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Chapter 12 - Special Superstructure Elements

12.1 Common Types of Bridge Bearings

12.1.1 Foreword

Bridge bearings transfer loads from the superstructure (dead load, live load, and wind load) to substructure and allow beam end translations and rotations. There are two major categories of bridge bearings, those that allow for longitudinal translation (expansion bearings) and those that do not allow longitudinal translation (fixed bearings). Longitudinal translation is developed from changes in temperature, creep and shrinkage. This chapter will mainly discuss the maintenance and repair of expansion bearings, however, discussion will also be provided for fixed bearings where applicable.

What To Look For

- Debris
- Loose anchor bolts
- Missing/broken anchor bolts
- Bearing has moved on seat
- Corrosion
- Frozen bearings
- Inadequate lubrication

12.1.1 Mechanical Bearings

12.1.1.1 Sliding Bearings

Sliding bearings (Figure 12.1) allow beams to slide during expansion and contraction of the superstructure. Sliding bearings generally consist of a sole plate, sliding or rotation plate, and a masonry bearing plate that slide on each other. The flat surface allows for translation from expansion and contraction. The curved surface allows for beam rotation. The plates can be of similar or dissimilar materials. Sliding bearings can also employ the use of a dividing plate made of stainless steel, polytetrafluoroethylene (PTFE), or bronze to reduce friction between the surfaces.

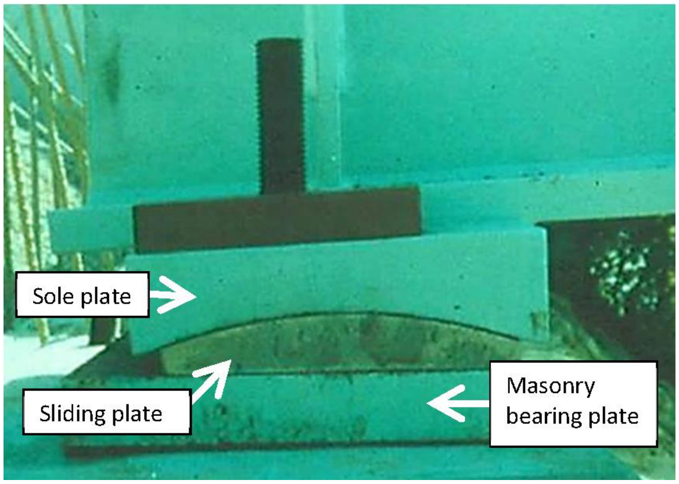

Figure 12.1 Example of a Sliding Bearing

12.1.1.2 Rocker Bearings

Rocker bearings allow expansion, contraction, and rotation of the superstructure by simply rocking back and forth. This type of bearing generally consists of a sole plate, pin, rocker and masonry plate. Rocker bearings can either be unpinned (Figure 12.2 Left) or pinned (Figure 12.2 Right).

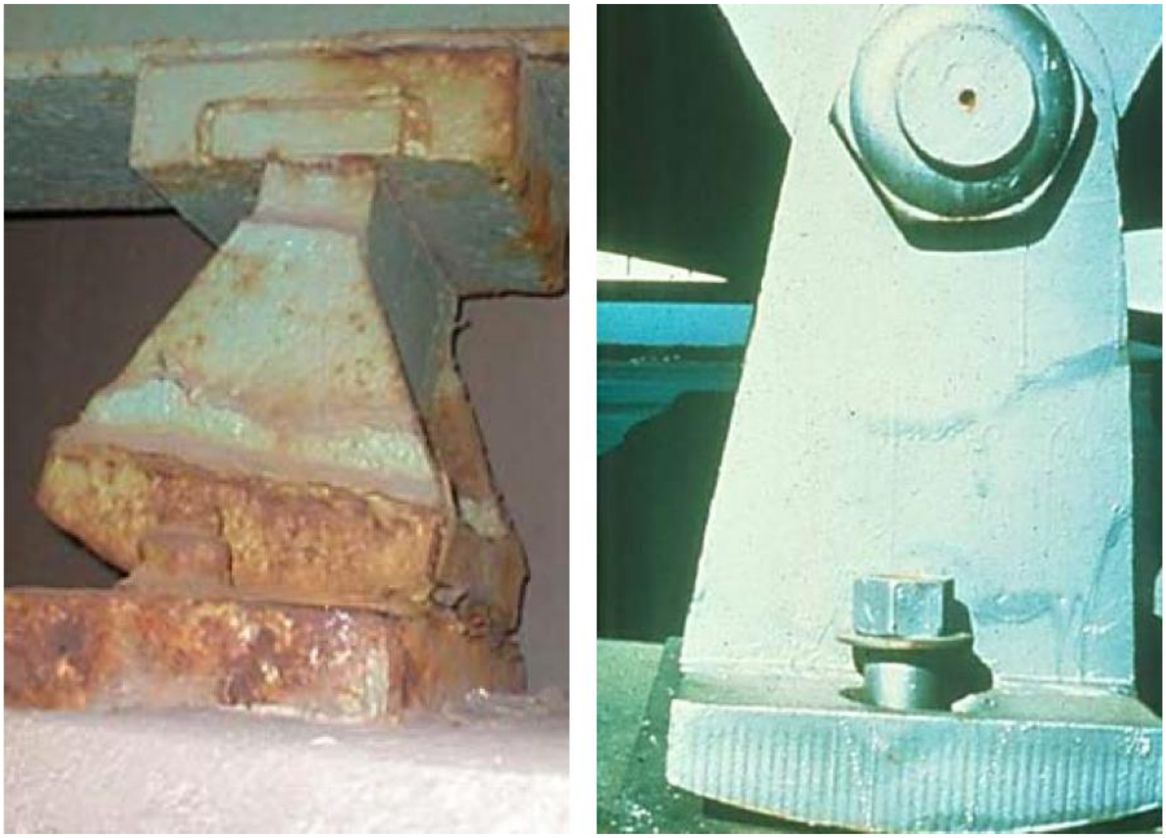

Figure 12.2 Examples of Rocker Bearings. Unpinned (left) and pinned (right)

A fixed pintle keeps the rocker in position on the masonry plate. The pintle is a vertical pin which is driven into the masonry plate at the shop that prevents the rocker from sliding instead of rocking. An example of a pintle is shown in Figure 12.3.

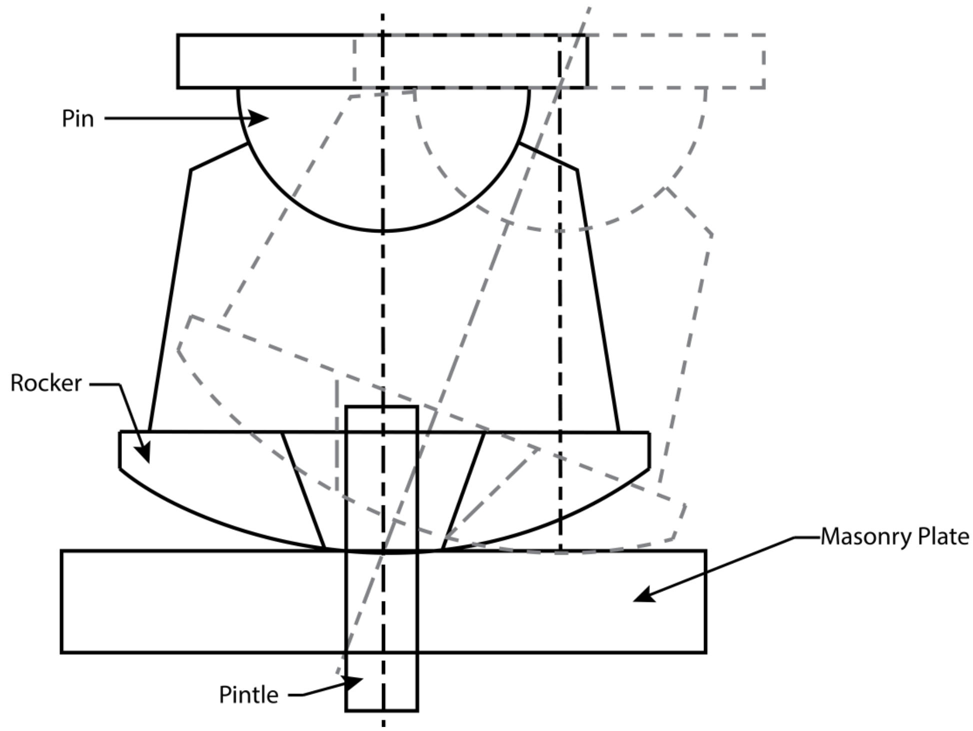

Figure 12.3 Schematic of Rocker Bearing Geometry Showing Pintle

12.1.1.3 Roller Bearings

Roller bearings generally consist of a cylindrical which bear and roll on a masonry plate. An example of a roller bearing is shown in Figure 12.4 (left). Other types of roller bearings will consist of a beam end which sits on a nest of encased ball bearings or rollers, an example of which is shown in Figure 12.4 (right). Generally, the encased roller bearing is difficult to maintain since access to the bearing assemblies is typically not achievable.

Figure 12.4 Roller bearings. Single Roller (left) and Nested Roller (right).

12.1.1.4 Pin and Hanger Bearings

Pin and hanger bearings are used for bridge trusses, girders and beams which connect a cantilevered span and a suspended span of a bridge where there is no substructure. An example of a pin and hanger bearing is shown in Figure 12.5. Pin and hanger bearings are typically located under deck expansion joints where high deterioration can take place. This could lead to freezing pins and overstressing the pins, hangers, and chord members.

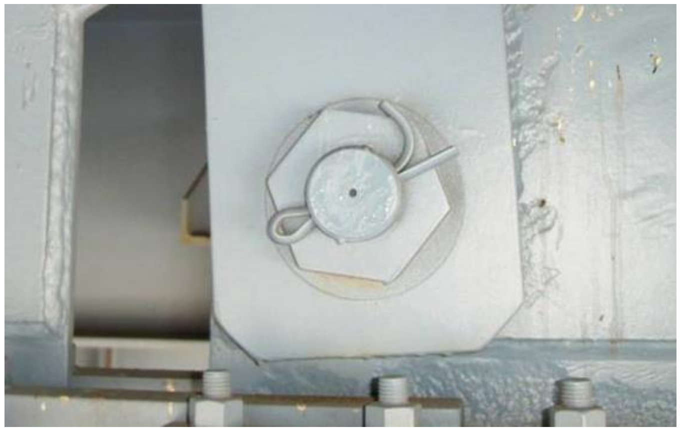

Figure 12.5 Example of a Pin and Hanger Bearing

12.1.2 Elastomeric Bearings

12.1.2.1 Plain Elastomeric

Plain elastomeric bearings consist of layers of elastic materials, typically rubber, which is compressed together. Elastomeric bearings can either be rectangular or circular. They may be flat or have internal beveled steel plates to accommodate steep profiles or beam cambers.

12.1.2.2 Reinforced Elastomeric

Like plain elastomeric bearings, reinforced elastomeric bearings consist of compressed layers of rubber, but will also contain layers of steel plates or fabric to reinforce them internally. An example of a reinforced elastomeric bearing is shown in Figure 12.6. The steel plates reinforcing the bearing can vary in thickness, but generally are around 11 gage thickness (0.1196 inch). Reinforced elastomeric bearings will generally be able to withstand higher loads and superstructure forces (e.g., dead, live, seismic, temperature, creep, shrinkage) than an unreinforced bearing. A schematic of a reinforced elastomeric bearing is shown in Figure 12.7.

Figure 12.6 Photo of a Reinforced Elastomeric Bearing

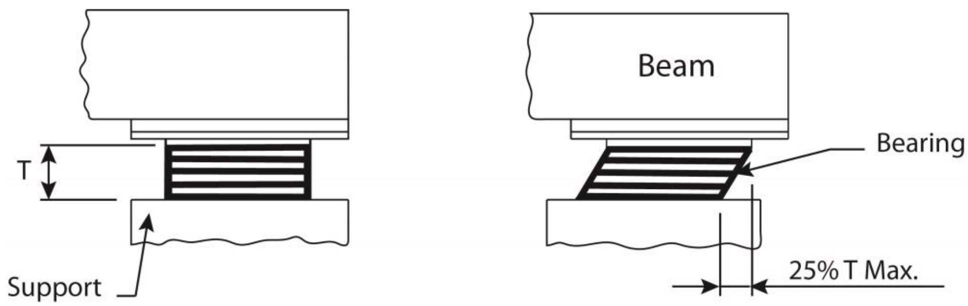

Figure 12.7 Schematic of an Elastomeric Bearing

12.1.3 High Load Multi-Rotational

12.1.3.1 Pot Bearings

Pot bearings generally consist of a masonry plate, steel pot plate which contains an internal elastomeric disc, a steel piston, and a layer of PTFE covered by a steel slide plate, as shown in the schematic in Figure 12.8. Pot bearings are generally used in situations where there are large loadings and rotations occurring in multiple/varying directions (i.e., large spans, deep heavy girders, curved bridges, skewed bridges, etc.). An example of a pot bearing is shown in Figure 12.9.

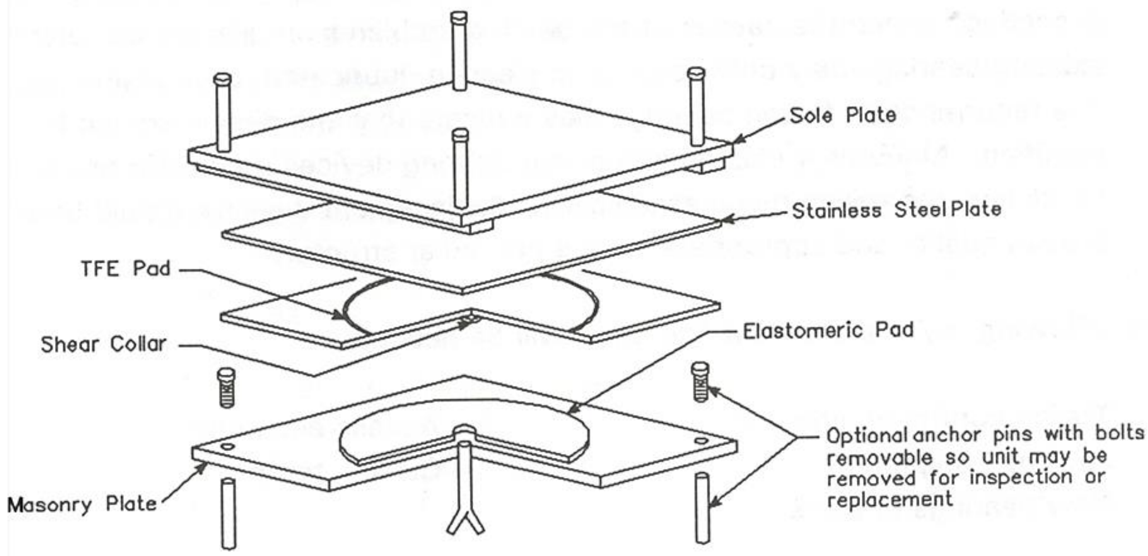

Figure 12.8 Schematic of Pot Bearing

Figure 12.9 Example of a Pot Bearing

12.1.3.2 Spherical Bearings

Spherical bearings generally consist of a concave bottom steel plate which may or may not contain a layer of PTFE within the machined surface and also a convex steel plate which is connected by a sole plate. Spherical bearings are typically used when there are very large loadings which also require rotations about any axis. The spherical bearing is described as a ball and socket which provides little resistance to rotation.

12.1.4 Specialty Bearings

12.1.4.1 Seismic Isolation Bearings

The purpose of seismic isolation bearings is to dampen the forces transmitted from the substructure to the superstructure during a seismic event. These bearings may appear to have configurations as other bearing previously described, but contain internal materials which cannot be inspected or maintained. Seismic isolation bearings can come in a variety of configurations and are typically proprietary to the fabricator of the bearing. An example of a seismic isolation bearing is shown in Figure 12.10.

Figure 12.10 Seismic Isolation Bearing

12.2 Preventive and Basic Maintenance of Bearings

Preventive and basic maintenance of bearings could sustain the design life of a bridge and/or prevent a bridge failure from occurring.

12.2.1 Cleaning

Removing foreign material such as dirt, debris, vegetation and pack rust will help the performance of the bearing since these items could cause the bearing to not function properly. These materials for instance could cause a sliding bearing to freeze, or a rocker bearing to not rotate properly if these materials are not removed from the area. Additionally, progressive ratcheting of rocker bearings can occur from accumulation of additional debris under one side of the bearing during each extreme temperature season, causing the bearing to be unable to rotate back to original position. This has led to bearings tipping over.

This task should be performed on routine intervals.

12.2.2 Anchor Bolt Tightening

Bearings should be inspected for loose anchor bolts. If during an inspection a bearing is found to have loose anchor bolts, they should be tensioned properly especially for a fixed bearing assembly, and even for an expansion bearing if uplift is a concern. If a bearing assembly has loose anchor bolts, the bearing may not be functioning properly and may be causing stress to the superstructure or substructure, as well as to the bearing, which may not be visible. If anchor bolts are not properly torqued, uplift may also be occurring.

12.2.3 Power Washing

Power washing of steel bearings which are exposed to corrosive chloride environments should help in maintaining integrity of the bearing protective coating. This is especially important for bearings at expansion joints where water and salts melt from the roadway above and leak onto the bearing area. Power washing of these locations should be considered a priority once the winter season is over.

12.2.4 Lubrication of Sliding and Rotating Surfaces

Surfaces which are meant to allow for sliding and rotation should be cleaned and lubricated as needed to ensure the bearing is functioning properly and is clean of debris, unless access to the bearing is not achievable. An example of bearing lubrication is shown in Figure 12.11. Power washing or compressed air can be used to clean the bearings. Lubrication can utilize grease, oil, or graphite or other product deemed satisfactory by the owner.

Figure 12.11 Bearing Lubrication

12.3 Repair and Rehabilitation of Bearings

Bearings that are not functioning as they were designed, such as a frozen expansion bearing, may overstress beams and supporting substructure or in the extreme case cause a bridge failure. If bearings are found not to be functioning as designed, they shall either be repaired or rehabilitated to match or exceed the original design intent.

12.3.1 Replacement vs. Repair

When to Call the Engineer

Call the Engineer when determining if bearings should be repaired or replaced.

If it is determined that action must be taken for a bridge bearing to function properly, replacement of the bearing or repair of the bearing should be evaluated. A few key questions should be asked during the evaluation process:

- Is the bearing stressed beyond the point of repair?
- If repaired, could it possibly require future repairs prior to the end of the expected life of the bridge?
- Is there a better option to improve the function of the bridge?
- Is it cheaper to replace than repair (thinking about future costs)?

It is obviously at the owner's discretion how to proceed, however answers to questions such as these can help an owner make an informed decision. Every circumstance will be a case by case basis, but replacement may be required to yield a long term economical solution that increases the life of the structure. If a bearing simply needs to be reset, the replacement cost may not be justified.

12.3.2 Jacking of the Superstructure

When to Call the Engineer

Call the Engineer before planning jacking activities.

Replacing or repairing bridge bearings often requires the superstructure to be lifted or "jacked." It is important to understand that jacking the superstructure is a potentially dangerous activity that could result in a bridge collapse, serious structural damage, injury to workers or a traffic accident. All jacking activities should be thoroughly planned by an engineer prior to being performed.

When jacking the superstructure, some general guidelines should be followed:

- A jacking procedure should be put together by the agency/contractor performing the work and should be reviewed by a licensed engineer prior to commencing.
- Lifting points shall be placed under the main carrying beams of the structure unless a licensed engineer has determined that the diaphragm connection has sufficient capacity to be utilized in lifting the superstructure.
- All beams in the cross section shall be lifted with the same amount of force to avoid excessive stress to the bridge.
- Lifting points shall be carefully considered and planned out prior to jacking the superstructure. Bearing lines of support should always be jacked to the same lift height. If the bridge is a simple span structure, each end of the structure can be lifted independent of the other. If the bridge is a continuous span structure, it should be evaluated by an Engineer to determine if the bridge type, span lengths, and jacking heights would require multiple lines of support to be simultaneously lifted.
- Jacking force shall be determined by calculating the weight of the structure at each particular lifting point and then multiplied by a factor of two or as otherwise determined by the Engineer
- During the jacking process, live load should not be allowed on the bridge unless the jacking forces have accounted for live load plus impact. If live load is allowed during the jacking process, the fluctuating forces being applied to the jacks may need to be considered. Both vertical and horizontal live load forces should be considered.
- As the structure is being jacked, temporary blocking should be placed adjacent to the jack in case the jack fails during the lifting process.

- Depending on the required height the structure needs to be jacked, temporary transitions over deck joints may need to be installed in order for traffic to smoothly transition on and off the bridge.
- If there is insufficient space at the point of support for jacking to be performed, a temporary shoring tower or bent can be constructed adjacent to that point of support.
- The amount of time the structure is lifted by the hydraulic jacks alone shall be determined by the manufacturer of the jacks. If the structure needs to be lifted for longer than the hydraulic jacks allow, the structure shall be lifted by the jacks and placed on temporary blocking until the work is completed.
- Prior to jacking, all bearing anchor bolt nuts shall be removed, bridge railing shall be disconnected (if applicable), and/or impacts to utilities on the bridge (if applicable) should be considered.
- Once the superstructure is jacked (see Figure 12.12), it should be periodically checked for settlement.
- Prior to lowering the superstructure, ensure that positions are correct and anchor bolts are properly aligned with holes/slots.
- After the superstructure is lowered, ensure that deck joints line up and are functioning properly.

Figure 12.12 Lifted or "Jacked" Superstructure

In some circumstances, jacking the bridge from underneath is not a feasible option for many reasons including clearance of existing roadway beneath, bridge is located high above water, bridge is over a railroad, etc. In these instances, the bridge can be jacked above the deck by means of a carrier beam. A carrier beam can be installed above the deck on timber blocking behind the existing support locations. Once the carrier beam is in place, support brackets can be connected to the existing beam by installing threaded rods through the deck. Once all supports are in place, the ends of the carrier beam will be jacked from behind the blocking, which then lifts the superstructure up off its bearings. A schematic of the carrier beam method for bridge jacking is shown in Figure 12.13.

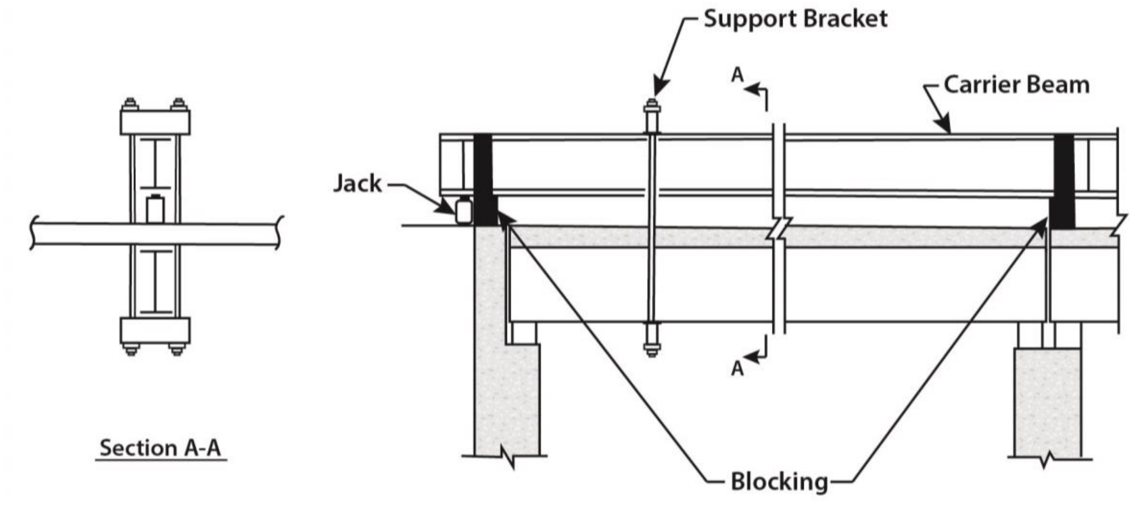

Figure 12.13 Carrier Beam Method for Bridge Jacking

Some of the drawbacks to using a carrier beam system include:

- It will limit space on the bridge deck for traffic and requires traffic control systems.
- It could require fabrication of a beam unless a salvaged beam is available with sufficient capacity.
- The top flange of the carrier beam may need to be braced for buckling resistance which would also limit space on the topside of the deck.
- It may only lift the bridge in segments rather than uniformly across the cross section.
- It requires holes to be drilled through the deck.

If it is determined necessary to use a carrier beam, it shall be designed by a licensed engineer to withstand all the necessary dead loads and live loads to which it will be subjected.

When to Call the Engineer

The carrier beam should be designed by a licensed engineer to withstand all the necessary dead loads and live loads to which it will be subjected.

12.3.3 Resetting of Bearings

If bearings require resetting, they should be positioned so that they are centered at the median temperature for the geographical area. If bearings need to be set or reset at temperatures other than median temperature, the bearings can be offset by using the (contributing expansion length in inches) multiplied by (coefficient of expansion) multiplied by (± delta degree from the median temperature). For steel superstructures, the coefficient of expansion is 0.0000065 ($6.5x10^{-6}$) per °F. For concrete superstructures, the coefficient of expansion is 0.0000055 ($5.5x10^{-6}$) per °F. An example is shown in Figure 12.14. The contributing expansion length can be the span length for a simple span but can be different for a continuous span. An engineer should be consulted.

Figure 12.14 Resetting Bearings

12.3.4 Replacement of Bent or Sheared Anchor Bolts

Anchor bolts that have been inspected and found to be bent or sheared off should be replaced.

Suggested Procedure

Replacement of Bent or Sheared Anchor Bolts

1. Put together a replacement plan and jacking procedure (See 12.3.2 Jacking of the Superstructure).
2. Refer to existing construction drawings (if available) and perform measurements to determine where the existing anchor bolts are located. Place new anchor bolts at least 2 inches from existing anchor bolt locations.
3. Fabricate required replacement parts (if necessary, masonry plates, bearings, sole plates, etc.)
4. Install traffic control devices (if necessary) and secure the work zone
5. Jack the existing superstructure, as described in 12.3.2 Jacking of the Superstructure.
6. Remove old bearing assemblies, clean off existing substrate of all debris, mark out locations of new anchor bolts, drill anchor bolt holes, install and grout new anchor bolts as required by design.
7. Install existing or new bearing assemblies
8. Lower the superstructure back into proper position
9. Remove jacking and traffic control devices

When bearings have broken or sheared anchor bolts, all bearings on the bridge should be inspected, as a bent or broken anchor bolt indicates that bearings/joints are not allowing enough movement, and the resulting forces from the restraint are damaging the anchor bolts.

12.3.5 Installation of Bearing Restraints

If during inspection it is recognized that the bridge bearings are "walking" or have shifted from their original design location, restraints can be installed to ensure the beams do not fall off the bearings or that the bearings are not damaged by misalignment. Bearing restraints generally consist of a plate that fits around the existing bearing with anchor bolts to hold it in place. An example of a restrainer plate is shown Figure 12.15.

Figure 12.15 Restrainer Plate

An Engineer must evaluate restrainer plate thickness to bearing depth to determine if the plates limit translation of the bearing. An alternative to restrainer plates would be to replace the bearings with a non-wax impregnated elastomer pad with adhesive attachment. By not having wax in the elastomer material, the tendency for the bearing to walk out is lower, as is the use of adhesive. If restrainer plates are acceptable to the Engineer, the following procedure should be followed:

Suggested Procedure

Installation of Bearing Restraints

1. Refer to existing construction drawings (if available) and perform measurements to confirm the existing bearing dimensions.
2. Fabricate required bearing restraint plates and anchor bolts.
3. Install traffic control devices (if necessary) and secure the work zone.
4. Jack the existing superstructure, as described in 12.3.2 Jacking of the Superstructure.
5. Remove and clean off existing bearings and substrate.
6. Drill anchor bolt holes, install and grout new anchor bolts.
7. Install existing bearings and restraints.
8. Lower the superstructure back into proper position.
9. Remove jacking and traffic control devices.

12.3.6 Blast Cleaning and Coating of Corroded Steel Bearings

If existing steel bearings are found to be in good condition with the exception that the protective coating is failing or has failed, the following procedure can be used to rehabilitate the bearings.

Suggested Procedure

Blast Cleaning and Coating of Corroded Steel Bearings

1. Install traffic control devices (if necessary) and secure the work zone.
2. Jack the existing superstructure, as described in 12.3.2 Jacking of the Superstructure.
3. Remove the existing bearings and clean off the substrate of all debris.
4. Blast clean the existing bearings in all areas that require recoating (if a sliding bearing, sliding surfaces should be cleaned and lubricated) .
5. The bearing shall then be prepared and painted in accordance with the owners/agencies current standards for such repairs.
6. Re-install the bearing device.
7. Lower the superstructure back into proper position.
8. Remove jacking and traffic control devices.

Note that if the coating is only failing in localized areas, attempt should be made to remove deterioration and repaint those localized areas. Another option of repairing localized areas of deterioration is to treat these areas with a spray applied product that removes the rust and simultaneously creates a protective coating. This protective coating would then prevent future deterioration. Both of these options will greatly reduce the scope of work since jacking the superstructure and complete removal of the bearings would not be required.

12.4 Gusset Plates

12.4.1 Introduction

What To Look For

- Accumulated debris
- Section loss/corrosion
- Cracks
- Deformation or buckling
- Missing or damaged bolts or rivets

Gusset plates are truss connecting elements that are located at the truss panel points. They connect truss chords, verticals, diagonals, and bracing members together. As such, they are a major load transfer element of the truss carrying significant loads and stresses.

Failure of gusset plates was determined to be a major contributing factor leading to the I-35W Mississippi River Bridge collapse that occurred in August 2007. Following this catastrophic event, the design load rating and inspection criteria for gusset plates were re-evaluated and updated nationwide.

Gusset plates are typically designated and identified based on their orientation and location, as indicated in Figure 12.16 below. Examples of gusset plate orientation and location include horizontal (lateral) and vertical (either internal or external).

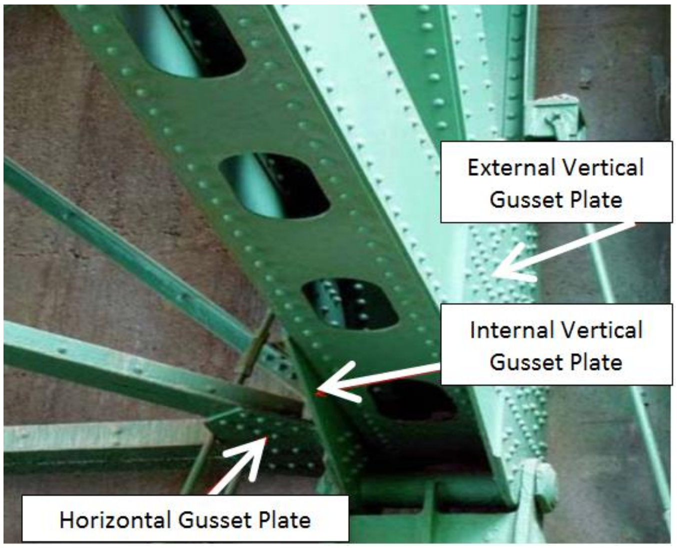

Figure 12.16 Examples of Gusset Plate Orientations and Locations

The truss member connections are susceptible to trapping debris. If not cleaned, the situation may lead to failure of the coating system allowing corrosion at the interface of the gusset plate and connecting members. Common locations of gusset plate detrioration are atop of horizontal gusset plates where gusset plates meet horizontal truss members, and inside the truss panel points. (The area that is semi enclosed by gusset plates and truss members).

12.4.2 Major Repairs, Strengthening or Replacement of Gusset Plates

Major repair, strengthening or replacement of gusset plates is complex and should be performed only by a qualified contractor or agency staff. Because gusset plates are critical to the structural integrity of the truss, repairs should not be attempted by inexperienced or unqualified personnel. Before any work on gusset plates is undertaken, the truss should be analyzed by a structural engineer to develop the necessary bracing, shoring, jacking, and installation procedures specific to the gusset plate being repaired. Failure to carefully follow the bracing, shoring, jacking and installation procedures could result in failure of the truss.

When to Call the Engineer

Contact the Engineer before working on a gusset plate.

12.4.3 Minor Repairs and Strengthening of Gusset Plates

Minor repairs and strengthening of gusset plates require much less effort and can be effectively performed by a bridge maintenance personnel or experienced ironworkers.

These repairs may include:

- Replacement of rivets with HS bolts to increase the connection capacity
- Stiffening of unsupported edges to prevent buckling
- Adding a reinforcement plate at localized section loss locations or for strengthening
- Replacement of horizontal (lateral) gusset plates connecting secondary members
- Other minor repairs that are not covered in this chapter may also be performed (e.g., replacement of lacing bars, end batten plates, internal diaphragms/bulkheads, etc.)

12.4.3.1 Replacement of Rivets with High Strength Bolts to Increase Connection Capacity

If structural analysis determines that a stronger connection is needed, and the rivets control the strength of the connection, strengthening can be achieved by replacing the existing rivets with High Strength (HS) bolts of the same or larger diameter. HS bolts are typically at least 10 percent stronger than rivets. Unless a structural analysis determines otherwise, no more than one or two rivets should be removed and replaced at a time. Rivet removal and replacement method and procedures were provided in Section 11.5. An example of rivet removal and replacement on a gusset plate is shown in Figure 12.17.

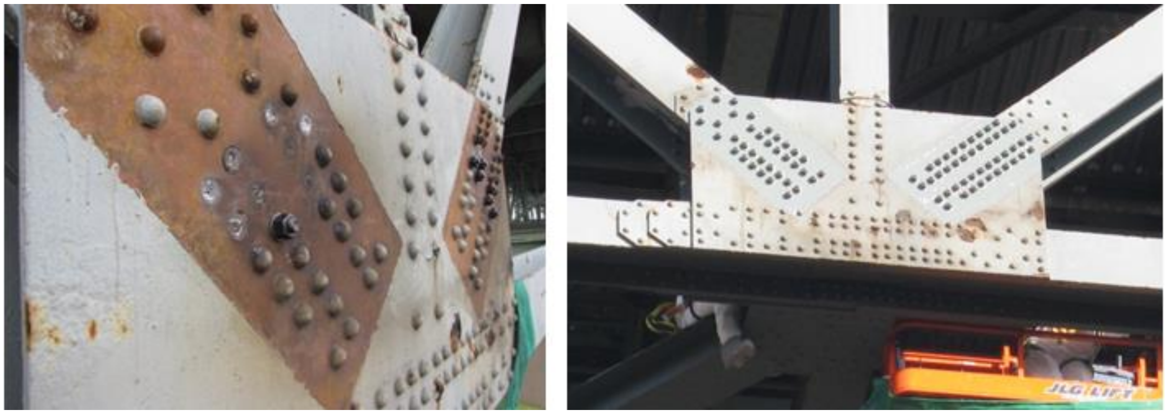

Figure 12.17 Example of Gusset Plate Repair. Rivet Removal (left) and Replacement with HS Bolts (right)

12.4.3.2 Stiffening of Unsupported Edge to Repair or Prevent Buckling

Truss connections can be very stiff but there are typically portions of gusset plates that are unsupported and may tend to bow or buckle when loaded. An example is shown in Figure 12.17. Engineers have been developing sophisticated analysis approaches to evaluate the existing buckling resistance in these connections. There used to be general guidelines based on the length of the unsupported edge as compared to the yield strength of the steel to help safety inspectors determine if the plates may be undersized. But that approach was too simplistic. The important thing for a bridge maintenance worker to remember when working in and around gusset plates is that these unsupported edges may buckle, and if any such bending such as shown in Figure 12.17 is noticed, it should immediately be reported to any engineer to determine the cause and if any strengthening is required.

When to Call the Engineer

Call the Engineer if bending or buckling of the gusset plates is observed, to determine the cause and if additional strengthening is required.

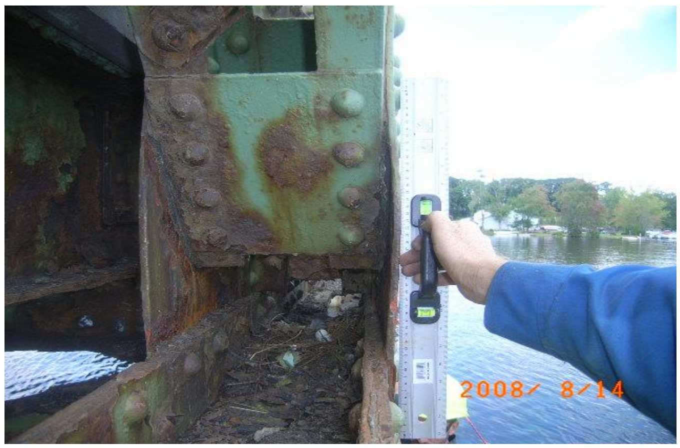

Figure 12.18 Example of Gusset Plate Buckling

A stiffening angle is often added to prevent or repair buckling. The angle selected should have a leg thickness greater than or equal to the gusset plate thickness. 7/8 inch diameter A-325 HS bolts spaced at 3 inches to 6 inches are typically used to attach the stiffening angle. Examples of this repair are presented in Figure 12.19.

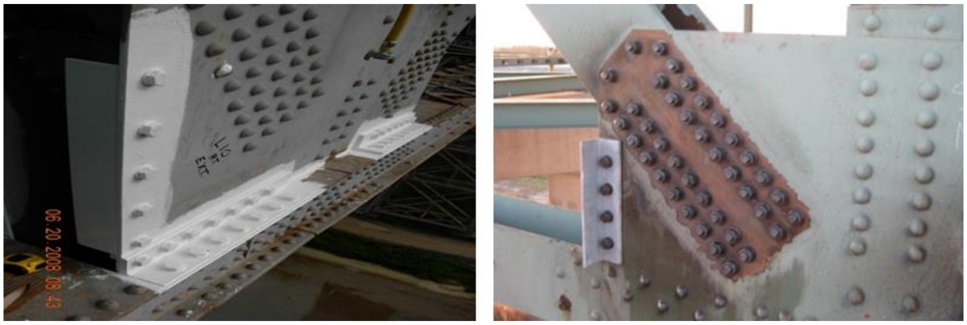

Figure 12.19 Examples of Stiffening Plates Added to Gusset Plate Edges

When to Call the Engineer

All repair procedures should be developed or approved by a qualified engineer.

12.4.3.3 Reinforcement at Localized Section Loss Locations

Surface pitting and localized section loss of the gusset plate surfaces can be repaired by installation of a reinforcement plate to cover and reinforce the affected area as shown in Figure 12.20.

Figure 12.20 Gusset Plate Repair by Installation of Reinforcement Plate

Suggested Procedure

Gusset Plate Repair

1. Fabricate the reinforcement plate with holes drilled to match the existing rivet pattern. The reinforcement plate should be the same grade of steel, and have a thickness greater than or equal to the existing gusset plate.
2. Thoroughly clean the repair area, removing all loose paint and oxidized metal. The cleaning should be performed utilizing needle scalers, power wire brush, grinder, or sandblaster. If grinding, do not gouge which could later cause crack initiation.
3. Paint the repair area with a zinc based primer.
4. Remove rivet heads and verify fit of the reinforcement plate.
5. Drive first rivet shank out and attach reinforcement plate with HS bolt of the same diameter. The bolt shall be tightened snug tight.
6. Remove second rivet shank, preferably located at the diagonally opposite location, and install HS bolt.
7. Verify that the remaining bolts will fit.
8. Install remaining bolts one at a time.
9. Initially snug tighten all the bolts making sure all surfaces are mated. Use turn-of-nut method to fully tension all the bolts after the snug tight operation, or use tension-controlled bolts. See turn-of-nut requirements published by the Research Council on Structural Connections and Chapter 13 of this manual.
10. Paint the repair with a paint system to match the existing paint.

A similar procedure can be used for a gusset plate for connection strengthening.

12.4.3.4 Replacement of Horizontal (Lateral) Gusset Plates

These repairs are typically performed for secondary truss members such as lateral bracing, and sway frame members. The repair may require bracing to stabilize the existing members prior to disconnecting them from the gusset plate and should be completed under the guidance of an Engineer following development of a location specific repair procedure.

Typically the following order of repair operations should be followed:

1. Install support or bracing in accordance with the repair procedure. Tension ties can be used for tension members and compression struts for members that are in compression. Sometimes support from other truss members can be effective, as can be seen in Figure 12.21.
2. Make a template of the existing gusset plate; fabricate replacement plate and connecting elements.
3. Disconnect bracing member from the deteriorated gusset plate.
4. Remove existing gusset plate.
5. Clean the repair area; remove all loose paint and oxidized metal utilizing needle scaler, power wire brush, grinder, or sandblaster. If grinding, do not gouge which could later cause crack initiation.
6. Paint the repair area with a zinc based primer.
7. Install replacement gusset plate.
8. Reconnect previously disconnected bracing member using high strength bolts.
9. Paint the repair with a paint system matching existing.

Figure 12.21 End Diagonal Support

The actual step-by-step repair procedure shall be developed based on repair specifics and actual field conditions.

Before and after repair photos of a vertical gusset plate replacement are shown in Figure 12.22.

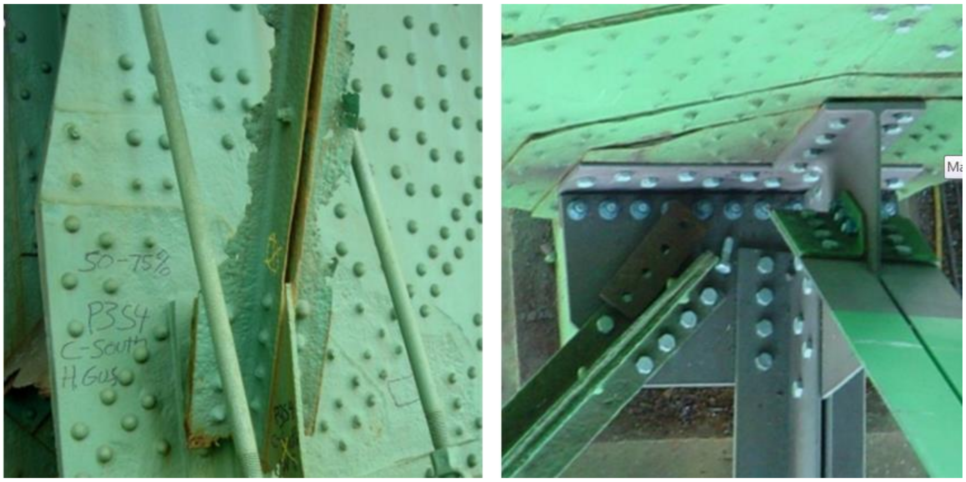

Figure 12.22 Lateral Gusset Plate Repair. Before Repair (left). After Repair (right).

12.5 Cables

12.5.1 Introduction

There are essentially three types of bridges that use the cable system:

- Cable Stayed Bridges
- Suspension Bridges
- Tied Arch Bridges

12.5.2 Cable Types

Regardless of the bridge design and type, these are the types of cables generally available:

- Cables of locked coil construction
- Cables with parallel wires
- Cables with parallel strands
- Parallel-bar Cables

12.5.2.1 Locked-Coil Cables

In the locked-coil cables, the wires are arranged in successive layers, wound around a central core which consists of circular, parallel wires (Figure 12.23). On the outside, elongated S-sections are used, and in view of the extent of their overlapping, they form an envelope which is more or less watertight (hence the name 'locked-coil cable'). The advantages of locked-coil cables are the ease of placement, the economy (because ducts and grouting are unnecessary), the reduced anchorage space, and the great flexibility which makes it possible to use guiding saddles at the pylons instead of intermediate anchorages.

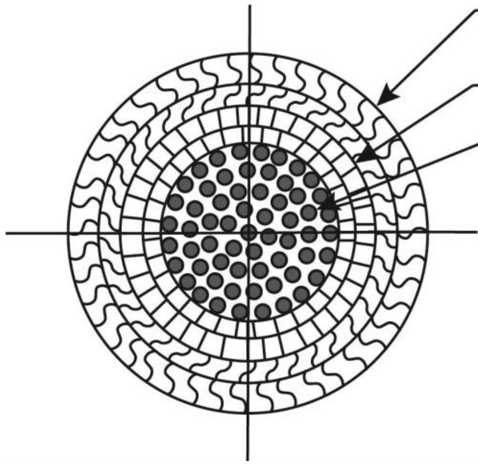

Figure 12.23 Locked-Coil Cable

12.5.2.2 Cables with Parallel Wires

These are of high-strength, drawn steel that are placed in metal or polyethylene ducts. Parallel wire cables used in cable-stayed bridges conforms to ASTM A421, type BA, low relaxation. Corrosion protection is provided by the polyethylene sheathing filled with cement grout (Figure 12.24). The tubing is usually wrapped with polyvinyl film tape.

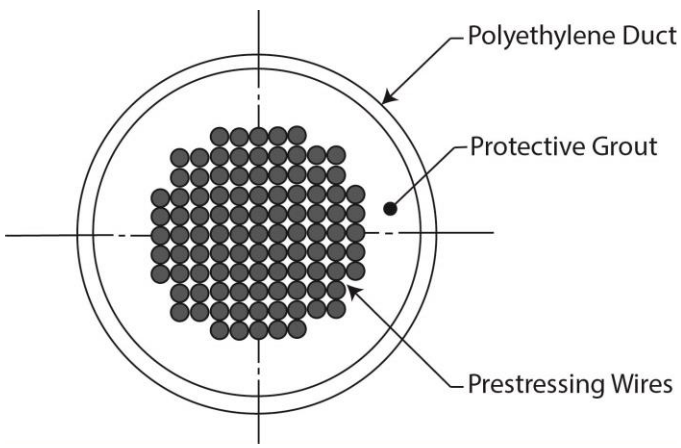

Figure 12.24 Parallel Wire Cable

12.5.2.3 Cables with Parallel Strands

Structural wire strand is an assembly of wires formed helically around a center wire in one or more symmetrical layers. A schematic of a cable with parallel stands is shown in Figure 12.25. Cable sizes normally range from 50 to 100 mm.

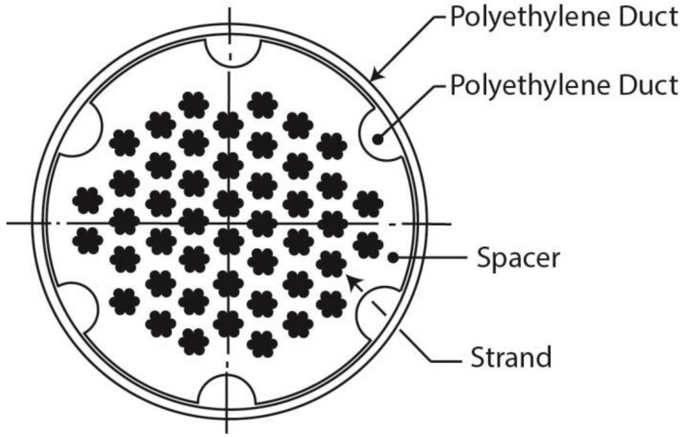

Figure 12.25 Parallel Wire Strand

When the cables are stressed, the resultant lateral stresses reduce the fatigue resistance. Also, sensitivity to corrosion is increased, since, for a given cross-sectional area the perimeter of a section made up of many wires is greater than that of a single circular member.

12.5.2.4 Parallel Bar Cables

Parallel bar cables are formed of steel rods or bars which are parallel to each other and encased in metal ducts kept in position by polyethylene spacers. Examples of parallel bar cable cross-sections, with and without couplers, are shown in Figure 12.26. The bars can slide in the longitudinal direction, which simplifies the process of tensioning them individually. Injection of cement grout, carried out after erection, enables the system to act as one unit in resisting stresses.

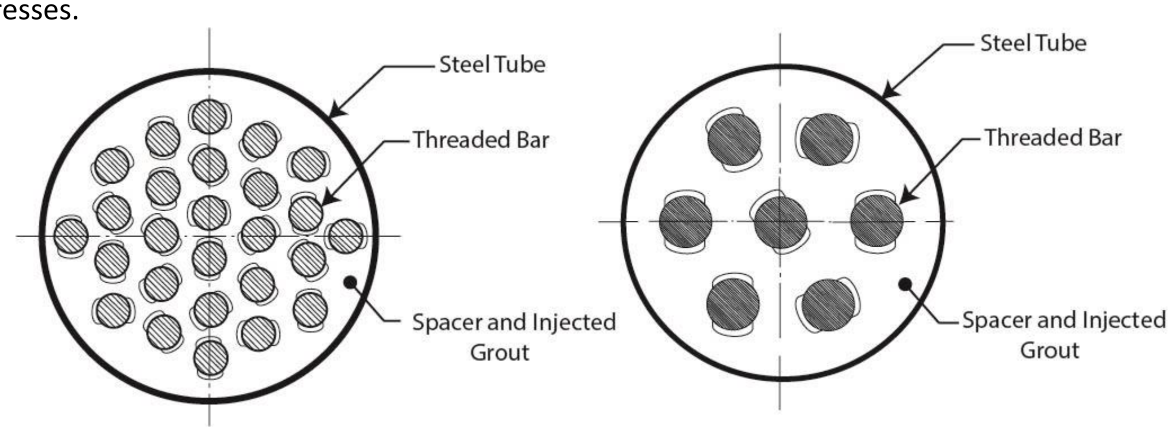

Figure 12.26 Parallel Bar Cables. Without Couplers (left) and with Couplers (right)

12.5.3 Suspension Bridge Components

The main suspension cables in a suspension bridge are typically supported on saddles at the top of the towers and are anchored at each end, as shown in Figure 12.27. The suspension cables are in tension and require massive anchorage at both ends, and are typically load-path non redundant. The main cables are usually of parallel wires clamped at points where suspenders connect with them to support the bridge deck. The individual wires have a 0.192 inch diameter, and a 0.002 inch zinc coating around the wire, resulting in a total diameter of 0.196 inch. The zinc coating provides cathodic protection against corrosion. The suspension bridge cables transfer loads to the towers via the saddles atop the towers, the performance of the cables is affected by the saddle detail.

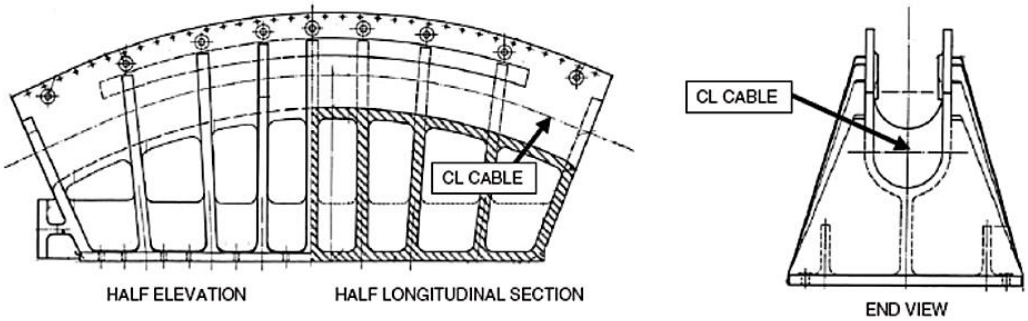

Figure 12.27 Elevation (left) and Cross-Section View of a Typical Saddle (right)

Suspender cables are the vertical cable elements that connect the deck sections to the main cables. The composition of the suspender cables varies considerably. Suspenders made of wire rope have two legs, but they are actually a single continuous piece that rises from the deck, loops over the cable band, and returns to the deck, using only two sockets. Examples of suspender cables are shown in Figure 12.28. When suspenders are designed to ride cross saddle over the cable bands, then they contribute to the normal force provided by the cable band bolts and increase resistance to cable sliding. If suspenders are made of wire strands that cannot be bent over the main cable, then they require a socket, as shown in Figure 12.28 (right). They are much stronger and thus lighter than rope suspenders and consequently simplify cable band detailing.

Figure 12.28 Suspender Cable Looped over Cable Band (left) and Suspender Cable with Open Socket Connection (right).

Cable bands consist of two cylinder halves bolted together over the circumference of the cable (Figure 12.29). The number of bolts per cable band is dependent on the slope of the cable at the suspender attachment points. The tension in the cable band bolt that squeezes the two halves together decreases with time due to creep of the zinc coating on the wires.

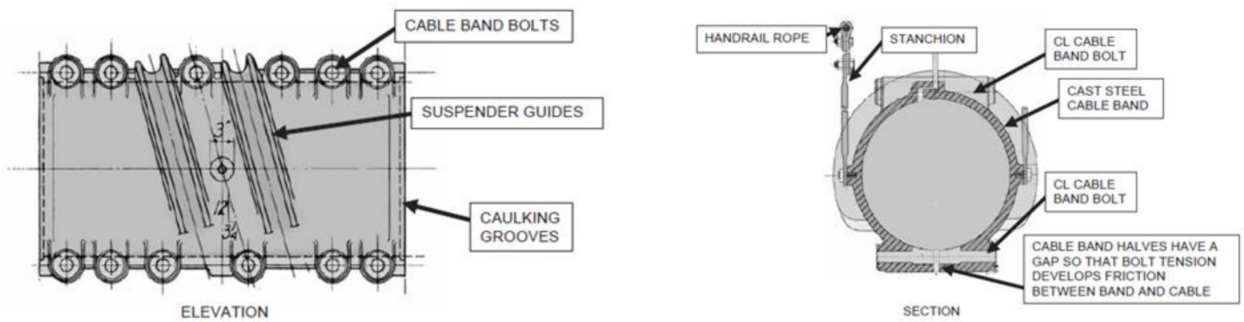

Figure 12.29 Cable Band Schematic. Elevation (left) and Section (right) Views.

12.5.4 Cable Stay Bridges

The concept of a cable-stayed bridge is simple. A bridge carries mainly vertical loads acting on the girder. The stay cables provide intermediate support for the girder so that it can span a long distance. The basic structural form of a cable stayed bridge is a series of overlapping triangles comprising the pylon, the cables and the girder. All these members are under predominantly axial forces, with the cables under tension and both the pylon and the girder under compression.

Cables are the most important elements of a cable stayed bridge. They carry the load of the girder and transfer it to the tower and the back stay cable anchorage. The cables in a cable-stayed bridge are all inclined. The most popular type of cable nowadays uses seven wire strands. These strands were originally developed for prestressed concrete applications and offer good workability and economy. They can be either shop fabricated or site-fabricated. In most cases, corrosion protection is provided by a high-density polyethylene pipe filled with cement grout.

As an alternative to cement grout, greased or galvanized strands of the cables could be individually sheathed. A sheathed, galvanized strand may have wax or grease inside the sheathing.

12.5.5 Tied Arch Bridges

The tied arch bridge is the other bridge type that relies on hangers of the cable type as part of its load supporting system. The hangers are mostly in tension and are vertically connected to the deck. Some hangers cross other hangers at least twice in which case the bridge is known as network arch bridge.

12.5.6 Cable Defects

What To Look For

- Corrosion
- Pitting
- Section Loss
- Failure of the Paint System
- Collision Damage
- Overload Damage
- Fatigue Cracking

12.5.7 Inspection Locations and Procedures

Cable supported bridges are unique in their design and behavior. Typically, newer Cable Stayed Bridges and Suspension Bridges have an individualized maintenance manual akin to an owner's manual. Older and less complex wire rope or eyebar suspension bridges may not have such a manual. When available, it should be first resource of the inspector to gain understanding of the material type of the cable and the design protocol. While the procedures enumerated below are not necessarily exhaustive, they can serve as a guideline to a satisfactory inspection regime in conjunction with the maintenance manual if available. However, the ability to recognize potential issues in between the regular biennial inspections is very important.

12.5.7.1 Main Suspension Cable

Main Suspension Cables

Inspect the main suspension cables for indications of corroded wires. Inspect the condition of the protective covering or coating especially at low points of cables, areas adjacent to the cable bands, saddles over towers and at anchorages.

Figure 12.30 Main Cable Inspection

Cable Wrappings

Inspect the wrapping wire for cracks, staining and dark spots. Check for loose wrapping wires. If there are cracks in the caulking where water can enter, this can cause corrosion of the main suspension cable. Check for evidence of water seepage at the cable bands, saddles, and splay casting saddles. Note that the force from the main cable is distributed through the splay saddle, bridge wires, strand shoes, and anchor bars. These items are shown in the anchor block schematic in Figure 12.31.

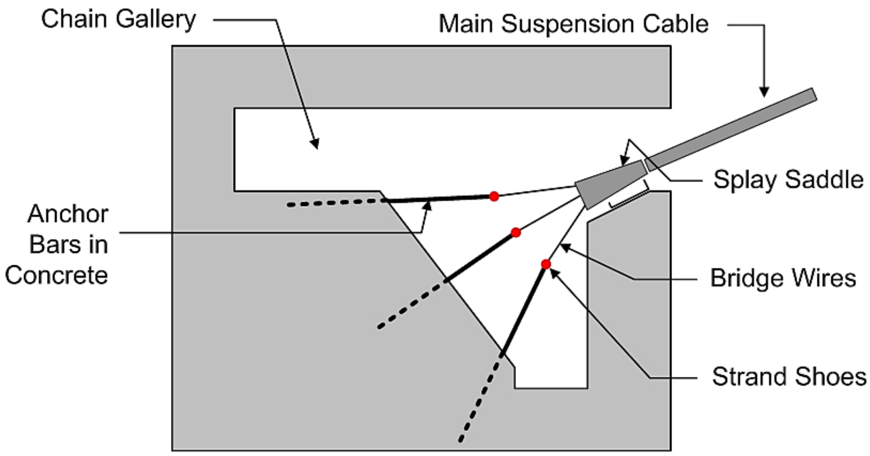

Figure 12.31 Anchor Block Schematic

Cable Bands

Inspect the cable bands for missing or loose bolts or broken suspender saddles. Signs of possible slippage are caulking that has pulled away from the casting or "bunching up" of the soft wire wrapping adjacent to the band. Check for the presence of cracks in the band itself, corrosion or deterioration of the band, and loose wrapping wires at the band.

Sockets

Inspect the suspender rope sockets for corrosion cracks or deterioration

- Abrasion at connection to bridge superstructure
- Possible Movement

Suspender Cables and Connections

Inspect the suspender cables for corrosion or deterioration, broken wires and kinks or slack. Check for abrasion or wear at sockets, saddles, clamps and spreaders. Note any excessive vibrations.

Vibrations

Note and record all excessive vibrations.

Hand Ropes

Inspect the hand ropes and connections along the main cables for loose connections of stanchion to cable bands or loose connections at anchorages or towers. Check also for corroded or deteriorated ropes or stanchions, bent or twisted stanchions (hand rope supports), and too much slack in rope.

12.5.7.2 Cable Stay Bridge Inspection

The inspection of the cable elements should include the following:

- Cable wrappings and wrap ends near the tower and deck
- Cable sheathing assembly
- Dampers
- Anchorages

An example of stay cable inspection is shown in Figure 12.32.

Figure 12.32 Inspection of Stay Cables

Cable Wrapping

Common wrapping methods for corrosion protection of finished cables include spirally wound soft galvanized wire, neoprene, or plastic wrap type tape. The wrappings should be inspected for corrosion and cracking of soft galvanized wire, staining, and dark spots indicating possible corrosion of the cables and loose wrapping wire or tape.

Check for evidence of water seepage at the cable bands, saddles and splay castings.

Cable Sheathing Assembly

The most common types of cable sheathing assemblies are steel sheathing and polyethylene sheathing.

If steel sheathing is used, inspect the system for corrosion of protective coatings and weld fusion issues. Bulging may indicate broken wires. An example of bulging is shown in Figure 12.33. Splitting may be caused by water infiltration and corrosive action. Cracking is sometimes caused by fatigue. An example of deterioration of steel sheathing is shown in Figure 12.33.

If polyethylene sheathing is used, inspect the system for nicks, cuts, and abrasions.

Check for cracks and separations in caulking and in fusion welds. Bulging may indicate broken wires. Splitting is sometimes caused by temperature fluctuations because the coefficient of the thermal expansion for polyethylene is three times higher than the value for steel or concrete. Cracking is sometimes caused by fatigue.

Figure 12.33 Example of Steel Sheathing Deterioration. Corrosion (left) and Bulging (right).

Maintenance worker repair of any cracking or splitting of the sheathing should only be temporary in nature until an engineered solution can be determined.

When to Call the Engineer

If cracking, splitting, or bulging of cable sheathing is observed, it may indicate more significant distress or damage of the cable inside.

Anchorages

Inspect the transition area between the steel anchor pipe and cable for water tightness of neoprene boots at the upper ends of the steel guide pipes. Check for drainage between the guide pipe and transition pipe, and defects, such as splits and tears, in the neoprene boots. Check for sufficient clearance between the anchor pipe and cable, noting rub marks and kinks.

Tower Anchorage

Inspect the cable anchorages for corrosion of the anchor system. Check for cracks and nut rotation at the socket and bearing plate, and seepage of grease from the protective hood.

Other Items

For example, the inspection of the cable system should also include anchor pipe clearances, flange joints, and polyethylene expansion joints. Note and record all excessive vibrations including amplitude and type of vibration along with wind speed and direction.

12.5.8 Cable System Maintenance

In this segment we consider some of the techniques and methods available for maintaining the aforementioned bridge cable systems once an inspection has been completed.

12.5.8.1 Cable Compaction

Cable compaction may be required of the main cable of a suspension bridge. Cable recompaction starts at one of the cable bands and proceeds towards the other cable band. The compactor normally consists of a segmented steel ring with four 100 ton center hole hydraulic jacks operating simultaneously to constrict the ring. The jacks were equally pressurized through a manifold and a hydraulic pump powered by compressed air. Compaction intervals and temporary seizing band spacing are determined in the field based on the degree of expansion of the cable after wedging. Cable circumference measurements are taken after pressurizing the compactor and after banding and releasing the compactor to monitor the relaxation of the bands and to ensure that the original diameter was not exceeded. Examples of cable compaction are shown in Figure 12.34.

Figure 12.34 Cable Compaction Photos (Courtesy of Caltrans)

12.5.8.2 Oiling

The recent practice in the United States is to treat damaged cables by oiling and rewrapping them for their entire lengths. This entails major construction work and installation of work platforms below the cables to provide access and would not normally be done by typical bridge maintenance forces. The existing wrapping is removed panel by panel, wedges are driven into the cable, and oil (usually linseed oil with or without additives) is poured into the wedged grooves. The cables are then rewrapped, usually with wire and a sealing paste and sometimes with a neoprene overwrap.

12.5.8.3 Painting

Traditionally suspension bridge cables were protected with the same paint system used for the steel structure. More recently water-based acrylic coatings that contain highly elastic polymers and cure to a rubbery coating have been used for painting suspension cables. Because of their ability to sustain up to 200 percent elongation without cracking or peeling, they have been successfully used for the maintenance painting of wire wrapped cables on many existing suspension bridges and new bridges. In addition, these coatings have proved to have a long life in other applications, especially in environments where superior salt water and chemical resistance are required. One of such materials is the proprietary coating Noxyde®, manufactured originally in Belgium and now licensed for manufacture in other countries.

It is important for bridge maintenance workers to recognize that these coatings are very different from the typical coatings used on steel bridges, and therefore should not be touched-up or spot painted without first consulting a specialist.

12.5.8.4 Cable Vibrations

A number of different methods have been considered and used on bridges to control aerodynamic instability problems in cable stays, and these include:

- Use of neoprene cushioning pads between cables and the ends of the anchor pipes.
- Cross-ties or cable restrainers have been used primarily as a temporary solution to cable stay vibration problems.
- Hydraulic dampers can serve as vibration control as permanent mitigation of rain vibration of the stay cables. The dampers act similar to automotive shock absorbers, absorbing the vibratory motion of the stay cables (motion is absorbed as strain energy), and providing additional damping to prevent further motion of the stay cable.

When to Call the Engineer

Call the Engineer when any vibration greater than 1 inch is observed.

12.5.8.5 Dehumidification

Many of the main components of major bridges are steel structures. To ensure a long service life and provide an appropriate level of safety, these structures must be protected from corrosion. Corrosion protection has traditionally been provided by means of surface treatment, such as blasting and painting. More recently, dehumidification has been developed as an alternative method. Dehumidification has economic and environmental advantages to traditional surface treatment methods.

A dehumidification system is considered a state-of-the-art method for protecting main cables from corrosion. It is composed of a sealing system, a dry air system and a monitoring system. This is the only system which completely prevents corrosion, whereas other systems at best can only slow it down. The dehumidification system produces dry air and blows it through sections of the main cables. The system assures overpressure inside the sealed cable system. While the sealing system may have minor imperfections in the form of small leaks, no water or moisture will enter the cables (due to the overpressure).

Dehumidification systems have also been installed in the anchorage housings of most suspension bridges. As a bridge maintenance worker, it is important to understand the importance of the system. An operation and maintenance manual is usually supplied with these systems.

The dehumidification system is made up of the following main components:

- A sealing system for the main cables, including cable bands, saddles and other connected components.
- A dehumidification system capable of producing and blowing dry air through the main cables (see Figure 12.35).
- A control and monitoring system.

An example of a dehumidification plant injection site and exhaust are shown in Figure 12.36

Figure 12.35 Dehumidification Plant (Courtesy of COWI A/S)

.

Figure 12.36 Dehumidification Plant Injection Site (left) and Exhaust (right) (Courtesy of COWI A/S)

12.6 Earthquake Restrainers

12.6.1 Introduction

Bridges in seismically active regions may have earthquake restrainers attached to the superstructure as part of a seismic retrofit strategy. The earthquake restrainers may be steel rods or cables and may be visible from the ground or they may be hidden within the structure. Earthquake restrainers may be placed along the length of the bridge, vertically or transverse to the length. Regardless of the orientation, the functions of the restrainers are to hold the superstructure together during a seismic event and to prevent the superstructure from falling off its support. The maintenance of earthquake restrainers from corrosion or deterioration is similar to other steel superstructure components. Earthquake restrainers have additional unique maintenance needs that should also be considered. To effectively maintain earthquake restrainers, it is important to understand how they are intended to function during daily or seasonal thermal expansion cycles and during a seismic event, and what to do once they have been engaged during an earthquake.

12.6.2 Earthquake Restrainer Design Background

In past earthquakes, bridges have collapsed because the superstructures were displaced by seismic forces beyond the ends of the bearing supports at columns, piers, and abutments. Earthquake restrainers are rods or cables attached to the superstructure that are designed to prevent the superstructure from moving beyond their supports. Example photos and schematic designs are presented in Figure 12.37 through Figure 12.41.

Earthquake restrainers are designed to limit superstructure displacements during a seismic event; however they must accommodate normal thermal movements that occur every day. The accommodation of daily or seasonal thermal movements requires that the earthquake restrainer rods or cables be free to expand and contract without engaging the superstructure. A maintenance crew should never tighten any earthquake restrainer that appears loose or that has a sag in the cable before consulting an engineer.

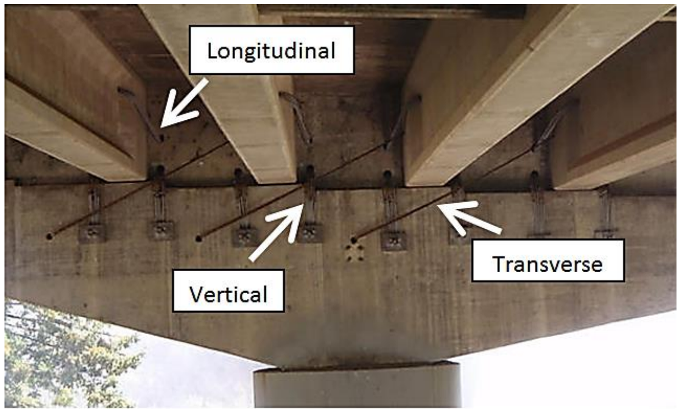

Figure 12.37 Vertical, Transverse and Longitudinal Restrainers

Figure 12.38 Earthquake Restrainer System

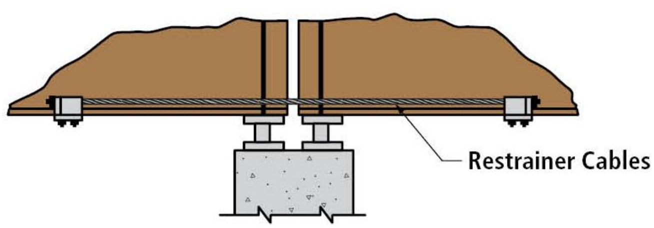

Figure 12.39 Longitudinal Restrainer of Steel Girders

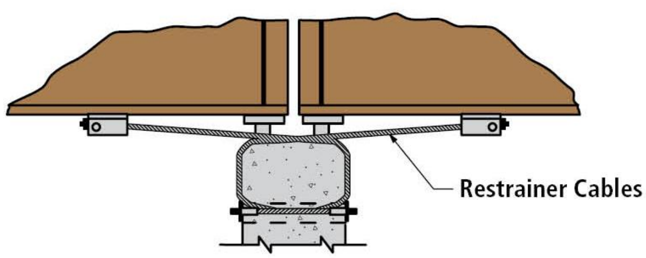

Figure 12.40 Longitudinal Restrainer of Steel Girders with Connection to Substructure

In some applications, the earthquake restrainers are designed to hold the superstructure down from seismic uplift forces. The vertical orientation is common at supports with rocker bearings or similar bearings that could topple over if the superstructure was lifted off the bearing by seismic forces (See Figure 12.41). The vertical orientation of earthquake restrainers are typically much tighter than longitudinal or transverse applications because they need to engage quickly to restrain uplift and because their vertical orientation allows for thermal expansion without slack in the cable.

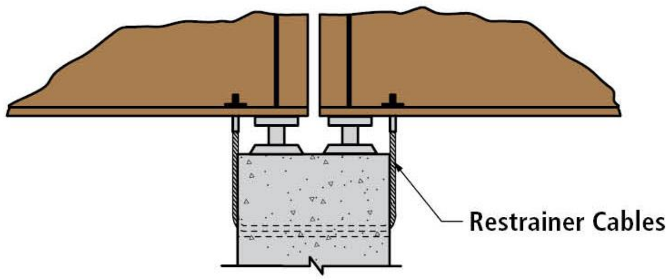

Figure 12.41 Vertical Restrainer

12.6.3 Common Maintenance Activities

12.6.3.1 Corrosion Mitigation

Earthquake restrainers are typically constructed of galvanized steel rods or cables and are fairly resistant to corrosion but not immune. Restrainers are typically around joints and can be subject to significant chloride levels from decks that are salted as the salted water drains through the joints. Coastal bridges have also been seen to have earthquake restrainers corrode to the point of replacement within 10 years of installation. Like other galvanized steel, the restrainers can be painted to protect exposed portion of the restrainers. Experience in California has shown that the cable or rod length spanning the joint is often the critical corrosion location. This location cannot be painted effectively and is also subject to abrasive wear from seasonal and daily thermal cycles that tend to wear away any surface corrosion protection. Proper joint maintenance is the key preventive measure that can be performed by maintenance crews. Flushing with fresh water can also reduce chloride levels on the steel and slow down the corrosion. Earthquake restrainers are typically fairly easy to remove and replace once corrosion begins to reduce the steel section.

12.6.3.2 Securing Restrainer Nuts

Earthquake restrainers come in varying lengths but always have threaded rods at the ends to allow nuts to be tightened to hold the restrainer in place at the ends. To allow for normal thermal expansion and contraction without engaging the restrainers, the restrainers are not tightened. Because the restrainer nuts are not torqued down, they can work their way loose from normal traffic vibrations. To prevent the nuts from coming loose, a second “jam nut” is typically placed behind the restrainer stud nut (see Figure 12.42). The jam nut is tightened against the back of the stud nut by applying torque in both nuts in opposing directions to lock in the nuts without over tightening the restrainer rod or cable. During post-earthquake inspections in California, bridges have been discovered with both nuts laying inside box girders and the cables pulled through hinges intact. Peening the threads after the jam nuts are installed should avoid nuts walking-off the end of the restrainer studs. Alternatively, a commercial thread locking product can be used after installing both nuts.

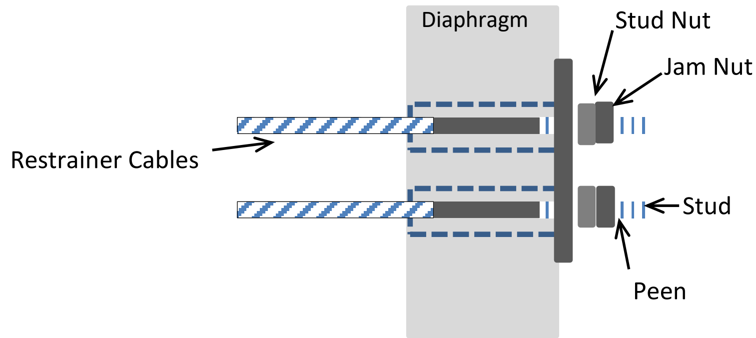

Figure 12.42 Typical Restrainer Stud End Configuration

12.6.3.3 Adjusting Cable Sag

Restrainers are designed to allow movement before they become taut in an earthquake. A sag in a cable or a loose restrainer rod is normal and should not be tightened by maintenance crews without consulting an engineer. In some cases, restrainers have lost the appropriate sag in the cables and will require adjustment. The change in cable sag can be caused by rotation of the superstructure particularly on high skew bridges or by movement of substructure elements. The need for adjustment can be identified by observing the relative sag between cables or by observed differences in tension at a single location. All cables or rods at a single location should have a similar amount of allowed displacement before engagement. If this slack distance is too little, the restrainers may engage during thermal movement possibly causing significant restrainer or superstructure damage. If the restrainer has too much slack before engagement, the superstructure may displace past the bearing causing collapse during a seismic event. To get consistent tension in the cables or rods, they can be tightened to a similar tension and then backed off enough to permit thermal movement. Alternatively, a string line can be used to measure the sag in the middle of the cable drape, and the nuts can be adjusted to achieve a specified drape distance. In either case, the maintenance crew should consult an engineer to determine the appropriate cable drape or expected thermal movement to ensure that the restrainers will function as intended during a seismic event.

12.6.3.4 Post Seismic Event Maintenance

Following a significant seismic event, maintenance crews may find earthquake restrainers that are not uniformly tensioned or broken. Restrainers are designed to work together as a system to restrain displacements during a seismic event. If the restrainers do not have uniform tension when the earthquake happens, the tightest restrainers will sustain the greatest forces and may be damaged or severed. Any restrainer that is suspected of sustaining significant seismic force (e.g., permanently elongated) should be replaced. Restrainers with any damage to the threaded stud ends should also be replaced.

Following a seismic event, it is fairly common to have damage to the concrete diaphragms that anchor restrainers. The damage can range from cracking to significant spalling. In most cases, diaphragm damage can be repaired using techniques covered within this chapter. In cases of severe diaphragm damage, the diaphragm may need to be replaced or supplemented with a second diaphragm behind the original.

12.7 Chapter 12 Reference List

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