
An Introduction to Steel Bridge Maintenance and Repair

Course No: S03-017

Credit: 3 PDH

J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI



Continuing Education and Development, Inc.
22 Stonewall Court
Woodcliff Lake, NJ 07677

P: (877) 322-5800
info@cedengineering.com

An Introduction to Steel Bridge Maintenance and Repair



J. Paul Guyer, P.E., R.A.
Editor

Paul Guyer is a registered civil engineer, mechanical engineer, fire protection engineer and architect with 35 years of experience designing buildings and related infrastructure. For an additional 9 years he was a principal staff advisor to the California Legislature on capital outlay and infrastructure issues. He is a graduate of Stanford University and has held numerous national, state and local offices with the American Society of Civil Engineers, Architectural Engineering Institute and National Society of Professional Engineers. He is a Fellow of ASCE and AEI.

CONTENTS

Preventive Maintenance for Corrosion

- 1. INTRODUCTION**
- 2. STRUCTURAL STEEL**

Repair and Strengthen

- 3. GENERAL REPAIR**
- 4. CONNECTIONS**
- 5. REPAIR OF STRUCTURAL MEMBERS**

Member Replacement

- 6. TENSION MEMBERS**
- 7. COMPRESSION MEMBERS/COLUMNS**
- 8. BEAMS**

Upgrade Steel Bridges

- 9. CREATION OF A COMPOSITE ACTION**
- 10. POSTTENSIONING**
- 11. TRUSS SYSTEMS**

(This publication is adapted from the Unified Facilities Criteria of the United States government which are in the public domain, have been authorized for unlimited distribution, and are not copyrighted.)

Preventive Maintenance for Corrosion

1. INTRODUCTION. Rust and corrosion are the greatest enemies of steel. When rust is allowed to progress without interruption, it may cause a disintegration and subsequently complete loss of strength in a bridge member. The corrosion also causes other problems such as pressure or friction between the surfaces.

2. STRUCTURAL STEEL. Preventive maintenance of steel bridge 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. Protection from corrosion can take various forms:

2.1 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 poor performance from their bridges constructed with this type of steel. Therefore, members constructed from weathering steel should be monitored for excessive corrosion and painted if necessary.

2.2 PAINT. Typical painting requirements are based on whether the steel is new or is to be repainted. The following steps are usually necessary:

2.2.1 NEW STEEL. One prime coat applied in the shop, one prime coat applied in the field, two color coats applied in the field.

2.2.2 REPAINTING (depends on the condition of the existing paint). If cleaned to bare metal, use one prime and two color coats. If cleaned to prime coat, use two color coats. If no prime exposed, use one color coat.

2.2.3 PAINT SEAL. The intersections and edges of metal surfaces can be protected from corrosion with a paint seal. This is a paste paint that prevents moisture penetration between the metal parts.

2.2.4 NOTES.

2.2.4.1 WHEN REMOVING LEAD-BASED PAINT, precautions must be taken to protect against lead inhalation, ingestion, and pollution.

2.2.4.2 SCHEDULE FIELD PAINTING at the end of maintenance projects to avoid damage to the fresh paint.

2.2.4.3 SEPARATE CLEANING and painting operations to avoid contaminating the fresh paint.

2.2.4.4 PROTECT CLEANED STEEL until paint can be applied.

2.2.4.5 APPLY PAINT to a dry surface that is not too hot. This ensures a good bond that does not blister (ambient temperature greater than 40 ° F, relative humidity less than 85 percent).

2.3 CATHODIC PROTECTION. Zinc or aluminum anodes are attached to H piles to abate corrosion of steel in salt or brackish water (figure 11-1). 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.

2.4 GOOD HOUSEKEEPING. Steps to follow:

2.4.1 KEEP DRAINS open to remove standing water from steel surfaces.

2.4.2 KEEP DECK JOINTS watertight to prevent water leakage onto steel members.

2.4.3 KEEP EXPOSED AREAS clean by pressure washing.

2.4.4 SPOT PAINT and repaint as necessary.

2.4.5 MAINTAIN STEEL CABLES by removing foreign objects from the cable support system, cleaning and lubricating cable supports, tightening and replacing stirrups, and repairing cable wrapping.

Repair and Strengthen

3. GENERAL REPAIR.

3.1 REPAIR DECISION. Each repair decision must carefully weigh the long-term operational requirements and existing environmental factors that can help accelerate corrosion prior to evaluating initial and life cycle costs. The physical condition of the structure must first be determined by a detailed inspection. The structural capacity of the steel should be known. Once the physical condition of the bridge is evaluated, a determination of whether damaged bridge components should be repaired or replaced is made.

3.2 COMMON REPAIRS. The most common steel repairs are:

3.2.1 ADDING METAL TO STRENGTHEN cross sections that have been reduced by corrosion or external forces.

3.2.2 WELDING OR ADDING COVER-PLATES to repair structural steel cracks caused by fatigue and vehicle loads.

3.3.3 RETROFITTING connections.

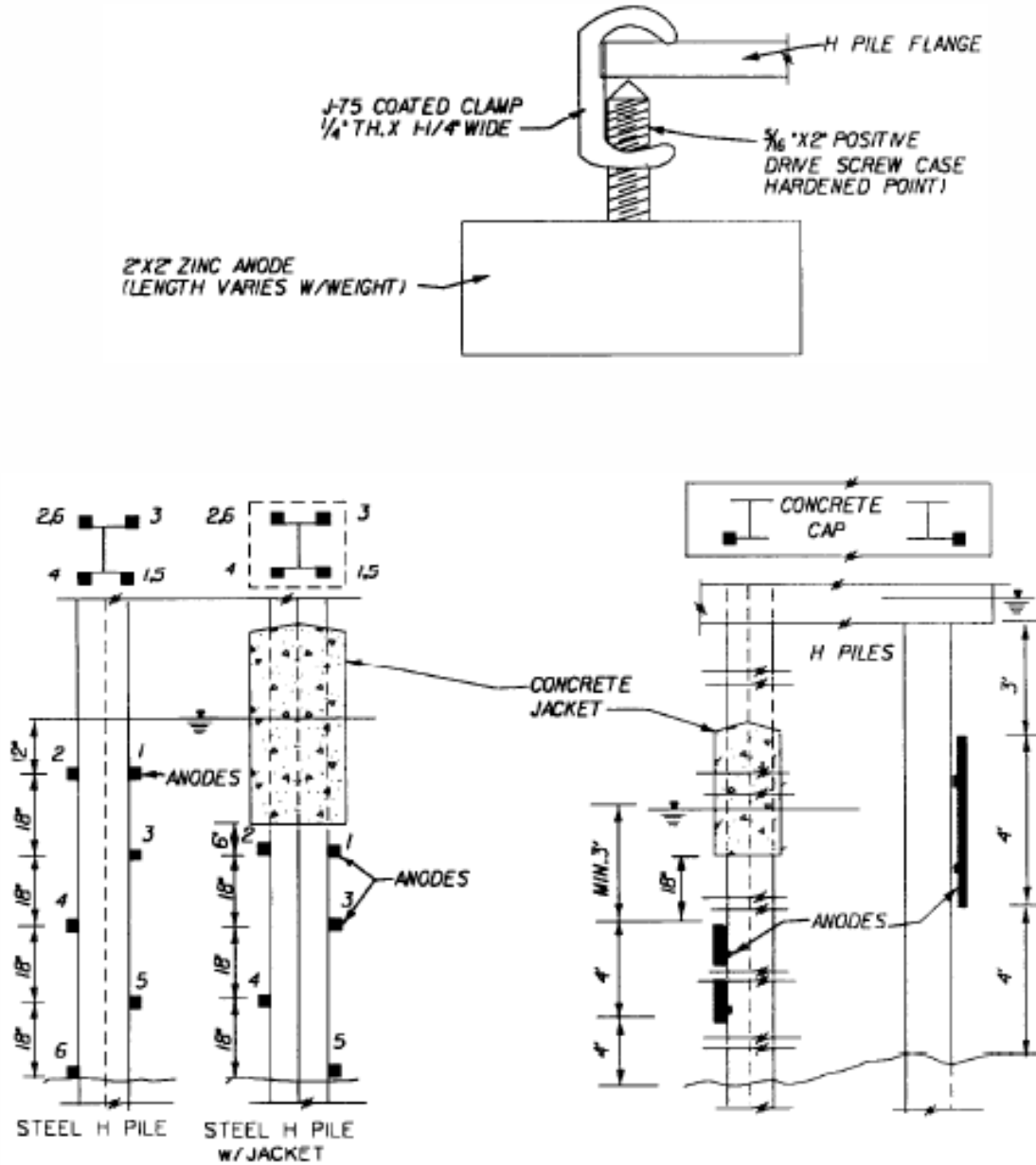


Figure 11-1

Anodes placed on steel H piles for corrosion protection

3.3 RULES FOR ADDING STEEL. When steel members are strengthened to carry a specified load, the permissible stresses in the added material must comply with the load

design stresses. To properly analyze and design repairs that involve adding metal, the following rules are applied:

3.3.1 METAL ADDED TO STRINGERS, floorbeams, or girders shall be considered effective in carrying its portion of the live loads only.

3.3.2 NEW METAL ADDED to trusses, viaducts, etc., shall be considered effective in carrying its portion of the live load only. The exception is when: The dead load stress is temporarily removed from these members until the new metal is applied, or the dead load stress is applied to the new metal when it is applied.

3.3.3 THE ADDED MATERIAL shall be applied to produce a balanced section, thus eliminating or minimizing the effect of eccentricity on the strengthened member. Where balanced sections cannot be obtained economically, the eccentricity of the member shall be taken into account in determining the stresses.

3.3.4 STRENGTHENED MEMBERS shall be investigated for any decrease in strength resulting from temporary removal of rivets, cover plates, or other parts. In some cases falsework or temporary members may be required. Where compression members are being reinforced, lacing bars or tie plates shall be replaced before allowing traffic over the bridge.

4. CONNECTIONS. Primary connections involve the use of welds, bolts, or rivets. However, pin connections and threaded fasteners are used commonly in tension members.

4.1 WELDS. Electric arc welding may be employed subject to the approval of the engineer. In general, welding can be used to repair broken or cracked welds, strengthen rivet connections, and add metal to existing steel members.

4.1.1 BROKEN OR CRACKED WELDS. Remove all dirt, rust, and paint for a distance of 2 inches from the damaged weld. File or grind down the damaged weld to ensure the weld will bond with the steel surfaces being welded together. For cracks, grind down the cracked weld until the crack is no longer visible then check the weld with dye penetrant to ensure the crack has been completely ground out. Replace the weld. Apply paint or a corrosion protector to welded area.

4.1.2 WELDED RIVET CONNECTIONS. Remove all dirt, rust, and paint for a distance of 2 inches from the steel surfaces in which the weld is to be applied. Apply welds to join the steel surfaces. Where overstressed rivets/bolts can carry the dead load, the weld is designed to carry the impact and live loads. Where overstressed rivets/bolts cannot carry the dead load, the weld is designed to carry the total load. Apply paint or a corrosion protector to welded area.

4.1.3 ADDED METAL FOR STRENGTH. Clean the steel surfaces in which metal is to be added and remove any severely damaged or corroded steel portions. Use welds to fill cracks and holes, to replace removed steel portions, or to add coverplates to strengthen individual members. With cracks, ensure the weld penetrates the full depth of the crack. With holes, work the weld from the steel surface to the center of the hole ensuring no voids are allowed in the weld. Replace removed steel portions with steel of the same strength, and, if a torch is used to cut the steel, ensure the edges are ground smooth to ensure a good welding surface. When adding coverplates that will be subjected to compression, ensure the maximum clear spacing distance (d) is less than 4,000 multiplied

by t divided by F_y , where t = plate thickness in inches and F_y = yield stress in pounds per square inch. This prevents local buckling of the attached plate when loaded in compression (figure 11-2). Apply paint or a corrosion protector to welded area and added steel.

4.2 RIVETS. Riveted connections can be repaired using many different methods. The most common repair requirements are for loose or missing rivets or an understrength connection. The repair techniques for each are as follows:

4.2.1 LOOSE OR MISSING RIVETS. Clean working surface. Replace all missing rivets with high strength bolts of the same size and draw the nut up tight. This will help support the connection during the repair operations. Tighten or remove and replace loose rivets with high-strength bolts or new rivets. Work on only one rivet at a time to help maintain the proper load distribution to the rivets. Remove and replace high-strength bolts with rivets, one at a time, if the engineer requires rivets for the repair work (high-strength bolts can be substituted for rivets). Check all bolts and/or rivets to ensure tightness. Apply paint or corrosion protector.

4.2.2 UNDERSTRENGTH CONNECTION. Several options exist for an understrength connection:

4.2.2.1 RIVETS OR BOLTS can be added to the existing connection plate.

4.2.2.2 A LONGER CONNECTION PLATE can be added to allow for more rivets.

4.2.2.3 LARGER RIVETS OR BOLTS can be substituted for the existing ones.

4.2.2.4 WELDS can be added to the connection plate of sufficient strength to carry impact and live loads or the total load depending on the condition of the connection.

4.3 PIN CONNECTION. The pin connections discussed herein refer to those used in tension members. The repair of such connections may involve the pin itself or the pin housing. To repair or replace the pin or housing, the load must be shifted from the connection through use of jacks or winches. The pin can then be removed from the housing. Repair the housing using welds or by adding metal to build up the connection, as necessary. The pin can either be replaced or a bolt of the same size can be used. The pin connection should be replaced with a welded or riveted connection if it is functioning as a fixed connection or if the bridge is considered a permanent structure.

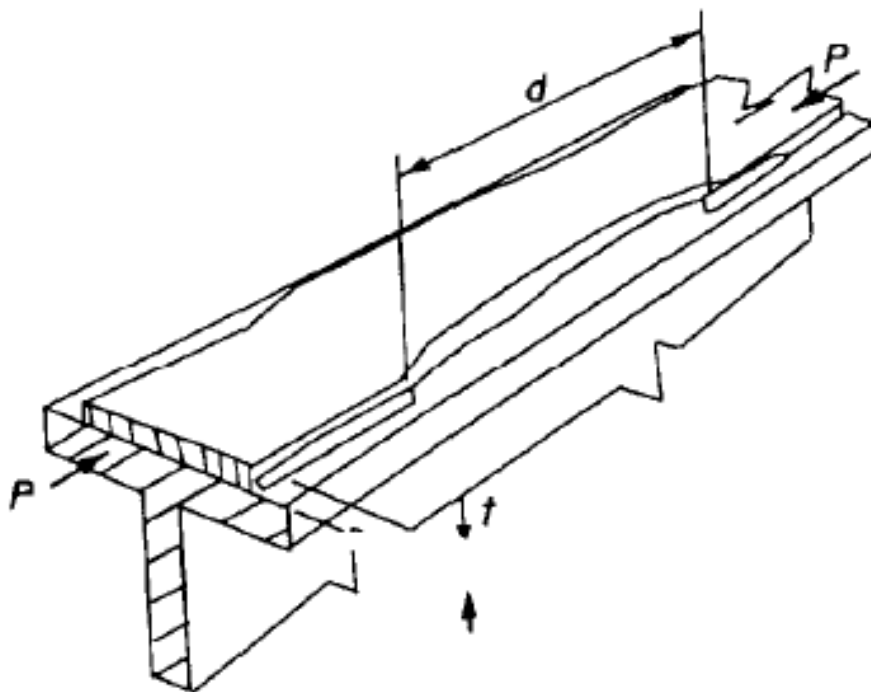


Figure 11-2

Local buckling under compression

4.4 THREADED FASTENER. Threaded fasteners are used primarily in conjunction with a tension rod or cable. Typical problems with these fasteners involve stripped threads, a rust frozen shaft, or a broken threaded shaft.

4.4.1 STRIPPED THREADS. Remove the threaded shaft and rethread if necessary. Drill out the threads in the female housing. Place the rethreaded shaft through the female housing and retighten the fastener with a bolt on the backside of the housing.

4.4.2 RUST FROZEN SHAFT. Clean the shaft and housing of external rust and apply a lubricant to the threads. Attempt to rotate the shaft; if the shaft still refuses to rotate, the fastener must be replaced. Cut the threaded portion of the shaft from the tension member and splice a new threaded shaft to the member. Remove the frozen portion of the shaft from the housing using a torch. Place a bolt on the backside of the housing and pull the tension member tight.

4.4.3 BROKEN SHAFT. Splice the shaft as shown in figure 11-3.

5. REPAIR OF STRUCTURAL MEMBERS. Structural steel members are generally classified by the function they perform. The primary members are tension members, compression members, beams, and beam-columns. The repair of various structural members is discussed in the following paragraphs.

5.1 BARS. Structural bars can be either round or rectangular and have a pin or threaded connection. Repair of the bar itself involves tightening the bar to account for elongation, adding metal to the eye of a pin connection, or splicing the bar to repair breakage.

5.1.1 TIGHTENING ADJUSTABLE CONNECTIONS OR TURNBUCKLES. Clean the components and attempt to tighten the bar. If adjustments cannot be made, adjustments can be made to the eyes or turnbuckles can be added as follows:

5.1.1.1 ADJUSTMENTS TO THE EYES. For slack of less than 1 inch, the pin connection can be shimmed to take up any slack between the pin and the eye of the bar. Shimming is accomplished by removing the pin from the housing and placing a metal sleeve snugly around the pin and the inside of the eye of the bar. The metal sleeve will take up the slack between the pin and the eye of the bar.

5.1.1.2 ADD TURNBUCKLE. A turnbuckle can be added to a round bar which previously had no adjustable tension system (figure 11-3). This is accomplished by cutting a section out of the existing bar, threading both adjacent ends of the cut, and screwing on a turnbuckle.

5.1.2 BROKEN/DAMAGED BARS. Repair broken or damaged bars as follows:

5.1.2.1 ADD TURNBUCKLE. Cut out the damaged area and use the same technique discussed above.

5.1.2.2 SPLICE BARS. Broken bars can be spliced by welding bars or plates on both sides of the damaged area as shown in figure 11-3. Bolts and rivets can also be used if desired.

5.1.3 REINFORCEMENT OF EYEBARS with loop bars. Eyebars can be reinforced with loop bars in the following manner. Release tension from the eye or consider the added metal for carrying live load and impact loading only. Weld a plate onto the existing eyebar. This plate can be used to attach a supplemental eye (loop or forged bar which reinforces the eye of the bar). Place loop bars around the pin and weld to the steel plate (figure 11-4, part a). Reapply tension and paint repaired area.

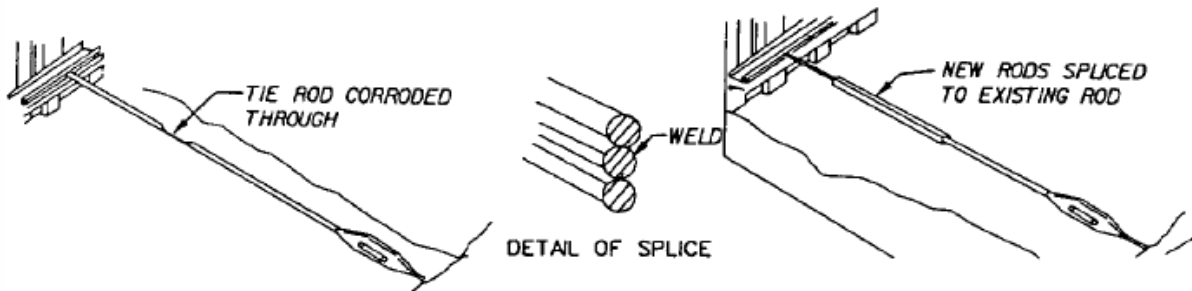


Figure 11-3

Repairing tie rods with splices or turnbuckles.

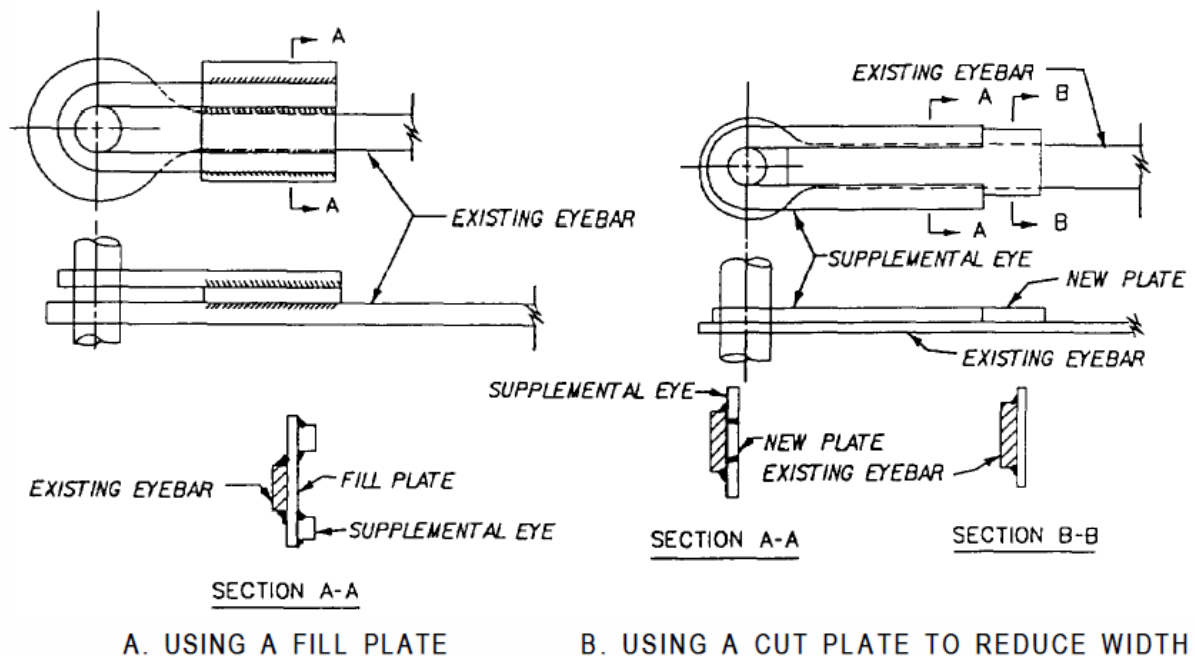


Figure 11-4

Strengthening pin connections using a supplementary eye.

5.1.4 REINFORCEMENT OF EYEBARS with steel plates (figure 11-4, part b). Eyebars can be reinforced with steel plates by the following procedure. Release tension from the eye. Place a supplementary eye around the existing eyebar. Slide a new plate between the arms of the supplementary eye. The thickness of the new plate should be equal to that of the supplementary eye. Its width should be equal to the diameter of the pin for the approximate length of the arms of the supplementary eye, and then it should widen to a width greater than the existing eyebar. Its length should be determined by the load carrying capacity requirements of the welds. Weld the supplementary eye, new plate, and eyebar together. Replace the pin, reapply tension, and paint the repair.

5.2 HANGER PLATES. Pin and hanger connections are especially vulnerable to corrosion, which may freeze the connection and increase the internal stresses in the

hanger, causing cracks to form. If the hanger must be removed for cleaning or repair, a technique which can be used is:

5.2.1 FASHION A TEMPORARY HANGER to support the dead load normally carried by the hanger. This can be accomplished as follows:

5.2.1.1 PLACE A STEEL PLATE across the expansion dam on the road surface. The plate should have two holes running the length of the dam and at a distance slightly greater than the flange width of the girder apart.

5.2.1.2 RUN TWO THREADED BARS capped with nuts through the holes to the bottom of the girder's bottom flange.

5.2.1.3 ATTACH A PLATE to the bars below the bottom flange.

5.2.1.4 TIGHTEN THE NUTS on the top plate to draw the bottom plate up tight to the bottom flange and adjust the tension on the hanger.

5.2.2 ONCE THE TEMPORARY HANGER is in place, the connection can be cleaned and repaired as follows:

5.2.2.1 ATTACH A SAFETY cable to the outside hanger and remove the hanger from the pins.

5.2.2.2 CLEAN THE PINS and hanger thoroughly and repair any damage to these components.

5.2.2.3 SPOT PAINT the inside face of the hanger with light layers of paint and allow time for the paint to dry while working on the pins.

5.2.2.4 LUBRICATE the pins and replace the hanger.

5.2.2.5 REPAINT the outside face of the hanger.

5.2.2.6 REPEAT THE PROCEDURE for the inside hanger.

5.2.3 REMOVE THE TEMPORARY HANGER.

5.3 CABLE. The most common damage that occurs to cable is fraying of the steel wires forming the cable. Any repair requiring strengthening the damaged portion of the cable involves removing the tension on the cable. There are three repair techniques that can be used on damaged cables.

5.3.1 IF THE CABLE STILL retains adequate strength to carry its design loading despite the frayed area, then clip off the frayed wires, clean any rust and debris from the cable, and paint or wrap the damaged portion of the cable with a protective coating.

5.3.2 IF THE CABLE REQUIRES strengthening, then replace the cable, run an additional cable parallel to the existing cable to carry the balance of the load, or cut the cable and emplace a turnbuckle.

5.4 ROLLED SECTIONS OR PLATE GIRDERS. The most common repairs to these sections are repairing cracks in welds and strengthening the sections with cover plates. In some cases, bent steel sections are repaired using a technique called structural steel flame straightening.

5.4.1 CRACK REPAIR. The typical cracks that occur in rolled sections and plate girders are caused by fatigue and overloading. The cracks generally begin in the flange and propagate through the flange into the web. To properly repair these cracks, the cracks must first be closed and then a weld applied. The importance of closing the crack is to ensure that the dead load is properly transferred across the entire cross section of the steel member. There are various methods which can be used to close these cracks:

5.4.1.1 POSTTENSIONING THE MEMBER

5.4.1.2 JACKING THE LOAD OFF THE MEMBER

5.4.1.3 USING A HEATED COVER plate across the crack and following these steps. Weld a cover plate to the member along only one side of the crack. Heat the cover plate to expand the plate's length. While still heated, weld the opposite side of the plate to the member and allow the plate to cool and contract. This will pull the crack together. Weld the crack and apply a continuous fillet to the cover plate.

5.4.2 COVER PLATES. The cover plate is a relatively easy and inexpensive technique to use in steel repair. It can be used to bridge over a crack and transfer the dead load throughout the cross section of the steel member or to just add strength to the member's cross section. A key dilemma when adding steel cover plates is the method used to introduce dead load stresses into the new material. The most common method used with major members (i.e., W-sections) is to calculate the amount of shorting required to produce the dead-load stresses in the existing member. Holes are drilled into the old and new members in such a way that the new members will be shortened by drifting, as the sections are bolted together. Another method is heating the cover plate after welding one end and then welding the expanded plate into place as discussed. As the plate cools and contracts, stresses will be added to the cover plate. Examples of various uses of the cover plate are:

5.4.2.1 EXTENDING AN EXISTING cover plate to bridge a welded crack

5.4.2.2 BUILDING UP THE BOTTOM FLANGE, top flange, or the web of the member to increase the load capacity of a steel member.

5.4.2.3 BRIDGING OR STRENGTHENING steel sections damaged by corrosion or collisions (figure 11-5).

5.4.3 RULES FOR USING COVER PLATES.

5.4.3.1 WHEN ONE OR MORE COVER PLATES must be renewed, consideration must be made for replacing the defective plates with one plate of adequate size.

5.4.3.2 COVER PLATES should be connected by continuous fillet welds, high-strength bolts, or rivets.

5.4.3.3 WHERE THE EXPOSED SURFACE of old plates are rough or uneven from corrosion and wear, they should be replaced with new plates.

5.4.3.4 WELDED COVER PLATES should be of sufficient thickness to prevent buckling without intermediate fasteners.

5.4.3.5 WHERE THE WEB WAS not originally spliced to resist moment, it may be spliced by adding cover plates or side plates.

5.4.3.6 WHERE FATIGUE CRACKING can occur at the top of welds on the ends of the cover plate, it is recommended that bolting be used at the cover plate ends.

5.4.3.7 WHEN COVER PLATES are used in compression members, care must be taken to maintain symmetry of the section to avoid eccentric loadings.

5.4.3.8 ALTERNATIVE TO COVER PLATES. Where the cost of removal and replacement of the deck would be excessive, as in ballasted-deck bridges, flange sections may be increased by adding full-length longitudinal angles, plates, or channels just below the flange angles. First remove the stiffener angles and then replace them with new stiffeners after the flange steel is added (figure 11-6).

5.4.4 STIFFENERS. Stiffeners are used to reinforce areas of the beam which are susceptible to web buckling (intermediate transverse stiffeners), concentrated loads

greater than allowable stresses (bearing stiffeners), and web buckling due to bending (longitudinal stiffeners).

5.4.4.1 INTERMEDIATE STIFFENERS. Additional stiffeners may be added by riveting, high-strength bolting, or welding angles or metal plates perpendicular to the top flange and web. These stiffeners should not be connected to the tension flange of the member.

5.4.4.2 BEARING STIFFENERS. These stiffeners can be reinforced by adding angles or plates to the existing stiffeners, grinding the bearing ends of the new parts to make them fit closely, or welding the bearing ends to the flanges.

5.4.4.3 LONGITUDINAL STIFFENERS. Stiffness may be added to the member by bolting or welding longitudinal angles to the web of the steel member.

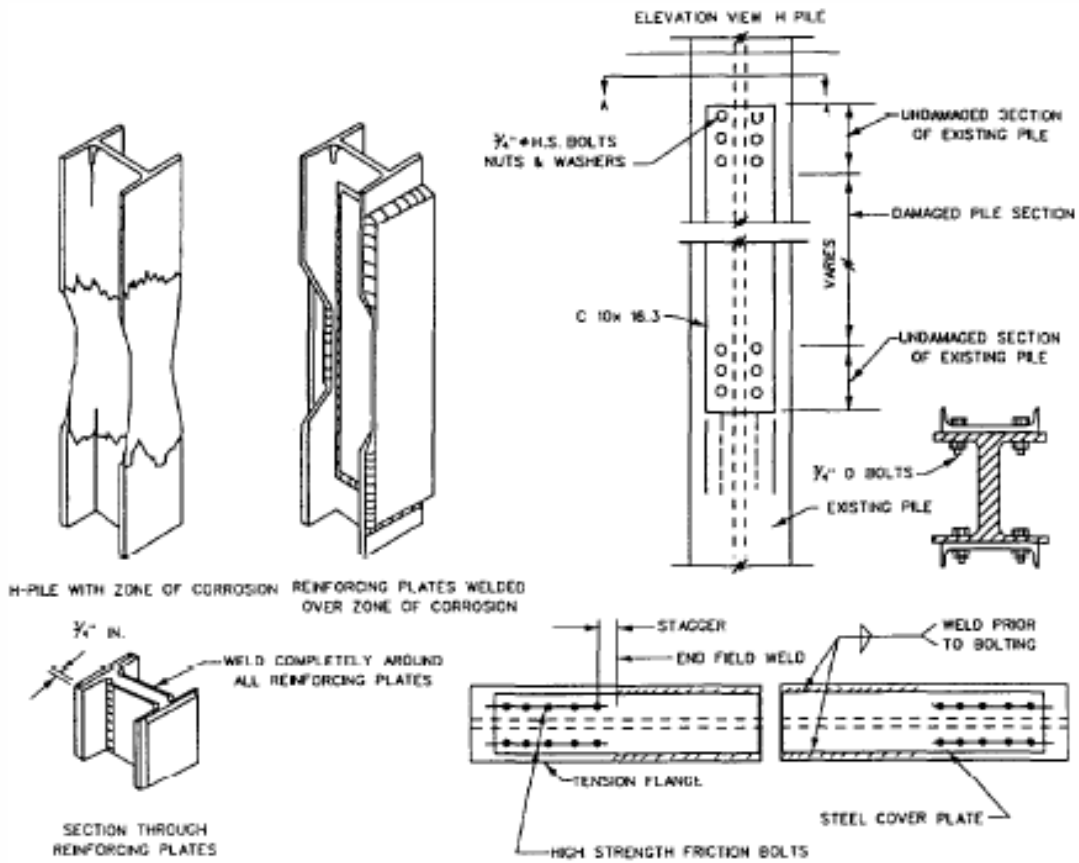


Figure 11-5. Use of cover plates on rolled steel sections.

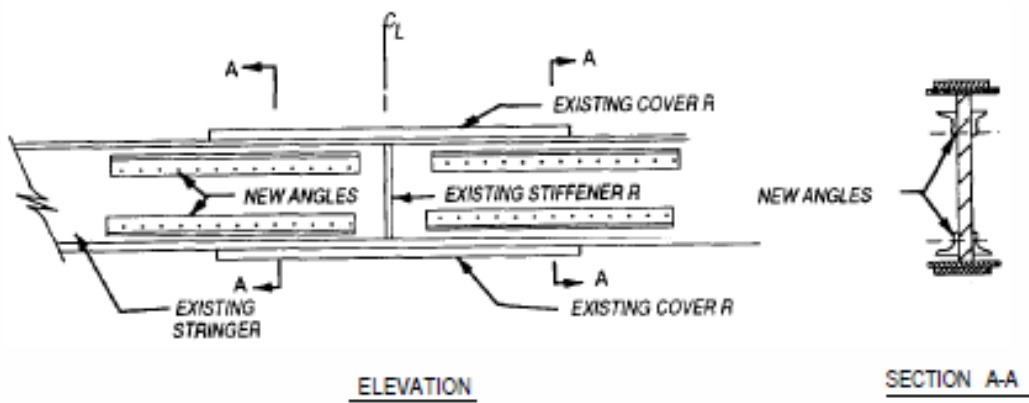


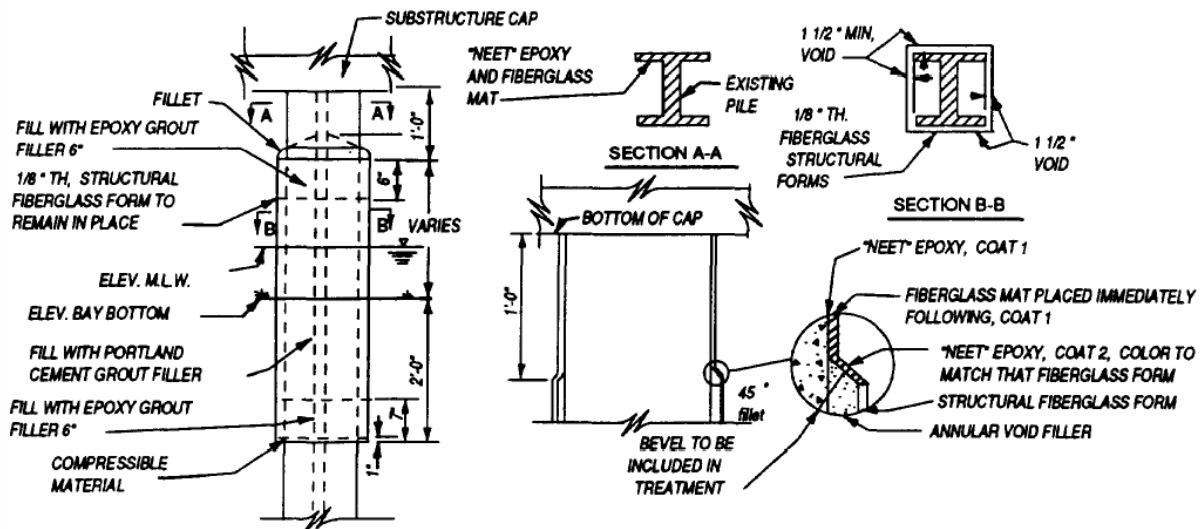
Figure 11-6

Iowa DOT method of adding angles to steel I-Beams.

5.4.5 PILES.

5.4.5.1 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.

5.4.5.2 A PROCEDURE FOR INSTALLING an integral pile jacket follows (figure 11-7). Sandblast the surfaces clean of oil, grease, dirt, and corrosion (near white metal). Place the pile jacket form around the pile. Ensure standoffs are attached to the form. Seal all joints with an epoxy bonding compound and seal the bottom of the form to the pile. Brace and band the exterior of the form to hold the form in place. Dewater the form. Fill the bottom 6 inches of the form with epoxy grout filler. Fill the form to within 6 inches of the top with a Portland-cement grout filler. Cap the form with a 6-inch fill of epoxy grout. Slope the cap to allow water to run off. Remove the external bracing and banding and clean off the form of any deposited material.



DETAIL OF STANDARD TREATMENT OF TOP 12" OF PILING

Figure 11-7

Integral pile jacket for steel piles

5.4.6 FLAME STRAIGHTENING. Flame straightening has been used for over 40 years to straighten bent beams or align members for proper connections. This process involves using “V” heats or triangle heats on flanges in conjunction with jacking devices to shrink the beam in the desired direction. The “V” heat is not heated completely, nor is it gone over again until cooled. The base of the “V” heat should not exceed 6 inches to avoid warping of the flange. The heat used in the process should not exceed 1,200 o F and in most areas will probably be less. It is usually necessary to heat the webs of damaged beams in conjunction with the flange. Overheating and jacking can cause the flange to exceed its yield strength and move vertically, instead of the desired horizontal direction. For these reasons, this process should be conducted with trained and qualified operators only to direct and monitor all heats, jack placements, and to supervise the program’s sequence of events.

5.5 BUILT-UP SECTIONS. These sections are primarily used to form truss systems. Cracks due to fatigue and overloading are repaired in the same manner as rolled sections discussed previously. A combination of cover plates, plates, angles, and other rolled sections can be used to reinforce or strengthen the built-up member. Adding metal to these sections increases the cross-sectional steel area in tension members, reduces the slenderness ratio in compression members, and increases the sectional modulus in beams. Examples of strengthened members are shown in table 11-1.

5.6 COMPOSITE SECTIONS. Composite action is developed when two load-carrying structural members such as a concrete deck and the supporting steel beams are integrally connected and deflect as a single unit. To ensure that no relative slippage occurs between the slab and beam, the beam's flange is imbedded into the concrete or shear connectors are used to develop a composite action between the surfaces. Three areas may require repair on a composite bridge: the concrete deck, the steel beam, or the composite action between the deck and beam.

5.6.1 CONCRETE DECK. Concrete deck damage or faults can decrease the bridge's load capacity by reducing the composite action of the section. The concrete maintenance and repair techniques discussed in chapter 13 should ensure that the deck will carry the compressive forces required by the composite action.

5.6.2 STEEL BEAM. Any cracks or damage to the steel section should be repaired to ensure that, the correct composite action is received.

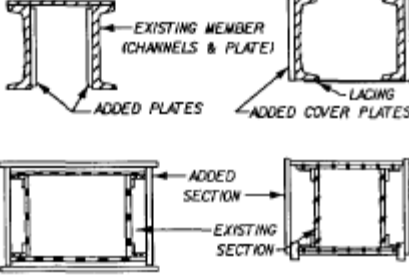
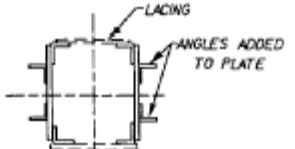
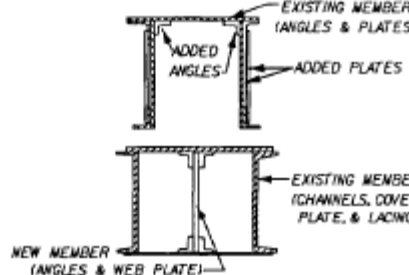
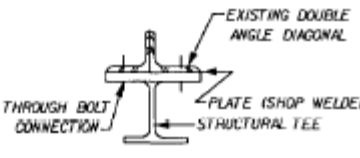
ADDED METAL	DESCRIPTION	FIGURE
COVER PLATE/ PLATES	<p>COVER PLATE IS WELDED TO THE COMPRESSION MEMBER TO INCREASE THE STEEL AREA AND REDUCE THE SLENDERNESS RATIO</p> <p>END POST AND BOTTOM CHORDS OF A THROUGH TRUSS ARE BOXED IN WITH STEEL PLATES.</p>	 <p>The figure contains two sets of diagrams. The top set shows a cross-section of a truss member with labels: 'EXISTING MEMBER (CHANNELS & PLATE)', 'ADDED PLATES' on the top flange, and 'ADDED COVER PLATES' on the bottom flange. A 'LACING' member is also shown. The bottom set shows a truss section with labels: 'ADDED SECTION' and 'EXISTING SECTION'.</p>
ANGLES	<p>ANGLES ARE ADDED TO THE MAIN EXISTING PLATES FOR ADDED STRENGTH.</p>	 <p>The diagram shows a cross-section of a plate with 'LACING' and 'ANGLES ADDED TO PLATE' indicated.</p>
ANGLES & PLATES	<p>PLATES AND ANGLES ARE ADDED TO AN EXISTING MEMBER TO REDUCE THE SLENDERNESS RATIO.</p> <p>PLATES AND ANGLES ARE ADDED TO PROVIDE A CENTRAL WEB IN AN EXISTING COMPRESSION MEMBER.</p>	 <p>The figure contains two diagrams. The top one shows a cross-section of an 'EXISTING MEMBER (ANGLES & PLATES)' with 'ADDED ANGLES' and 'ADDED PLATES'. The bottom one shows a 'NEW MEMBER (ANGLES & WEB PLATE)' with labels for 'EXISTING MEMBER (CHANNELS, COVER PLATE, & LACING)'.</p>
ROLLED STEEL	<p>A PLATE/TEE SECTION OR A I, W SECTION IS USED TO INCREASE THE STEEL AREA IN A TENSION MEMBER.</p>	 <p>The diagram shows a cross-section of a tension member with labels: 'EXISTING DOUBLE ANGLE DIAGONAL', 'PLATE (SHOP WELDED)', 'STRUCTURAL TEE', and 'THROUGH BOLT CONNECTION'.</p>

Table 11-1
Built-up members

5.6.3 COMPOSITE ACTION. Several repair techniques exist to address the loss of composite action:

5.6.3.1 ALLOW FOR NON-COMPOSITE ACTION. Build up the steel beam to carry the load neglecting composite action. Angles can be added to the bottom of the top flange, cover plates can be added to the bottom flange, and/or stiffeners can be used to offset web buckling.

5.6.3.2 REPAIR SHEAR CONNECTORS. The composite action of the section can be reactivated by repairing the shear connectors in the following manner. Use bridge diagrams and plans to determine the location and type of the shear connectors. Remove the concrete from around the shear connector. Repair the existing connectors or replace with welded studs. If welding is not feasible, high-strength bolts can be used as the shear stud as demonstrated in figure 11-8. High-strength bolts may also be added to increase the composite action.

5.6.3.3 DECK REPLACEMENT. The deck can be completely replaced to renew the bond between the concrete and the shear connectors. A new deck can be poured or a new precast deck can be emplaced with holes cast for the connectors, using grout in the holes around the connectors. Note that the composite action is normally designed for live and impact loading, unless the dead load is distributed during the concrete curing process.

5.7 STEEL GRID DECKS. Steel decks are often used to increase the live load capacity of bridges when used to replace concrete decks. The primary maintenance and repair problems with steel decks are deterioration from exposure to the weather, weld failure, and skid resistance. Repairs for corrosion and welds are the same for steel decking as with any other structural steel member.

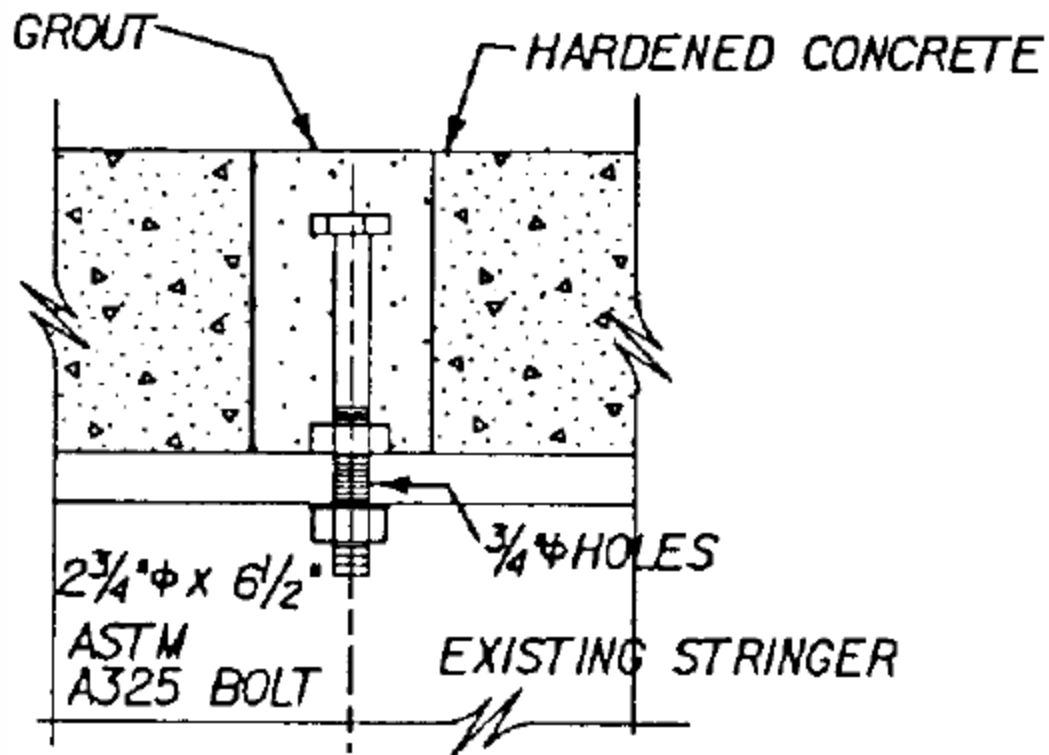


Figure 11-8

Details of double-nutted bolt shear connector.

5.7.1 CONCRETE FILL. Another method of repair commonly used is to fill or partially fill the steel grid with concrete. The concrete filled grid acts as a reinforced concrete deck. The steel grid provides the steel reinforcement and the concrete fill provides stiffness to help carry the load. This repair technique has several advantages: increased deck strength, reduction in the effect of weathering by limiting the water penetration, support of the welded grid joints, and increased skid resistance. A wearing surface can be added to the deck to provide additional skid and weather resistance. Recommended wearing surfaces are: latex modified concrete (1-inch thickness), asphalt (1.75inch thickness), concrete overfill (1.75inch thickness), or epoxy asphalt (5/8-inch thickness).

5.7.2 EXODERMIC DECK.

5.7.2.1 THIS DECK CONSISTS of a thin upper layer (3-inch minimum) of precast reinforced concrete deck panels joined to the steel grating. The panels can be precast and placed on a bridge or added to an existing steel deck using shear connectors welded to the steel grid.

5.7.2.2 THE EMPLACEMENT PROCEDURE FOLLOWS. Weld shear studs/connectors to the steel grid. Precast concrete deck panels with holes for the shear studs. Place a thin metal, wood, or cardboard plate with a diameter greater than the precast stud hole around the stud. Place the precast concrete deck panels on the steel grid and grout the stud holes. Seal the cracks between the concrete panels.

Member Replacement

6. TENSION MEMBERS. Any tension in the member must be transferred to a temporary cable support system prior to removing the damaged member (figure 11-9). Attach a cable/turnbuckle system to the supporting frame parallel to the member to be replaced. Transfer the load carried by the steel member to the cable by tightening the turnbuckle. Remove and replace the damaged steel member. Remove the temporary cable support system.

7. COMPRESSION MEMBERS/COLUMNS. The primary method to support the compressive load during replacement is block and bracing. Emplace a steel or wood section parallel to the member to be removed. Jack the load off the damaged member and place wood or steel shims on the temporary support to transfer the load to the temporary support. In some cases the shims may be driven between the temporary support and the frame to transfer the load. A cable support system wrapped around the temporary support and the frame to transfer the load. A cable support system wrapped around the temporary support and the frame can be used to hold the member in place during the replacement operation. Remove and replace the damaged compression member. Remove the shims and temporary support.

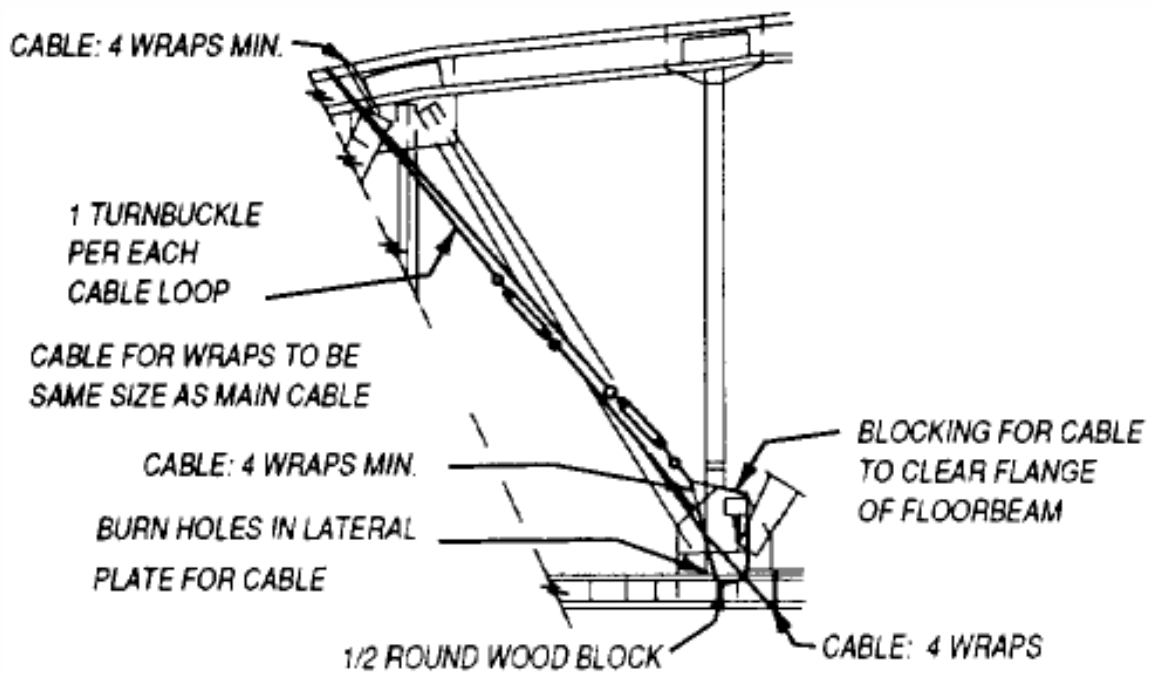


Figure 11-
Method for relieving stress in tension members.

8. BEAMS. The addition or replacement of a stringer is normally performed in conjunction with the replacement of the deck. If the deck is not removed the member must be replaced from under the bridge. The beam replacement method will depend upon whether the beam/deck system is composite or noncomposite.

8.1 NONCOMPOSITE BEAMS. Place jacks under the deck or under the beams that are not being replaced and jack the deck off the beam to be removed. Remove beam or repair the damaged end of the beam. The beam may be cut to facilitate removal. The beam may be jacked out of position or a lift truck used to lower the beam. Lift or jack the replacement beam into place. To use a lift truck or cable system, a hole must be cut or drilled into the deck to run the cable through. Position the beam on the bearing plates, jack the deck down onto the new beam and check for distress in the beam and deck. Remove jacks, temporary supports, and repair any holes in the deck.

8.2 COMPOSITE BEAMS (figure 11-10). Use jacks to lift the composite beam off its bearing. Burn or cut the lower portion of the beam (web and bottom flange) from the fixed top flange. Grind the cut area of the top flange smooth. Weld a new stringer to the old stringer top flange for continuity.

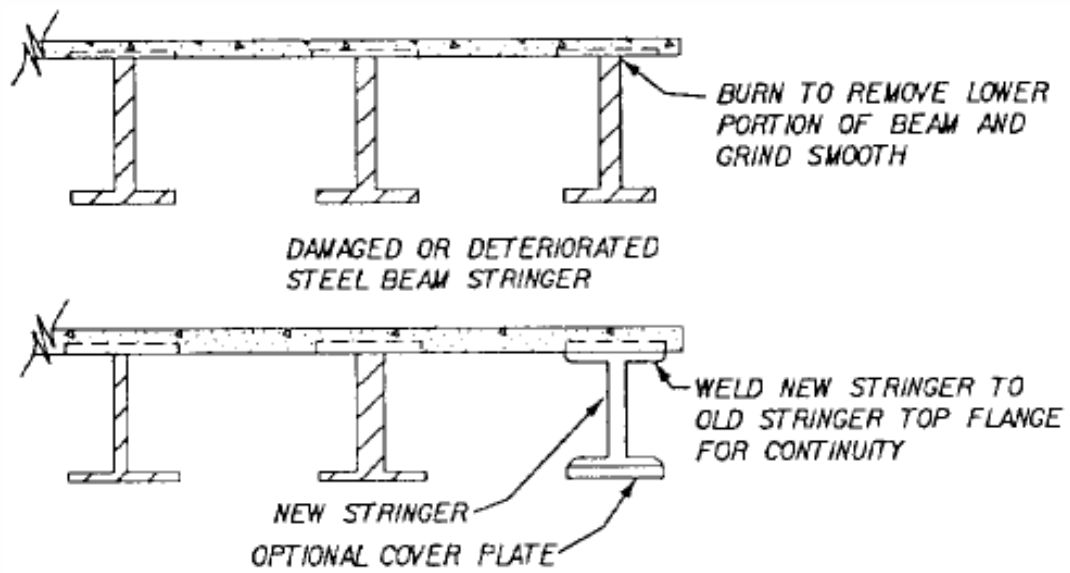


Figure 11-10

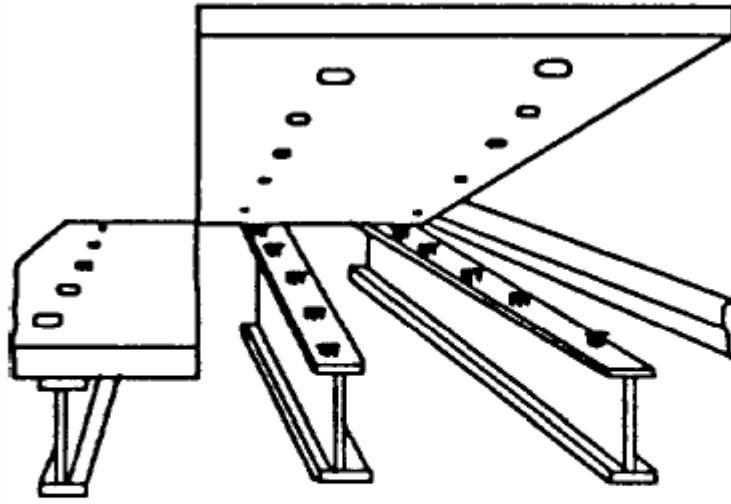
Replacement of a steel beam in a composite section.

Upgrade Steel Bridges

9. CREATION OF A COMPOSITE ACTION The overall strength of a noncomposite stringer/ deck configuration can be greatly increased by making the deck and stringers work together as a single unit using composite action.

9.1 CONCRETE DECK. The condition of the deck determines how to obtain composite action between the deck and the stringers. If the concrete deck does not need replacing, create a composite action between the deck and stringers by the introduction of shear connectors or studs across the interface of the two materials. If the deck is badly deteriorated, remove the deck and emplace shear connectors or high strength bolts as discussed in section II of this chapter. Another alternative to recasting the deck is to precast concrete panels to be used as bridge decking (figure 11-11). This method reduces the interruption of traffic by allowing the upgrade to be conducted in stages and not having to wait for a recast deck to cure.

9.2 STEEL GRID DECK. A varying amount of strength can be added to a structure by welding the grid to the top flange of the stringers. The strength increase is based on the stiffness that can be generated by the deck to resist bending. If the grid is filled with concrete, it would act as a concrete deck with the welds providing the interface normally achieved by shear connectors.



**NOTE: SHEAR STUDS SHOWN ARE
ACTUALLY ADDED AFTER
PRECAST DECK IS POSITIONED.**

Figure 11-11
Precast deck with holes.

10. POSTTENSIONING. Posttensioning can be applied to an existing bridge to meet a variety of objectives. It can relieve tension overstresses with respect to service load and fatigue-allowable stresses, reduce or reverse undesirable displacements, and add ultimate strength to an existing bridge. Posttensioning follows established structural analysis and design principles. A design procedure to posttension steel and composite stringer follows:

10.1 DETERMINE THE STANDARDS to which the bridge is to be strengthened (loads, allowable stresses, etc.).

10.2 DETERMINE LOADS and loads fractions for all stringers (dead load, long-term dead load, live load, impact load).

10.3 COMPUTE MOMENTS at all critical locations for dead load, long-term dead load, and live and impact loading.

10.4 COMPUTE SECTION properties as required.

10.5 COMPUTE STRESS to be relieved by posttensioning at all critical locations.

10.6 DESIGN POSTTENSIONING (tendon force, tendon eccentricity, distribution of axial forces and moments, and tendon length).

$$f = FF (P/A) + MF (Pet/I) \quad (\text{eq 11-1})$$

where:

f = stress at extreme fiber

P = tendon force

A = area of stringer (composite area if bridge is composite)

e = eccentricity of tendon with respect stringer or bridge

c = distance to extreme fiber

I = stringer moment of inertia (composite section moment of inertia)

FF = force fraction (similar to load fraction for live load)

MF = moment fraction (similar to load fraction for live load)

10.7 SELECT TENDONS, accounting for losses and gains:

- $P_{\text{adjusted}} = P / (1 - \text{losses \%} + \text{gains \%}) \quad (\text{eq 11-2})$

Assume a 4-percent loss for relaxation of tendon steel, 7-percent loss for potential error in distribution fractions, 2-percent loss for an approximate 10°F temperature differential between tendons and bridge. Assume a 25-percent gain from truck live load.

10.8 CHECK STRESSES at all critical locations.

10.9 DESIGN ANCHORAGES AND BRACKETS. Typical ones are shown in figure 11-12. Experience has shown brackets should be about 2 feet long.

10.10 CHECK OTHER DESIGN FACTORS (beam shear, shear connectors, fatigue, deflection, beam flexural strength, other, as required).

11. TRUSS SYSTEMS These systems can be strengthened by adding supplementary members to change to a stiffer system or superposition another system onto the existing structure. In cases where the dead load is increased, the substructure must be checked to ensure that it is adequate for the new loading requirements.

11.1 ADD SUPPLEMENTARY MEMBERS. This technique is most often applied to Warren and Pratt trusses (figure 11-13). The most common use of supplementary members is to reduce the unbraced length of the top chords in the plane of the truss. Additional lateral bracing may be required to reduce the effective length in the plane perpendicular to the truss. The load capacity of the top chords in compression can be increased by 15 to 20 percent using this technique.

11.2 DOUBLING A TRUSS.

11.2.1 STEEL ARCH SUPERPOSITION ON A THROUGH TRUSS. A method of upgrading through-truss bridges is to reinforce the existing truss with a steel arch (figure 11-14). A lightweight arch superimposed onto the truss carries part of the dead and live loads normally carried by the truss alone. The truss provides lateral support to the arch. There are two methods of attaching the steel arch to the truss and both methods may require the end panel verticals to be strengthened to ensure adequate lateral support to the arch. In method 1, the existing floorbeams and stringers are assumed adequate to carry the increased live load. In this case, the arch support system is attached to the truss at the existing truss verticals. A conservative design includes the dead load of the arch and the truss, along with the full live load. In method 2, the existing floorbeams and stringers will not carry the increased loading. This requires additional floorbeams at the midpoints of existing floorbeams to increase the capacity of the stringers. The existing stringers can be analyzed as two-span continuous beams, with the new floorbeams providing midspan support. Hangers are attached to the new floorbeams, and the arch is connected to the existing verticals. In the determination of the load-carrying capacity of the reinforced system, the analysis of the arch and truss should be conducted separately, with the two-span continuous stringers providing the loads to each. As an alternative to

these methods, the arch can be posttensioned along the bottom chords. Posttensioning will reduce horizontal forces transferred by the arch to the abutments.

11.2.2 SUPERIMPOSING A BAILEY BRIDGE. Superimposing Bailey trusses onto pony or through-truss bridges is a temporary upgrading method. Normally the Bailey trusses are a few feet longer than the existing truss and are supported by the abutments. The Bailey trusses are connected by hangers to the existing floorbeams (additional floorbeams may be added and connected to the Bailey truss if the stringers are inadequate). The hanger bolts are tightened until the existing truss shows some movement, indicating complete interaction between the Bailey truss and the existing truss (figure 11-15). The Bailey truss is placed inside the existing truss and blocked and braced against the existing truss to provide lateral bracing to the Bailey truss. This may restrict sidewalk or roadway width. A design procedure for this upgrade is as follows:

11.2.2.1 DETERMINE ADDITIONAL moment capacity required of the Bailey truss.

11.2.2.2 DETERMINE INITIAL Bailey truss assembly that meets required moment capacity.

11.2.3 REPLACE THE EXISTING truss with a beam equivalent flexural rigidity.

11.2.4 REPLACE THE SELECTED Bailey truss with a beam of equivalent flexural rigidity.

11.2.5 CONSIDER ADDING additional floorbeams between existing beams if the stringers are inadequate, and connect the Bailey truss to the old and new floorbeams.

11.2.6 CONNECT THE TWO TRUSSES rigidly at the points of application of the loads so that they deflect simultaneously an equal amount. The loads carried by each truss can then be determined based on deflected values and flexural rigidity. If the Bailey is inadequate, select another truss configuration with greater moment capacity.

11.2.7 CHECK REQUIRED shear capacity.

11.2.8 DESIGN HANGERS, lateral bracing, and bearing supports. If separate bearing supports are used as shown in figure 11-15, the Bailey truss adds no additional dead load to the structure.

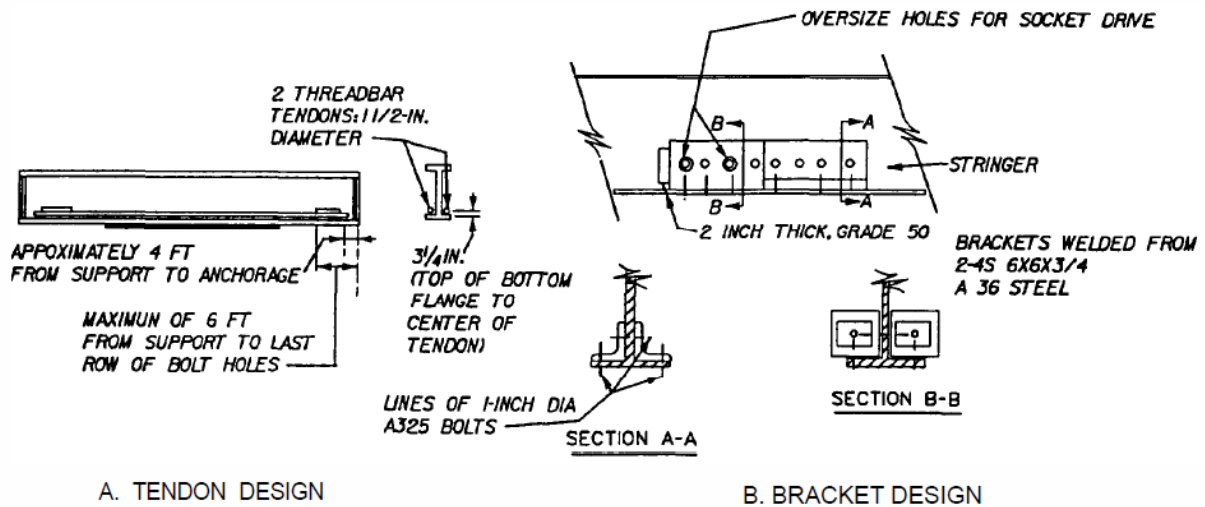
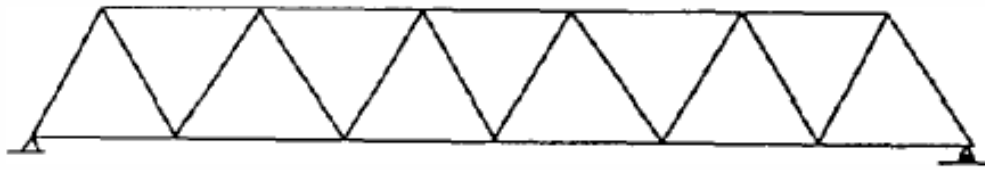
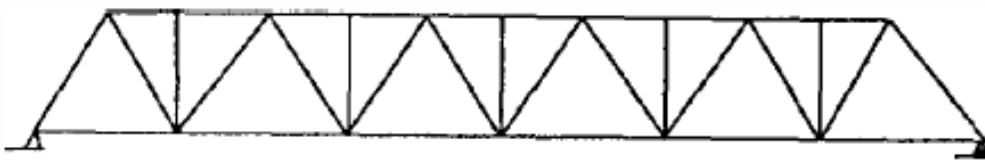


Figure 11-12
Design of posttensioning

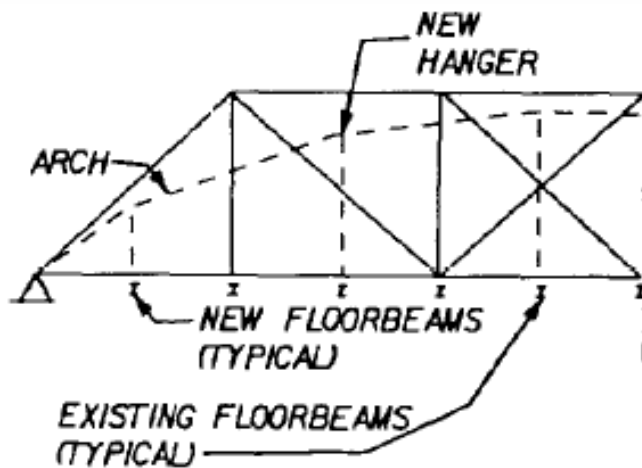


(A) EXISTING TRUSS



(B) MODIFIED TRUSS

Figure 11-13. Adding supplementary members to a truss frame.

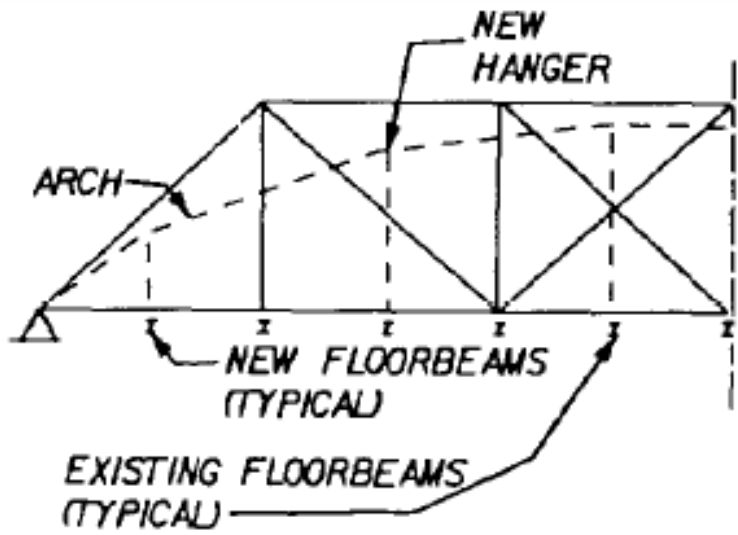


LEGEND

- COMPONENTS OF ARCH SUPERPOSITION SCHEME
- EXISTING TRUSS COMPONENTS

Figure 11-13

Adding supplementary members to a truss frame.



LEGEND

- COMPONENTS OF ARCH SUPERPOSITION SCHEME
- EXISTING TRUSS COMPONENTS

Figure 11-14
Arch superposition scheme.

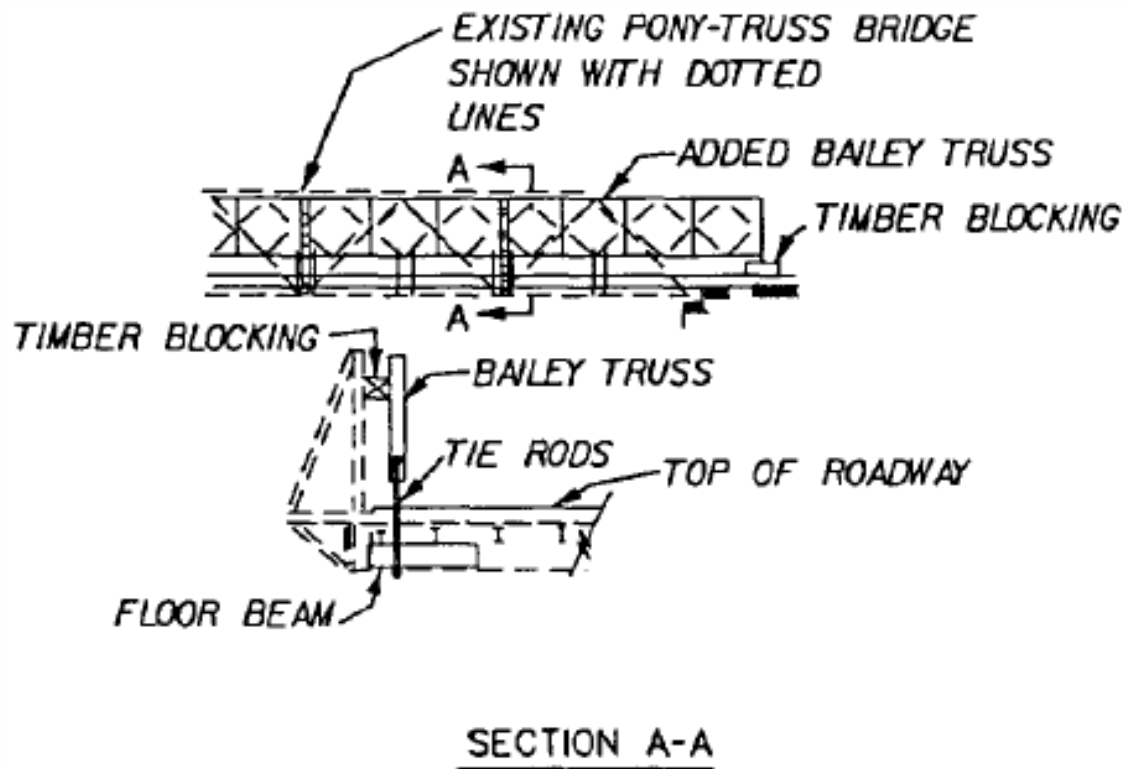


Figure 11-15
Reinforcing a pony truss with Bailey trusses.