack (right)

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 exceeds 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 shortest dimension 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 13.83). 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.

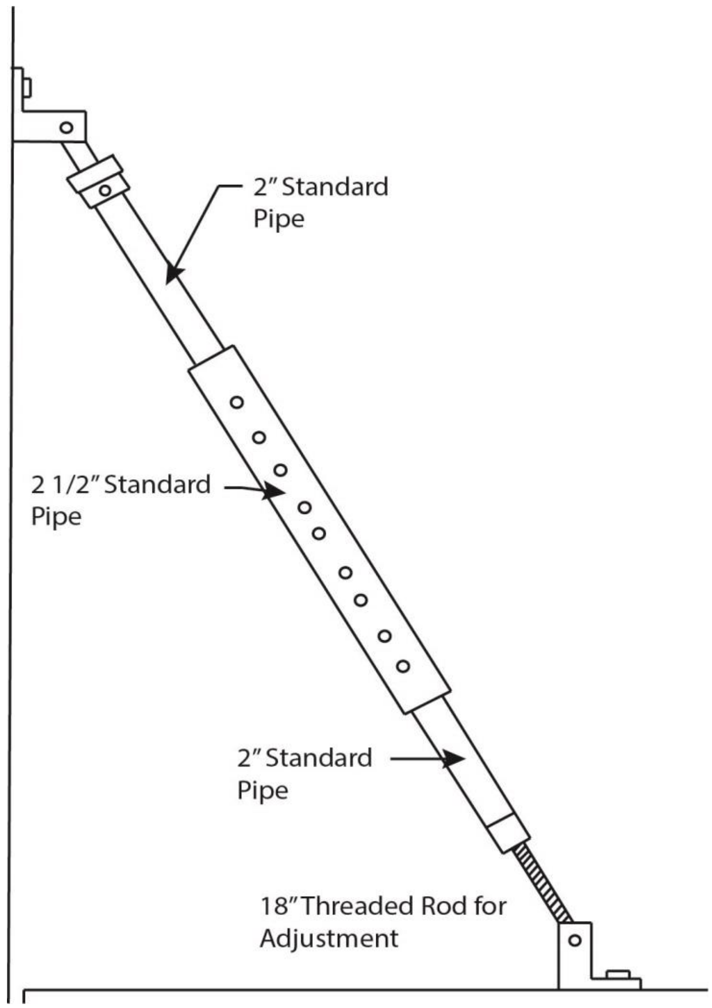


Figure 13.83 Raker Shore

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 13.84 is an example of a deteriorated concrete bent cap shored up with vertical steel bracing.

Figure 13.84 Temporary Steel Shoring used to Support Deteriorated Concrete Pier Cap

13.7.1 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.

Suggested Procedure

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.

Suggested Procedure

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 prepared 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.

13.7.2 Emergency Repairs

When the damage to a bridge is an immediate safety hazard (see example in Figure 13.85), 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 so that 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.

When to Call the Engineer

Call the Engineer when debating whether to close the bridge or merely restrict use.

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 is 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.

Figure 13.85 Problem Bridge

13.8 Maintenance of Seismic Retrofit Components

13.8.1 Introduction

Bridges in seismically active regions may have earthquake retrofit components attached to the substructure as part of a seismic retrofit strategy. The earthquake retrofit components generally provide confinement of concrete elements, limit displacement or dissipate energy during seismic events. Seismic retrofit components are typically constructed of reinforced concrete or steel, but can use innovative materials as well such as Fiber Reinforced Polymers (FRP). Much like any other concrete or steel bridge components, seismic retrofit components require typical maintenance such as painting or spall repair defined in respective chapters of this manual. Several seismic components have special maintenance needs that will be described in this section.

13.8.2 Reinforced Concrete Confinement Shells

13.8.2.1 Overview

Confinement shells are typically used on reinforced concrete columns or pier caps where there is a lack of adequate internal reinforcement to hold the concrete in place when it cracks during a seismic event. The confinement shells prevent the pieces of concrete that may crack and break off from falling away from the member leaving inadequate compressive strength, as shown in Figure 13.86. Confinement shells are typically constructed from steel or FRP, as shown in Figure 13.87 and Figure 13.88.

Figure 13.86 Inadequately Confined Column

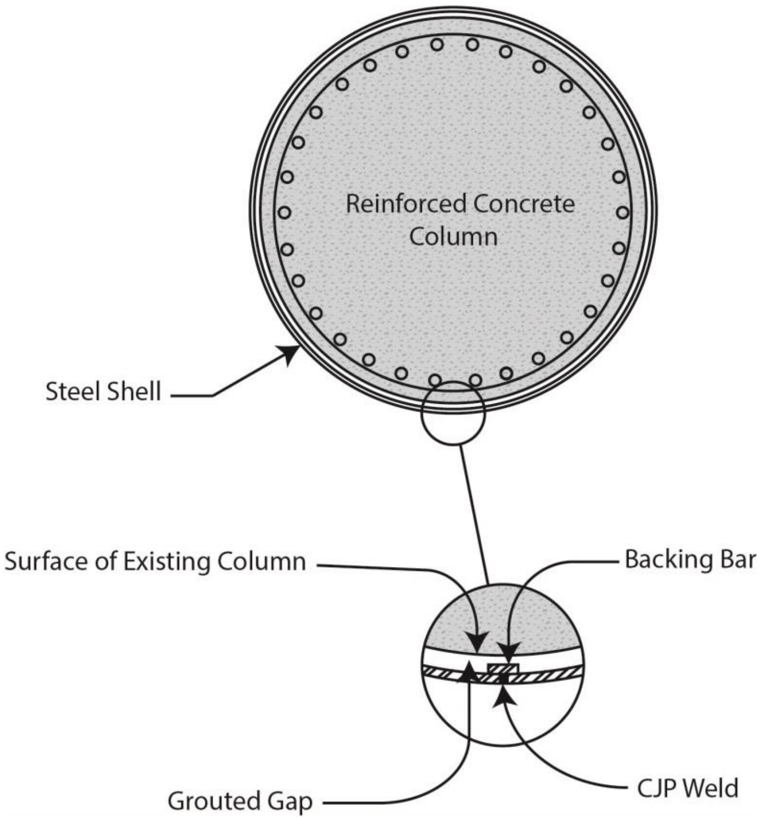


Figure 13.87 Typical Steel Column Confinement Cross Section

Figure 13.88 Fiber Reinforced Polymer Column Confinement Shells

13.8.2.2 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 material should be reported to an engineer for appropriate repair specifications and methods. This may include removal and replacement of the damaged FRP wrap.

13.8.3 Earthquake Restrainers

See Section 12.6.3 for the maintenance of earthquake restrainer cables.

13.8.4 Viscous Dampers

13.8.4.1 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 13.89. The dampers are generally connected between the bottom of the superstructure and the substructure although they can be configured in other 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 13.90.

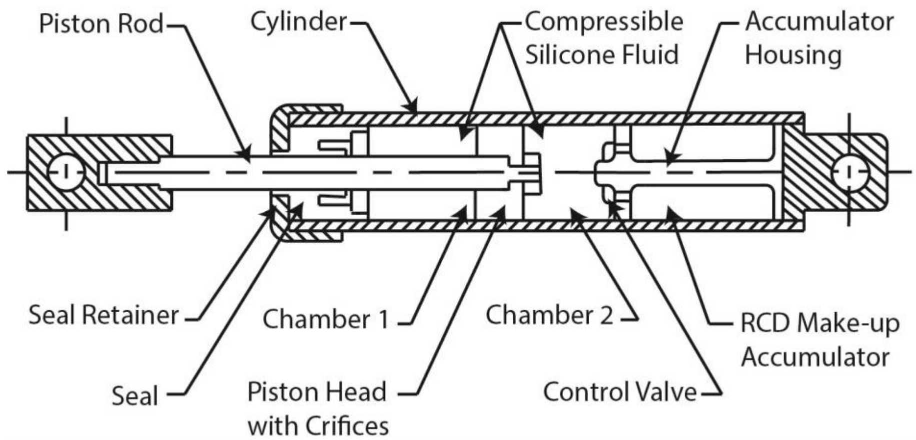


Figure 13.89 Viscous Damper Cross Section

Figure 13.90 Viscous Dampers (Courtesy of California Department of Transportation)

13.8.4.2 Common Maintenance Activities

Viscous dampers rely on the internal fluid in order to operate correctly during a seismic event. The seal at the piston end of the cylinder is known to leak in some bridge applications. The seals tend to wear out over time due to the daily thermal movement and general vibration in bridges. When the seals are leaking, the area under and around the piston end of the damper will have heavy oil splattered or dripping all over the structure and is readily visible. Some of the more modern viscous dampers have gauges on top of the cylinders to easily check the fluid levels. A small amount of fluid loss can have a significant impact on the performance of seismic dampers. Viscous dampers that have lost fluid can be refilled using the manufacture recommended fluid. Refilling the dampers in place requires a fluid pump capable of generating the required pressure inside the damper cylinder. The fluid pump is connected to the damper cylinder port and fluid is pumped in until the desired capacity has been achieved. The pumping should be done slowly as the pressure will build and dissipate as the piston moves. If the seals are leaking excessively or if the recommended pressure cannot be achieved, the damper will need to be factory resealed or replaced. Both resealing and replacement will require removal of the damper from the structure. If resealing or replacement is required, the new dampers(s) should be ordered and received before the existing dampers are removed from the structure.

Bridge dampers are likely custom made for each structure and may take several months to get replacements manufactured.

13.9 Chapter 13 Reference List

1. AASHTO. *Maintenance Manual for Roadways and Bridges.* Washington, D.C.: American Association of State Highway and Transportation, 2007.
2. American Concrete Institute Committee E706. *Field Guide to Concrete Repair Application Procedures Structural Crack Repair by Epoxy Injection.* ACI RAP Bulletin 1. 2003.
3. California Department of Transportation. *Graffiti.* District 11 Maintenance Department Web Document, http://www.dot.ca.gov/dist11/departments/mainten/graffiti.htm
4. California Department of Transportation. *Northridge Earthquake Lessons Learned 1992*, 2010.
5. Departments of the Army and the Air Force. *Bridge Inspection, Maintenance, and Repair*. TM 5-600/AFJPAM 32-1088, December 1994, http://armypubs.army.mil/eng/dr_pubs/dr_a/pdf/tm5_600.pdf
6. FEMA National US&R Response System. *Module 2a Shoring Basics.* Structural Collapse Technician, Federal Emergency Management Agency, 38 pages, 2000, http://www.fema.gov/pdf/emergency/usr/module2a.pdf
7. FHWA. *Bridge Inspector's Reference Manual (BIRM)*. Publication No. FHWA NHI 12-049. Washington D.C.: United States Department of Transportation, October 2002, Revised December 2006, Revised February 2012.
8. FHWA. *Bridge Rehabilitation Evaluation & Design Course*. NHI Course No. 134062, Publication No. FHWA NHI 08-013. Washington D.C.: United States Department of Transportation, November 2007.
9. FHWA. *Bridge Maintenance Training Reference Manual*. NHI Course 134029, Publication No. FHWA-NHI-03-045. Washington D.C.: United States Department of Transportation, March 2003.
10. FHWA. *Covered Bridge Manual*. Memorandum to Designers, 20-4, Publication FHWA-HRT-04-098. Washington D.C.: United States Department of Transportation, April 2005, http://www.fhwa.dot.gov/publications/research/infrastructure/structures/04098/04098.pdf
11. FHWA. *Seismic Retrofitting Manual for Highway Structures 2006*. Publication No. FHWA-HRT 06-032. Washington D.C.: United States Department of Transportation, 2006.
12. Johnson, Kenneth. *Repair and Rehabilitation of Treated Timber Bridges.* Wheeler Lumber, LLC, 36 pages, undated, http://www.wheeler-con.com/wp-content/uploads/2011/06/Repair-Rehab-of-Tbr-Bridges.pdf
13. Lopez-Anido, Roberto, P.M. Antonis, T. Sandford, and B. Goodell. *Repair of Wood Piles Using Prefabricated Fiber-Reinforced Polymer Composite Shells.* Journal of Performance of Constructed Facilities, Vol. 19, No. 1, 10 pages, February 2005, http://pilemedic.com/pdfs/Repair%20of%20Wood%20Piles%20Using%20Prefabricated%20Fiber-Reinforced%20Polymer%20Composite%20Shells.pdf
14. NCHRP, Transportation Research Board. *A Synthesis of Highway Practice Cathodic Protection for Life Extension of Existing Reinforced Concrete Bridge Elements*. NCHRP Synthesis 298. Washington, D.C. 2009, http://www.trb.org/Main/Home.aspx

15. NCHRP, Transportation Research Board. *Bonded Repair and Retrofit of Concrete Structures Using FRP Composites*. NCHRP Report 60 9, Project 10-59, Pilot Training Workshop, Powerpoint presented by: Amir Mirmiran, Mohsen Shahawy, Vistasp Karbhari, Woods Hole, MA, June 30-July 1, 2004, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_609.pdf
16. NCHRP, Transportation Research Board*. Cathodic Protection for Life Extension of Existing Reinforced Concrete Bridge Elements*. Synthesis of Information Related to Highway Problems, NCHRP Synthesis 20-05/Topic 39-03 [Final (Synthesis)], 2009, http://www.nap.edu/openbook.php?record_id=14292&page=R2
17. NCHRP, Transportation Research Board, *Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements*. Report 588, Project 18-6A ISSN 0077-5614 ISBN-13: 978-0-309-09862-5 ISBN-10: 0-309-09862-9 Library of Congress Control Number 2006932123, 2006, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_588.pdf
18. New York State Department of Transportation Office of Operations, Bridge Maintenance. *Cathodic Protection Systems: Use of Sacrificial or Galvanic Anodes on In-service Bridges.* Undated, 24 pages, https://www.dot.ny.gov/divisions/operating/oom/transportation-maintenance/repository/CathodicProtectionSystems.pdf
19. New York State Department of Transportation, VTrans, and FHWA. *Lake Champlain Bridge Project PAC Meeting #5.* Pictures of Crown Point Bridge, 48 slides, November 13, 2009, https://www.dot.ny.gov/regional-offices/region1/projects/lake-champlain-bridge/repository/LCB_PAC5_11-13-09.pdf?nd=nysdot
20. Paraschos, Andreas and Amde made. *A Survey on the Status of Use, Problems, and Costs Associated with Integral Abutment Bridges.* University of Maryland College Park, 2009, http://blogsdir.cms.rrcdn.com/31/files/2011/02/Paper-with-text-tables-and-figures-PDF-Document.pdf
21. Presuel-Moreno, Francisco, and William Hartt. *Protection of Reinforced Concrete Bridge Substructures using Submerged Bulk Anodes.* (BD 546-3). Submitted to Florida Department of Transportation Research Center January, 2009, http://www.dot.state.fl.us/research-center/completed_proj/summary_smo/fdot_bd546_03_rpt.pdf
22. Research Council on Structural Connections (RCSC). *Specification for Structural Joints Using High Strength Bolts.* December 2009, http://www.boltcouncil.org/files/2009RCSCSpecification.pdf
23. Reynolds, Tim, Ed Suttie, and Chris Coggins. *Preservative Treatment and Durability*, *External Treatment of Timber Structures Digest 503*. West Yorkshire: Wood Protection Association, 2007, http://www.forestry.gov.uk/pdf/External-timber-structures-preservative-treatment-and-durability_D503.pdf/$FILE/External-timber-structures-preservative-treatment-and-durability_D503.pdf
24. Seavey, Robert, and Timothy Larson. *Inspection of Timber Bridges*. Department of Wood and Paper Science, University of Minnesota, Minnesota Department of Transportation Office of Research Services, 2002, http://www.lrrb.org/media/reports/200234.pdf
25. Vector Corrosion Technologies*. Electro-chemical Extraction*. http://www.vector-corrosion.com
26. Western Wood Preservers Institute. *Guide to Pressure Treated Wood: Characteristics Use Specification.* 2012, http://www.wwpinstitute.org/documents/RevisedSpecGuideJan2012_000.pdf