Table of Contents

Section 10

Inspection and Evaluation of Substructures

This page intentionally left blank

Topic 10.2 Piers and Bents

10.2.1 Introduction

A pier or bent is an intermediate substructure unit located between the ends of a bridge. Its function is to support the bridge at intermediate intervals with minimal obstruction to the flow of traffic or water below the bridge (see Figure 10.2.1). The difference between a pier and a bent is simply in physical appearance. There is no functional difference between the two. A pier generally has only one column or shaft supported by one footing. Bents have two or more columns and each column is supported by an individual footing.

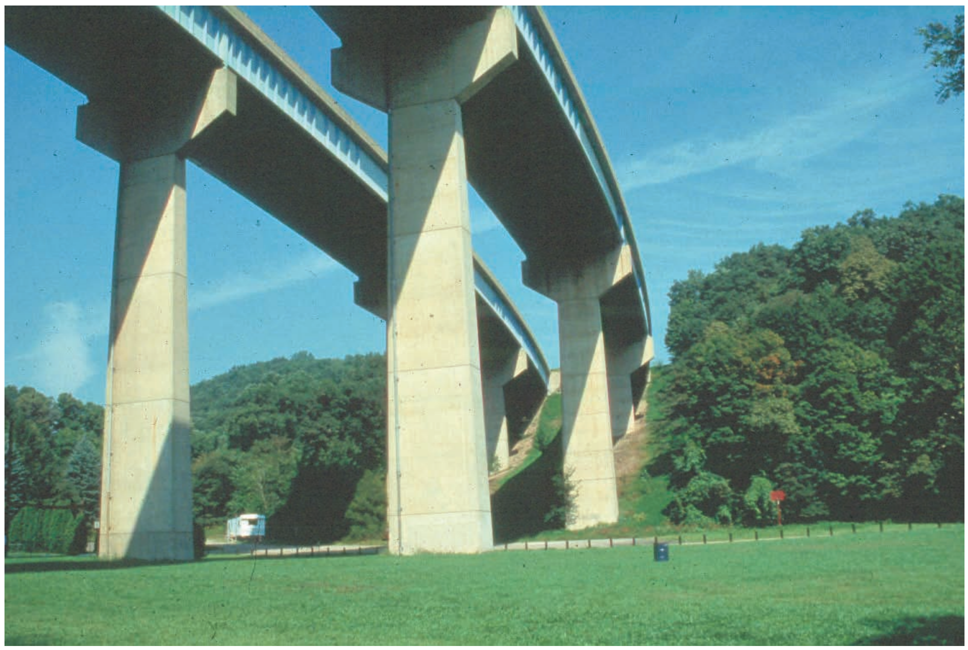

Figure 10.2.1 Example of Piers as Intermediate Supports for a Bridge

10.2.2 Design Characteristics

Pier and Bent Types

The most common pier and bent types are:

- Solid shaft pier (see Figure 10.2.2)
- Column pier (see Figure 10.2.3)
- Column pier with web wall (see Figures 10.2.4 and 10.2.5)
- Cantilever pier or hammerhead pier (see Figures 10.2.6 and 10.2.7)
- Column bent or open bent (see Figure 10.2.8)
- Pile bent (see Figure 10.2.9)

Detailed descriptions of pier and bent elements are provided on page 10.2.13.

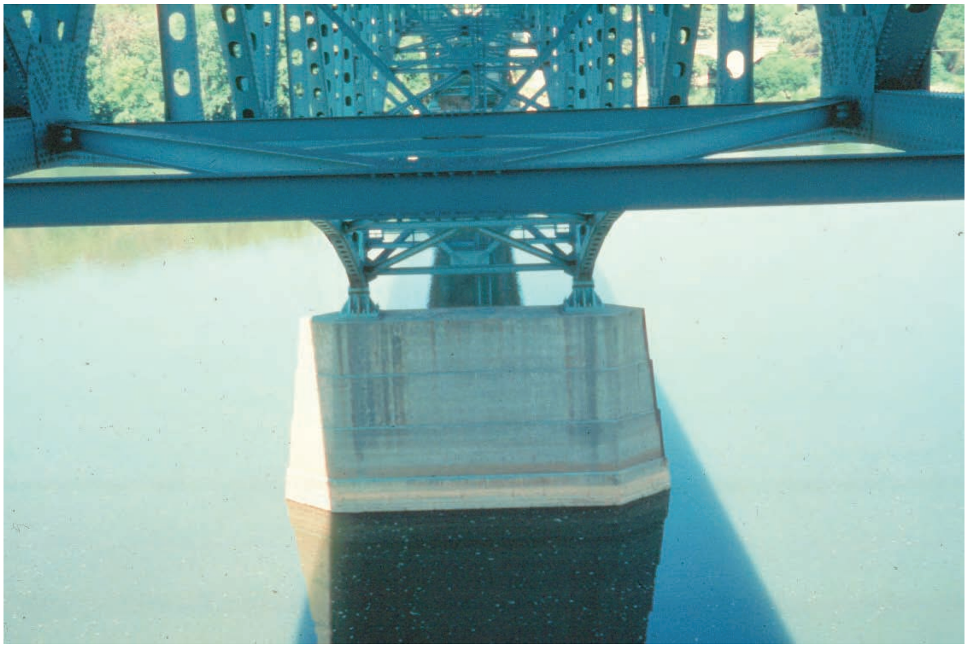

Figure 10.2.2 Solid Shaft Pier

Solid shaft piers are used when a large mass is advantageous or when a limited number of load points are required for the superstructure.

Figure 10.2.3 Column Pier

Column piers are used when limited clearance is available under the structure or when narrow superstructure widths are required.

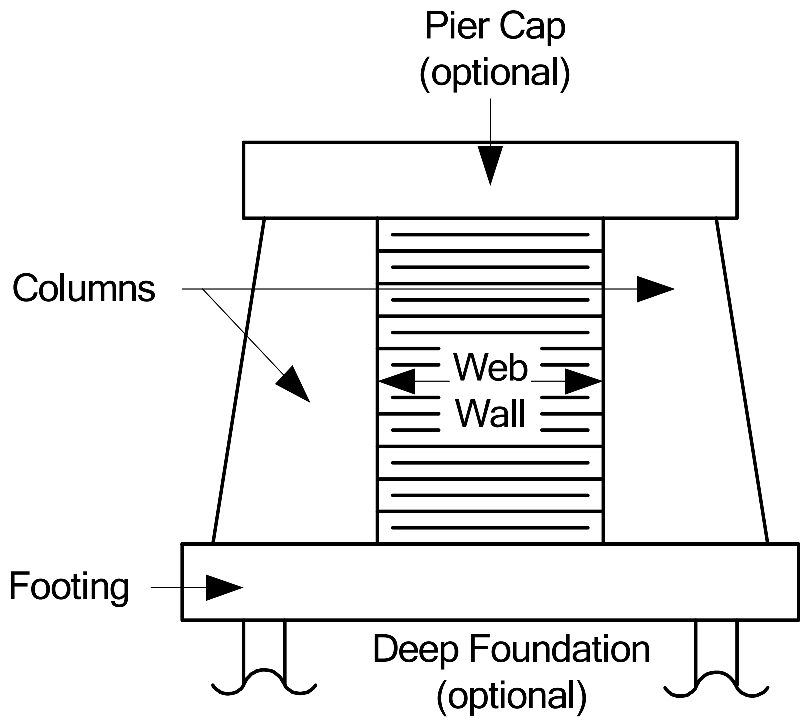

Figure 10.2.4 Column Pier with Web Wall

A web wall can be connected to columns to add stability to the pier. The web wall is non-structural relative to superstructure loads. Web walls also serve to strengthen the columns in the event of a vehicular collision.

Figure 10.2.5 Column Pier with Web Wall

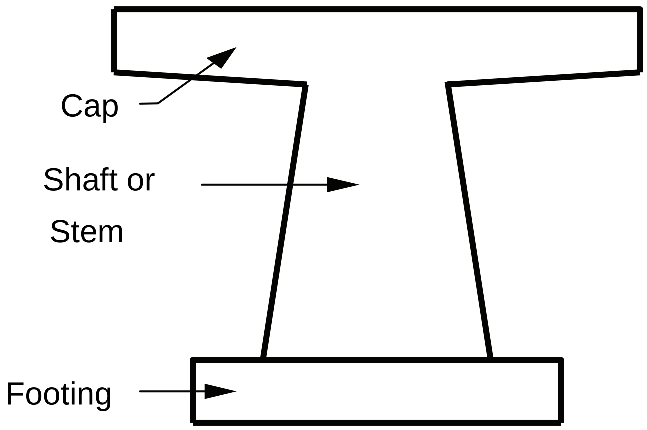

Figure 10.2.6 Single Stem Pier (Cantilever or Hammerhead)

The cantilever or hammerhead pier is a modified column pier for use with multi-beam superstructures.

Figure 10.2.7 Cantilever Pier

Figure 10.2.8 Column Bent or Open Bent

The column bent is a common pier type for highway grade crossings.

Figure 10.2.9 Concrete Pile Bent

Pile bents may be constructed of concrete, steel or timber. Typically, piles are driven in place and support a continuous cast-in-place concrete cap.

Two other specialized types of pier include the hollow pier and the integral pier. Hollow piers are usually tall shaft type piers built for bridges crossing deep valleys Being hollow greatly reduces the dead load of the pier and increases it’s ductility. Whether precast or cast-in-place, hollow piers are constructed in segments. If precast, the segments are post-tensioned together and the joints are epoxy-sealed.

The decrease in the dead load, or self-weight, of the piers provides ease in transporting them to the site, and the high ductility provides for better performance against seismic forces.

Integral piers incorporate the pier cap into the depth of the superstructure. Integral piers provide for a more rigid structure, and they are typically used in situations where vertical clearance beneath the structure is limited. Integral piers may consist of steel or cast-in-place caps within a steel girder superstructure. The concrete cap would likely be post-tensioned rather than conventionally reinforced (see Figures 10.2.10 to 10.2.12).

Figure 10.2.10 Integral Pier Cap

Figure 10.2.11 Integral Pier and Pier Cap

Figure 10.2.12 Integral Pier and Pier Cap

Primary Materials

The primary materials used in pier and bent construction are plain cement concrete, reinforced concrete, stone masonry, steel, timber, or a combination of these materials (see Figures 10.2.13 to 10.2.17).

Figure 10.2.13 Reinforced Concrete Piers under Construction

Figure 10.2.14 Stone Masonry Pier

Figure 10.2.15 Steel Bent

Figure 10.2.16 Timber Pile Bent

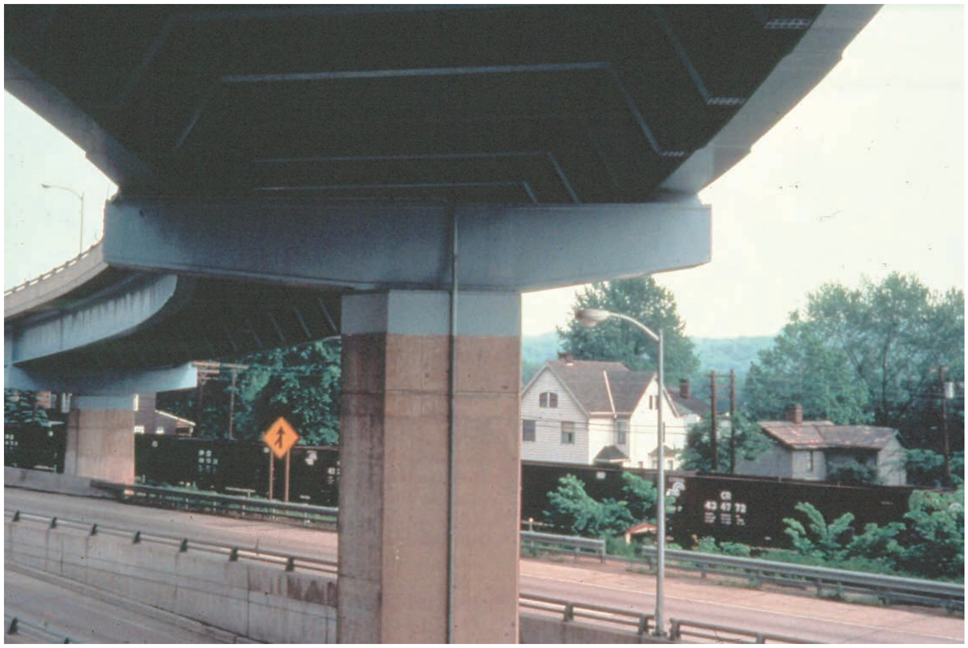

Figure 10.2.17 Combination: Reinforced Concrete Column with Steel Pier Cap

Primary and Secondary Reinforcement

The pattern of primary reinforcement for concrete piers depends upon the pier configuration. Piers with relatively small columns, whether of the single shaft, multi-column, or column and web wall design, have heavy vertical reinforcement confined within closely spaced ties or spirals in the columns. Pier caps are reinforced according to their beam function. Cantilevered caps have primary tension steel near the top surface. Caps spanning between columns have primary tension steel near the bottom surface. Primary shear steel consists of vertical stirrups, usually more closely spaced near support columns or piles.

Wall type piers are more lightly reinforced, but still have significant vertical reinforcement to resist horizontal loads.

If primary steel is not required at a given location, then temperature and shrinkage steel will be provided. All the concrete faces should be reinforced in both the vertical and horizontal directions.

Pier foundations are likewise reinforced to match their function in resisting applied loads. Shear stirrups are generally not required for footings as they are designed thick enough to permit only the concrete to resist the shear. Modern designs, however, do incorporate seismic ties (vertical bars with hooks at each end) to tie the top and bottom mats of rebar together.

Figures 10.2.18 – 10.2.21 illustrate typical reinforcement patterns.

New design specifications may call for epoxy coated reinforcement if the substructure will be subjected to de-icing chemicals or salt water.

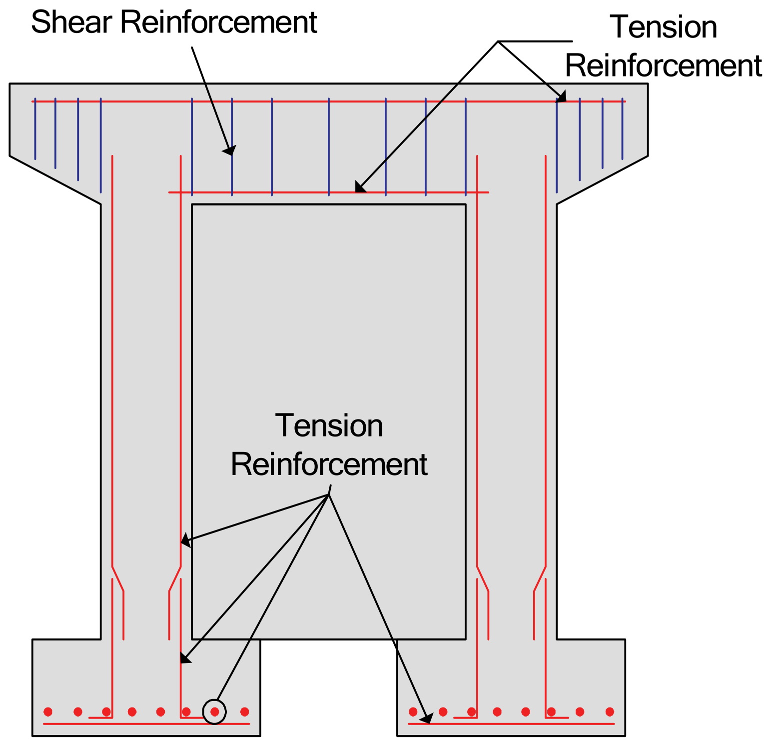

Figure 10.2.18 Primary Reinforcement in Column Bent with Web Wall

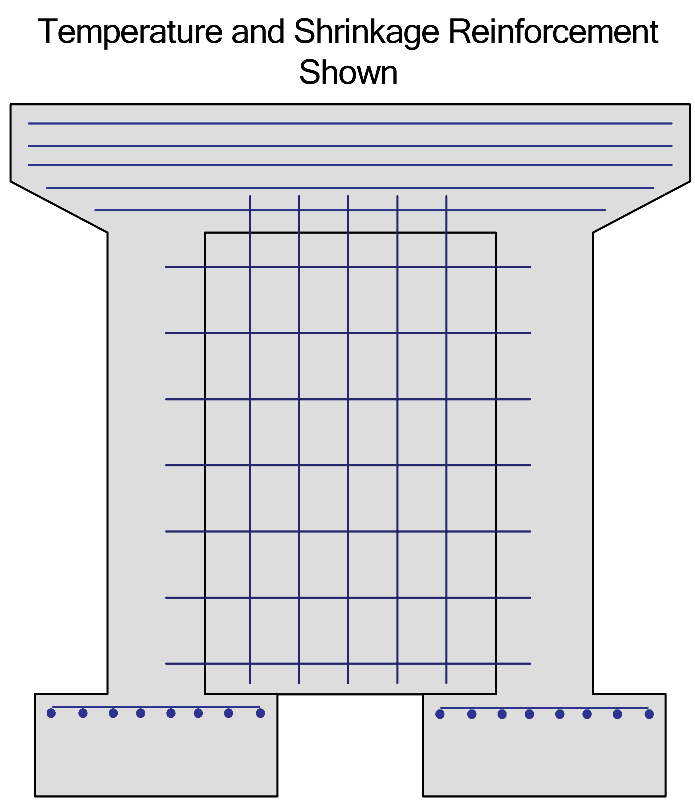

Figure 10.2.19 Secondary Reinforcement in Column Bent with Web Wall

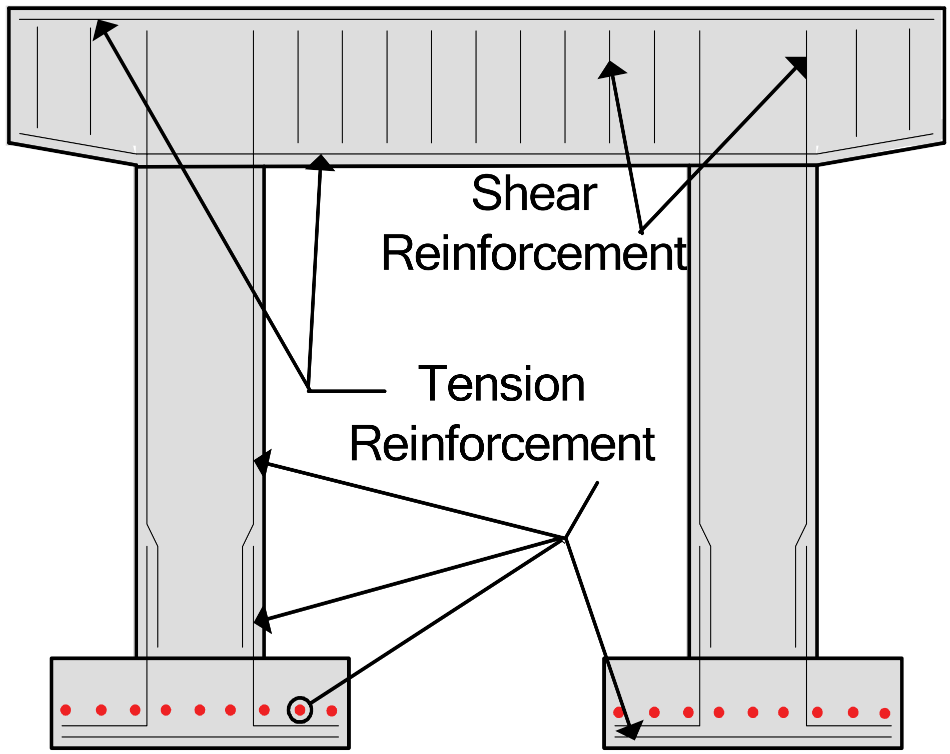

Figure 10.2.20 Primary Reinforcement in Column Bents

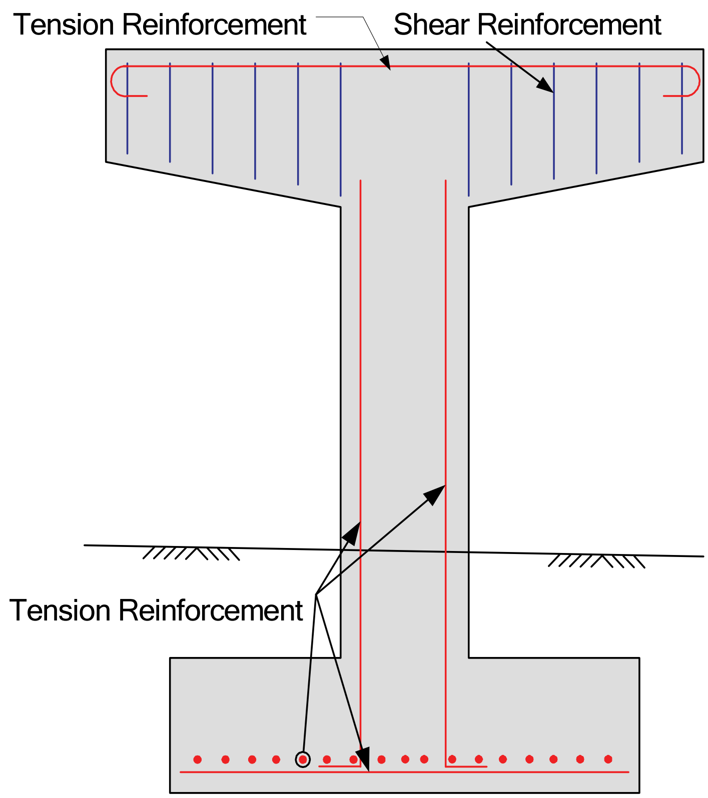

Figure 10.2.21 Primary Reinforcement for a Cantilevered Pier

Pier and Bent Elements

The primary pier and bent elements are:

- Pier cap or bent cap
- Pier wall / stem / or shaft
- Column
- Footing
- Piles or Drilled Shafts

The pier cap or bent cap provides support for the bearings and the superstructure (see Figures 10.2.22 and 10.2.23).

The pier wall or stem transmits loads from the pier cap to the footing.

Columns transmit loads from the pier or bent cap to the footing (see Figure 10.2.22).

The footing transmits the weight of piers or bents, and the bridge reactions to the supporting soil or rock. The footing also provides stability to the pier or bent against overturning and sliding forces.

Foundation Types

Foundations are critical to the stability of the bridge since the foundation ultimately supports the entire structure. There are two basic types of bridge foundations:

- Spread footings
- Deep foundations

Spread footing and deep foundations are described on page 10.1.16 of Topic 10.1, Abutments and Wingwalls.

Figure 10.2.22 Two Column Bent Joined by a Web Wall

Figure 10.2.23 Pile Bent

Pier Protection

Piers can be vulnerable to collision damage from trucks, trains, ships and ice flows. Wall type piers are resistant to this type of collision damage and are often used in navigable waterways and waterways subject to freezing for this reason. Web walls can also serve to protect columns (see Figures 10.2.24 and 10.2.25). External barriers are often provided for single- or multi-column piers. Dolphins are single, large diameter, sand-filled, sheet pile cylinders; clusters of timber piles or steel tubes; or large concrete blocks placed in front of a pier to protect it from collision (see Figures 10.2.26 and 10.2.27). Fenders are protective fences surrounding a pier to protect it from marine traffic. They may consist of timber bent arrangements, steel or concrete frames, or cofferdam sheets (see Figures 10.2.28 and 10.2.29).

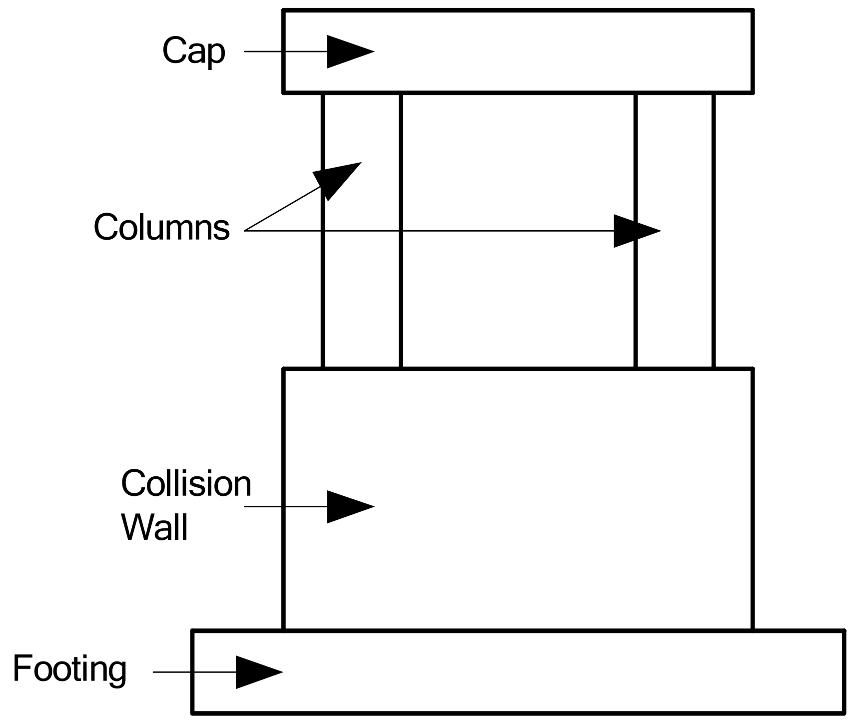

Figure 10.2.24 Collision Wall

Figure 10.2.25 Collision Wall

Figure 10.2.26 Concrete Block Dolphin

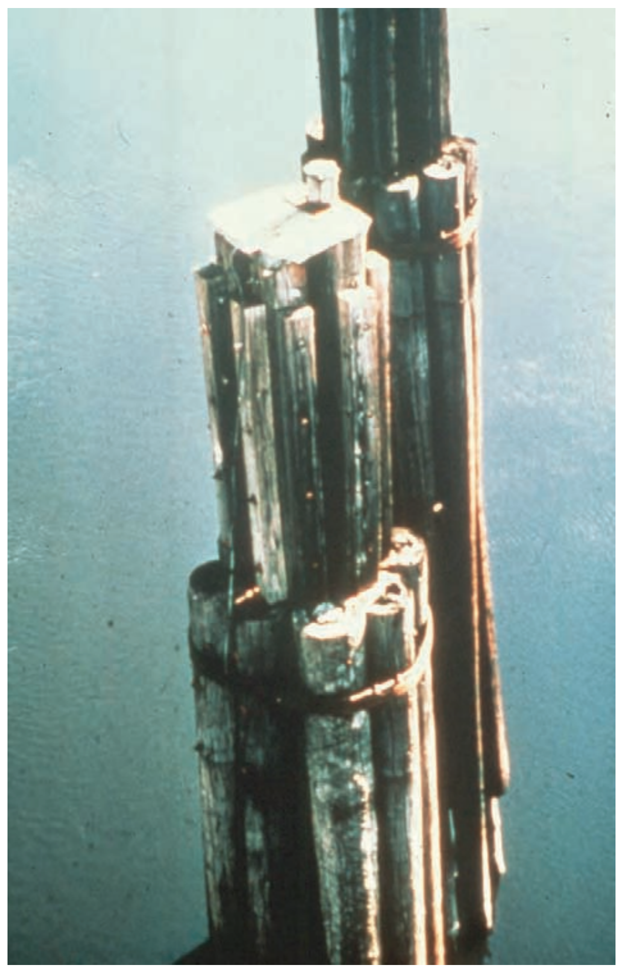

Figure 10.2.27 Timber Dolphin

Figure 10.2.28 Pier Fender

Figure 10.2.29 Fender System

10.2.3 Inspection Locations and Procedures

Inspection procedures for piers and bents are similar to superstructures, particularly when it involves material deterioration. See Topics 2.1 and 13.1 (Timber), Topics 2.2 and 13.2 (Concrete), Topics 2.3 and 13.3 (Steel) and Topic 2.4 (Masonry). However, because stability is a paramount concern, checking for various forms of movement is required during the inspection of piers or bents.

The locations for inspection are not particularly specific, but can be related to common pier and bent problems.

The most common problems observed during the inspection of piers and bents are:

- Vertical movement
- Rotational movement and lateral movement
- Material defects
- Scour and undermining
- Areas subjected to high stresses
- Areas exposed to traffic
- Fatigue prone details and fracture critical members
- Dolphins and fenders

Vertical Movement

Differential settlement at piers can cause serious problems in a bridge (see Figure 10.2.30). Deck joints can open excessively or close up completely. Local deterioration, such as spalling, cracking, and buckling, can also occur.

The most common causes of vertical movement are soil bearing failure, soil consolidation, scour, undermining, and subsidence from mining or solution cavities.

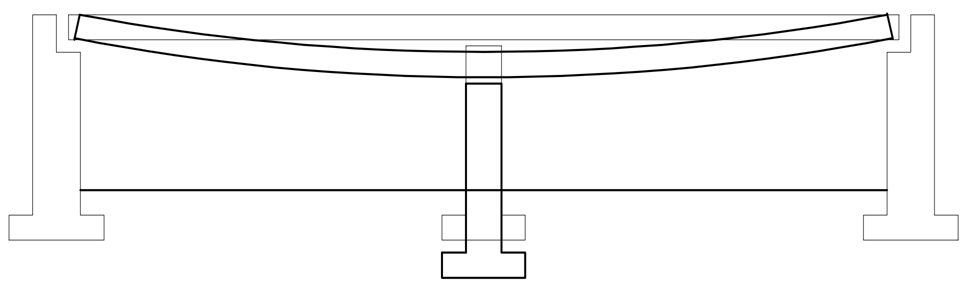

Figure 10.2.30 Differential Settlement Between Different Substructure Units

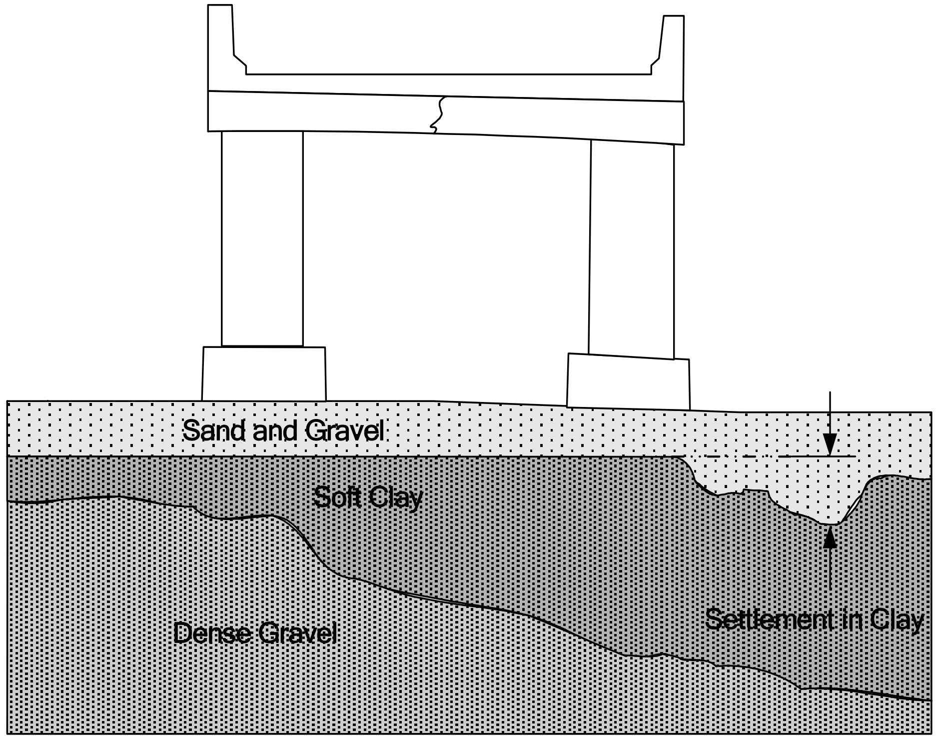

Figure 10.2.31 Differential Settlement Under a Pier

Inspection for vertical movement, or settlement, should include:

- For bridges with multiple simple spans, examine the joint in the deck above the pier as well as at adjacent piers and at the abutments.
- Check for any new or unusual cracking in the pier or bent.
- Investigate for buckling in steel columns of the pier or bent.
- Check the superstructure for evidence of settlement. Sight along parapets, bridge rails, etc. (see Figure 10.2.32).
- Investigate for scour and undermining around the pier footing.
- In some cases, a check of bearing seat or top of pier elevations using surveying equipment may be necessary.

Figure 10.2.32 Superstructure Evidence of Pier Settlement

Rotational Movement

Differential settlement or excessive longitudinal or transverse forces, such as those experienced during an earthquake, may cause rotational movement (tipping) and lateral (horizontal) movement of piers or bents.

Inspection for rotational movement, or tipping, should include:

- Checking vertical alignment of the pier using a plumb bob or level.
- Investigating the clearance between the ends of the simply supported beams at piers.
- Inspect for unusual cracking or spalling.

Lateral Movement

Inspection for lateral movement, or sliding, should include:

- Checking the general alignment.
- Check the bearings for evidence of lateral displacement.
- Investigate the deck joints. The deck joint openings should be consistent with the recorded temperature.
- Inspect for cracking or spalling that may otherwise be unexplained; in the case of inspections after earthquakes, such damage will be readily apparent (see Figure 10.2.33).
- Check for scour or undermining around the pier or bent footing (see Figures 10.2.34 – 10.2.35). Refer to Topic 11.2 for a more detailed description of scour and undermining. Refer to Topic 11.3 for a more detailed description of underwater inspection.

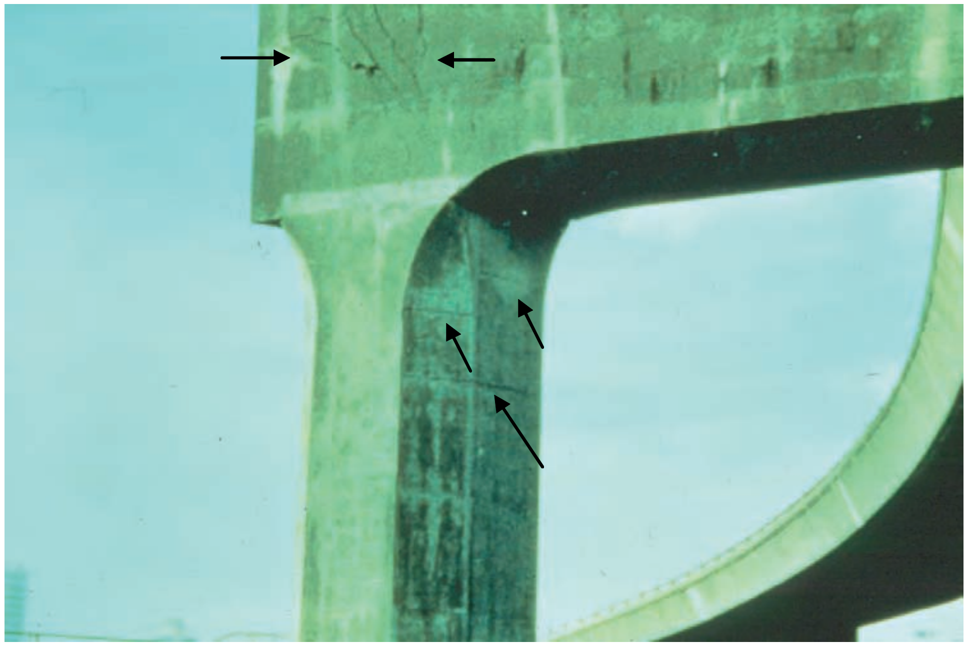

Figure 10.2.33 Cracks in Bent Cap due to Lateral Movement of Bent during Earthquake

Figure 10.2.34 Pier Movement and Superstructure Damage due to Scour/Undermining

Figure 10.2.35 Tipping of Bent due to Scour/Undermining

Material Defects

A common problem encountered during the inspection of piers and bents is material defects. Refer to Topics 2.1 – 2.4 of this manual for detailed descriptions of the types and causes of deterioration observed in timber, concrete, steel, and masonry.

Concrete

Inspection of concrete in piers and bents should include the following:

- Inspect for deterioration of the concrete, especially in the splash zone (i.e., up to 600 mm (2 feet) above high tide or mean water level), at the waterline, at the ground line, and wherever concrete is exposed to roadway drainage (see Figure 10.2.36).
- Examine the pier columns and the pier bent caps for cracks (see Figure 10.2.37).
- If steel reinforcement is exposed, check for section loss.
- Check the pier caps and bearing seats for cracking and spalling (see Figure 10.2.38).
- Examine grout pads and pedestals for cracks, spalls, and deterioration.
- Investigate any significant changes in clearance for pier movement.

- Check all pier and bent members for structural damage caused by collision or overstress (see Figure 10.2.39).
- Determine whether any earth or rock fills have been piled against piers, causing loads which were not provided for in the original design and producing unstable conditions.

Several advanced techniques are available for concrete inspection. Nondestructive and other methods are described in Topics 13.2.2 and 13.2.3.

Figure 10.2.36 Concrete Deterioration due to Contaminated Drainage

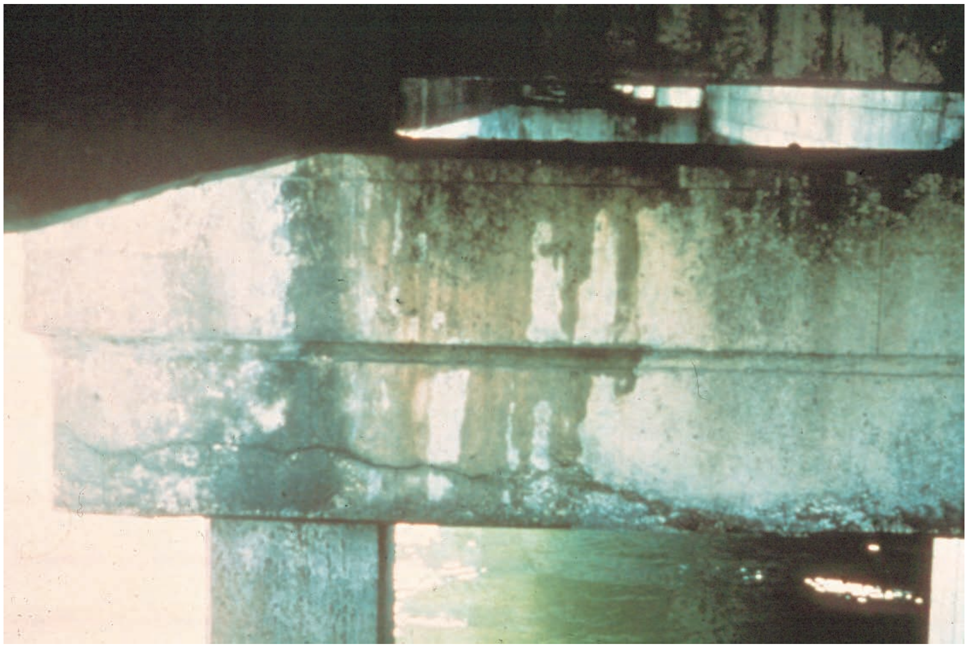

Figure 10.2.37 Crack in Concrete Bent Cap

Figure 10.2.38 Severe Concrete Spalling on Bent Cap

Figure 10.2.39 Collision Damage to Pier Column

Steel

Inspection of steel in piers and bents should include the following:

- Check pile bents for the presence of corrosion, especially at the ground line.
- Over water crossings, investigate the splash zone (i.e., up to 600 mm (2 feet) above high tide or mean water level) and the submerged part of the piles for indications of corrosion and loss of section (see Figure 10.2.41).
- Check for debris around the pile or pier bases; debris will retain moisture and promote corrosion.
- Examine the steel caps for rotation due to eccentric connections.
- Inspect the bracing for broken connections and loose rivets or bolts (see Figure 10.2.42).
- Check the condition of the web stiffeners, if present.
- Check the pier columns and pier caps for cracks (see Figure 10.2.43).
- When there are any significant changes in clearance, visually inspect and measure for pier movement.
- Examine all pier and bent members for structural damage caused by

collision, buckling, or overstress.

- Where a steel cap girder and continuous longitudinal beams are framed together, inspect the top flanges, welds, and webs for cracking.

Several advanced techniques are available for steel inspection. Nondestructive and other methods are described in Topics 13.3.2 and 13.3.3.

Figure 10.2.40 Deterioration of Concrete Pedestal Supporting Steel Column

Figure 10.2.41 Corrosion and Debris at Steel Pile Bent

Figure 10.2.42 Steel Column Bent

Figure 10.2.43 Steel Column Bent with Cantilever

Timber

Inspection of timber in piers and bents should include the following:

- Check for decay in the piles, caps, and bracing. The presence of decay can be determined by tapping with a hammer or by test boring the timber. Drilling with a decay detection device can also be used (see Figure 10.2.44). Inspect particularly at the ground line or waterline, joints and splices, checks in the wood, bolt holes, caps, or other connections, since decay usually begins in these areas (see Figures 10.2.45 to 10.2.47).
- Examine splices and connections for tightness and for loose bolts.
- Investigate the condition of the cap at those locations where the beams bear directly upon it and where the cap bears directly upon the piles. Note particularly any splitting or crushing of the timber in these areas.
- Observe caps and piles that are under heavy loads for excessive deflection(see Figure 10.2.48).
- Check all piers and bent members for structural damage caused by collision or overstress.
- In marine environments, check for the presence of marine borers, shipworms, and caddisflies (see Figures 10.2.49 to 10.2.50).
- Check for evidence of insect damage.

Several advanced techniques are available for timber inspection. Nondestructive and other methods are described in Topics 13.1.2 and 13.1.3.

Figure 10.2.44 Drilling a Timber Bent Column for a Core Sample

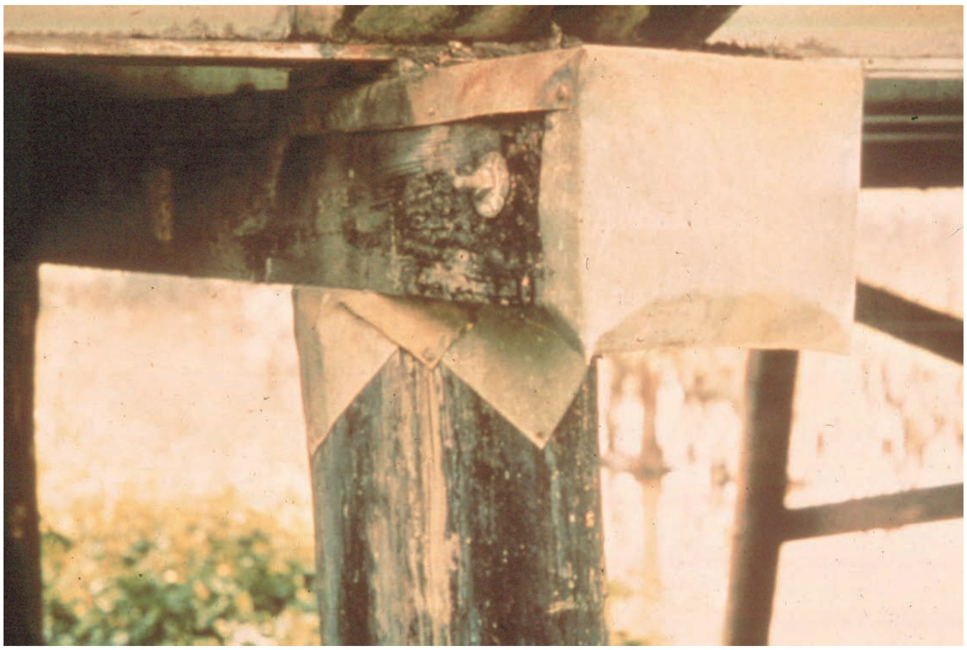

Figure 10.2.45 Decay in Timber Bent Cap (Note "Protective" Cover / Flashing)

Figure 10.2.46 Timber Bent Columns in Water

Figure 10.2.47 Decay of Timber Bent Column at Ground Line

Figure 10.2.48 Timber Pile Bent with Partial "Brooming" Failure at First Pile

Figure 10.2.49 Timber Pile Damage due to Limnoria Marine Borers

Figure 10.2.50 Timber Bent Damage due to Shipworm Marine Borers

Stone Masonry

Inspection of stone masonry in piers and bents should include the following:

- Inspect stone masonry for mortar cracks or loss of mortar in the joints.
- Examine stone masonry for vegetation, water seepage through cracks, loose or missing stones, weathering, split, spalled, loose or missing blocks (see Figure 10.2.51).

Scour and Undermining

Scour is the removal of material from a streambed as a result of the erosive action of running water. Scour can cause undermining or the removal of supporting foundation material from beneath the piers or bents when streams or rivers flow adjacent to them. Refer to Topic 11.2 for a more detailed description of scour and undermining.

Inspection for scour should include probing around the pier or bent footing for signs of undermining. Sometimes silt loosely fills in a scour hole and offers no protection or bearing capacity for the pier or bent footing.

Figure 10.2.51 Deteriorated and Missing Stone at Masonry Pier

Areas Subjected to High Stresses

Closely examine the high bearing zones, high shear zones, and high flexural areas.

High bearing zones include the bridge seats, the pier cap, the pier shaft or bent column/footing connection, and the area where the footing is supported by earth or deep foundations. In timber piers or bents, look for crushing. Look for cracking or spalling in concrete and masonry members. Examine steel members for buckling or distortion.

Horizontal forces cause high shear zones on the bottom of the pier shaft or bent column. In timber piers or bents, look for splitting. Look for diagonal cracks in concrete and masonry. Examine steel members for buckling or distortion.

High flexural moments caused by horizontal forces occur at the bottom of the pier shaft or bent column. High flexural moments may be occurring at the footing toe/pier shaft. Moments cause compression and tension depending on the load type and location of the member neutral axis. Look for defects caused by overstress due to compression or tension caused by flexural moments. Check compression areas for splitting, crushing or buckling. Examine tension members for cracking or distortion.

Areas Exposed to Traffic

Check for collision damage from vehicles passing adjacent to structural members. Damage to concrete piers or bents may include spalls and exposed rebars. Steel piers or bents may experience cracks, section loss, or distortion which must be documented.

Fatigue Prone Details and Fracture Critical Members

Steel piers or bents may contain fatigue prone details. Closely examine these details for section loss due to corrosion and cracking.

Steel piers or bents may be considered to be fracture critical (see Figure 10.2.52). See Topic 8.1 for a detailed description of fatigue prone details and fracture critical members.

Figure 10.2.52 Fracture Critical Steel Bent

Dolphins and Fenders

The condition of dolphins and fenders should be checked in a manner similar to that used for inspecting the main substructure elements.

In concrete pier protection members, check for spalling and cracking of concrete or corrosion of the reinforcing steel (see Figure 10.2.53). Investigate for hour-glass shaping of piles due to abrasion at the waterline, and check for structural damage caused by marine traffic.

In steel pier protection members, observe the splash zone (i.e., up to 0.6 m (2 feet) above high tide or mean water level) carefully for severe corrosion. Where there are no tides, check the area from the mean water level to 0.6 m (2 feet) above it. Also examine all other steel parts for corrosion, and check for structural damage (see Figure 10.2.54).

In timber pier protection members, observe the portions between the high waterline and the mud line for marine borers, caddisflies, and decay, and check for structural damage (see Figure 10.2.55). Also, check for hourglass shaping of piles at the waterline.

Figure 10.2.53 Concrete Dolphins

Figure 10.2.54 Steel Fender

Figure 10.2.55 Timber Fender System

10.2.4 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of substructures. The two major rating guideline systems currently in use are the FHWA's *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* used for the National Bridge Inventory (NBI) component rating method and the AASHTO element level condition state assessment method.

NBI Rating Guidelines

Using NBI rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the entire substructure including abutments and piers. Rating codes range from 9 to 0, where 9 is the best rating possible. See Topic 4.2 (Item 60) for additional details about NBI Rating Guidelines.

The previous inspection data should be considered along with current inspection findings to determine the correct condition rating.

Element Level Condition State Assessment

In an element level condition state assessment of a pier or bent structure, the AASHTO CoRe element typically is one or more of the following:

Element No.	Description
201	Unpainted Steel Column or Pile Extension (EA)
225	Unpainted Steel Submerged Pile (EA)
230	Unpainted Steel Cap (m or ft)
202	Painted Steel Column or Pile Extension (EA)
231	Painted Steel Cap (m or ft)
204	Prestressed Concrete Column or Pile Extension (EA)
226	Prestressed Concrete Submerged Pile (EA)
233	Prestressed Concrete Cap (m or ft)
205	Reinforced Concrete Column or Pile Extension (EA)
210	Reinforced Concrete Pier Wall (m or ft)
220	Reinforced Concrete Submerged Pile Cap/Footing (EA)
227	Reinforced Concrete Submerged Pile (EA)
234	Reinforced Concrete Cap (m or ft)
206	Timber Column or Pile Extension (EA)
228	Timber Submerged Pile (EA)
235	Timber Cap (m or ft)
211	Other Pier Wall (m or ft)

The unit quantity for the pier cap elements is meters or feet, measured horizontally across the pier cap and the total length must be distributed among the four available condition states depending on the extent and severity of deterioration. The unit quantity for columns and piles is each and the total quantity must be placed in one of the available condition states. In all cases, Condition state 1 is the best possible rating. See the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* for condition state descriptions.

A Smart Flag is used when a specific condition exists, which is not described in the CoRe element condition state. The severity of the damage is captured by coding the appropriate Smart Flag condition state. The Smart Flag quantities are measured as each, with only one each of any given Smart Flag per bridge.

For settlement of the pier or bent, the “Settlement” Smart Flag, Element No. 360, can be used and one of three condition states assigned. For scour at the piers or bents, the “Scour” Smart Flag, Element No. 361, can be used and one of three condition states assigned.

This page intentionally left blank.