Table of Contents

Section 10 Inspection and Evaluation of Substructures

Section 10

Inspection and Evaluation of Substructures

Topic 10.1 Abutments and Wingwalls

10.1.1 Introduction

The substructure is the component of a bridge that includes all elements supporting the superstructure. Its purpose is to transfer the loads from the superstructure to the foundation soil or rock.

An abutment is a substructure unit located at the end of a bridge. Its function is to provide end support for the bridge superstructure and to retain the approach roadway embankment. Wingwalls are also located at the ends of a bridge. Their function is only to retain the approach roadway embankment and not to provide end support for the bridge.

Wingwalls are considered part of the substructure component only if they are integral with the abutment. When there is an expansion joint or construction joint between the abutment and the wingwall, that wingwall is defined as an independent wingwall, i.e. a retaining wall, and not considered in the condition evaluation of the abutment/substructure component.

10.1.2 Design Characteristics of Abutments

Abutment Types

Abutments are classified according to their locations with respect to the approach roadway embankment. The most common abutment types are presented in Figure 10.1.1 and include:

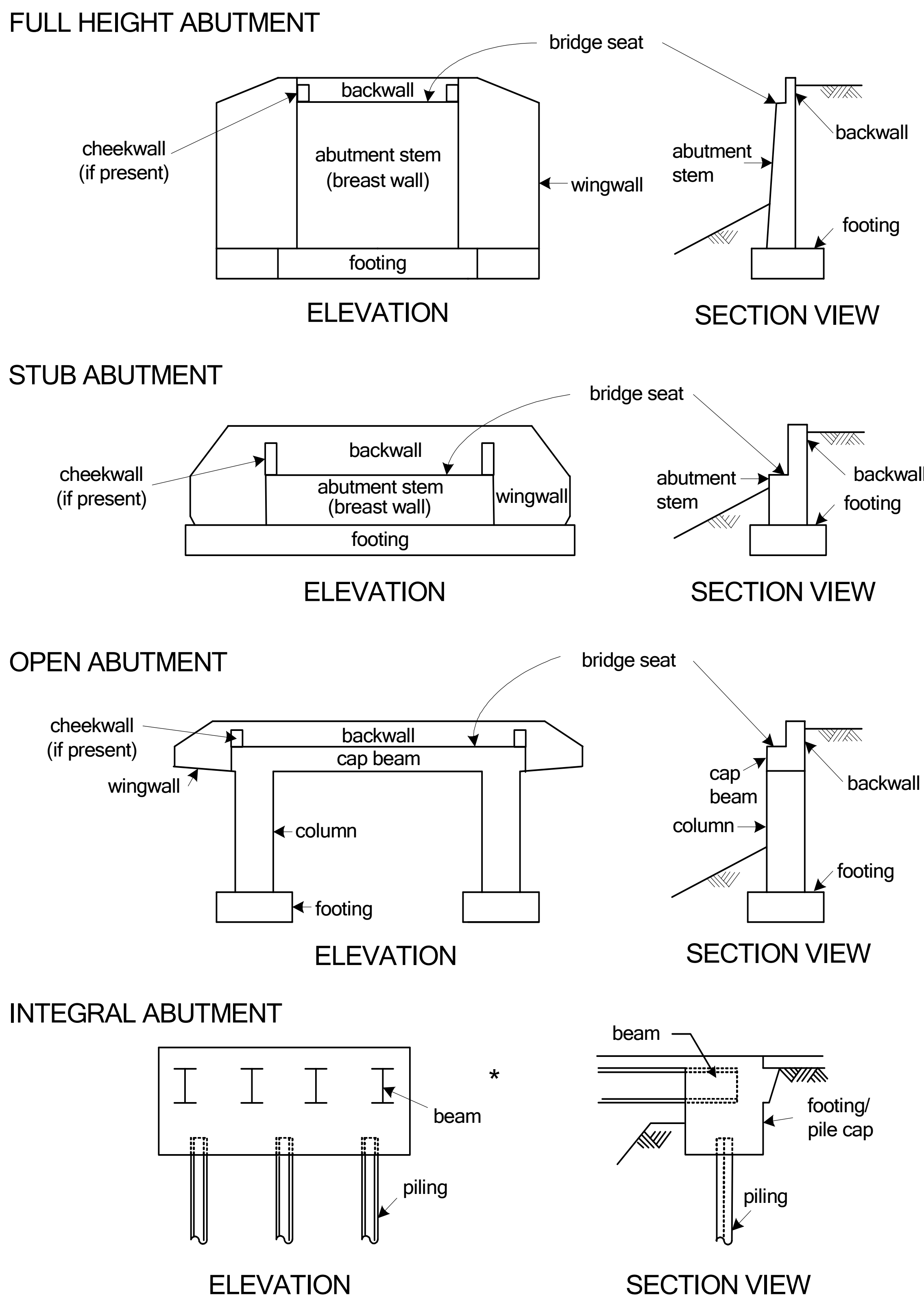
- Full height or closed type
  - Gravity
  - Counterfort
  - Cantilever
  - Curtain wall/Pedestal
  - Timber bent
  - Crib
- Stub, semi-stub, or shelf type
- Open or spill-through type
- Integral type

Foundations consist of either spread footings or deep foundations. See page 10.1.16 for a detailed description of abutment foundation types.

Less common abutments used to support highway bridges are shown in Figure 10.1.2 and include:

- Mechanically Stabilized Earth (MSE)
- Geosynthetic Reinforced Soil (GRS)

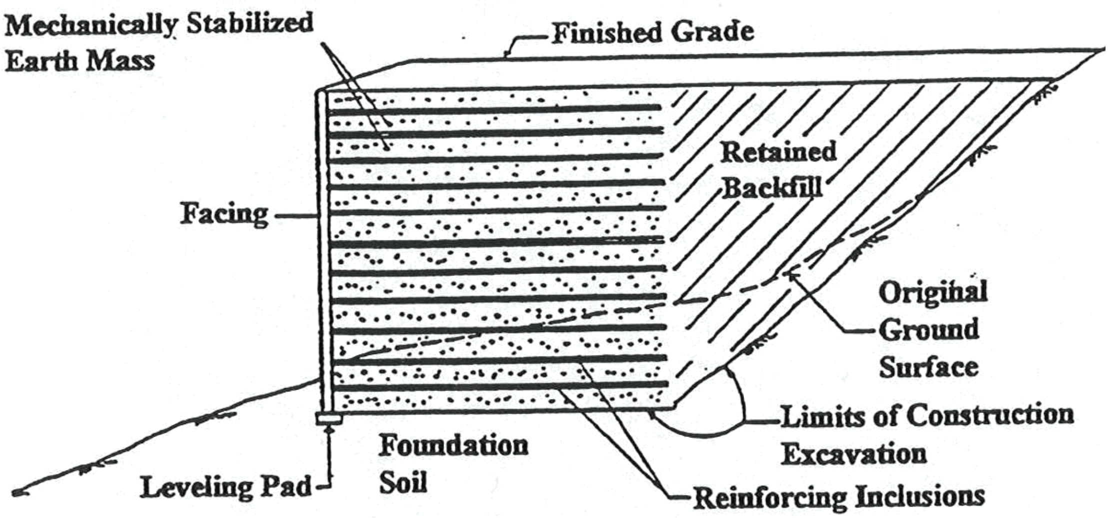
Detailed descriptions of abutment elements are provided on page 10.1.14.



* Some states weld beam and piles prior to concrete placement

Figure 10.1.1 Schematic of Common Abutment Types

MECHANICALLY STABILIZED EARTH (MSE)



GEOSYNTHETIC REINFORCED SOIL (GRS)

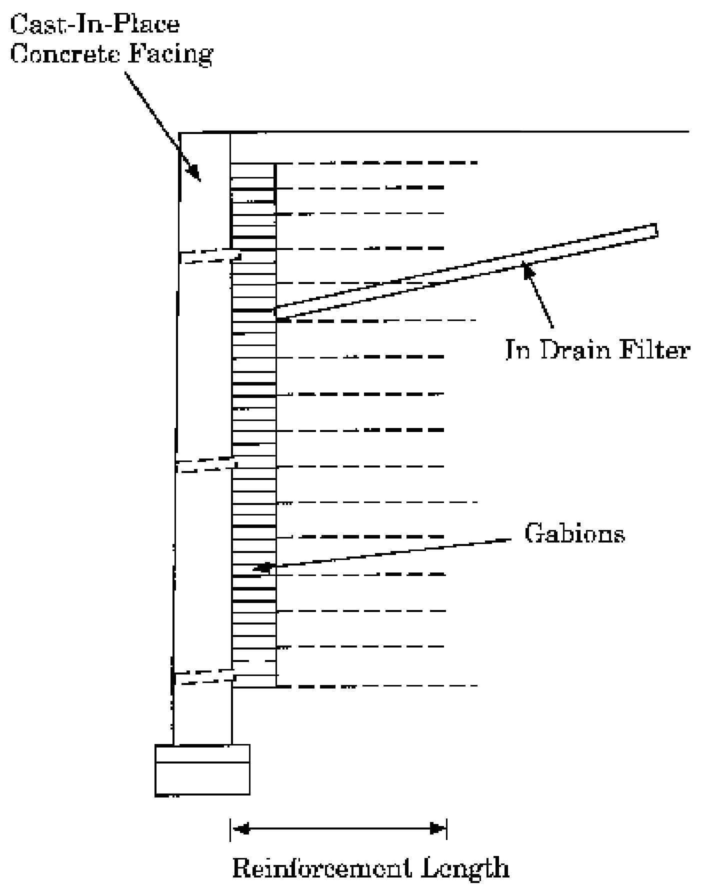


Figure 10.1.2 Section View of Less Common Abutment Types

Figure 10.1.3 Full Height Abutment

Figure 10.1.4 Stub Abutment

Full Height Abutments and Stub Abutments

Full height abutments are used when shorter spans are desired or if there are Right-of-Way or terrain issues. This reduces the initial superstructure costs. Stub abutments may be used when it is desirable to keep the abutments away from the underlying roadway or waterway. Longer spans are required when stub abutments are used. Using stub abutments reduces the cost of the substructure but increases the cost of the superstructure.

Figure 10.1.5 Open Abutment

Open Abutments

Open, or spill-through, abutments are similar in construction to multi-column piers. Instead of being retained by a solid wall, the approach roadway embankment extends on a slope below the bridge seat and between ("through") the supporting columns. Only the topmost few feet of the embankment are actually retained by the abutment cap.

The advantages of the open abutment are lower cost since most of the horizontal load is eliminated, so the massive construction and heavy reinforcement usually associated with the abutment stem is not needed. This substructure type has the ability to convert the abutment to a pier if additional spans are added in the future.

Open abutment disadvantages include a tendency for the fill to settle around the columns since good compaction is difficult to achieve in the confined spaces. Excessive erosion or scour may also occur in the fore slope. Rock fill is sometimes used to counter these problems.

This abutment type is not suitable adjacent to streams due to susceptibility to scour.

Integral Abutments

Most bridges have superstructures that are independent of the substructure to accommodate bridge length changes due to thermal effects. Expansion devices such as deck joints and expansion bearings allow for thermal movements but deteriorate quickly and create a wide range of maintenance needs for the bridge. In extreme cases, lack of movement due to failed expansion devices can lead to undesirable stresses in the bridge. Integral abutments supported by a single row of piles are becoming more popular and provide a solution to these problems.

In this design, the superstructure and substructure are integral and act as one unit without an expansion joint (see Figure 10.1.6). Relative movement of the abutment with respect to the backfill allows the structure to adjust to thermal expansions and contractions. Pavement joints at the ends of approach slabs are provided to accommodate the relative movement between the bridge and the approach roadway pavement.

The advantage of the integral abutment is that it lacks bearing devices and joints to repair, or replace, or maintain. There are two disadvantages of integral abutments: settlement of the roadway approach due to undercompaction of backfill and cracking of the abutment concrete due to movement restriction caused by overcompaction of backfill.

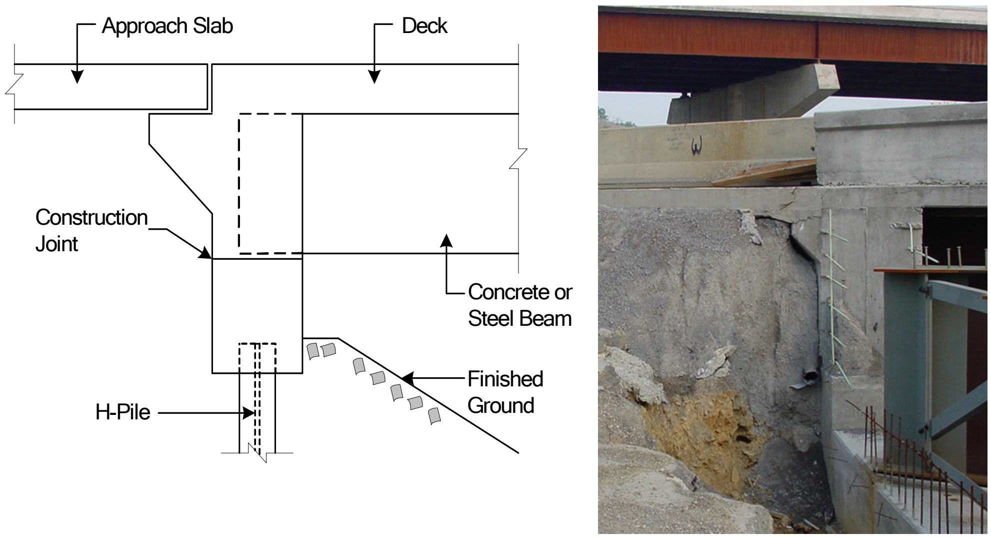


Figure 10.1.6 Integral Abutment

Figure 10.1.7 Integral Abutment

Less Common Abutment Types and Abutment Elements

Mechanically Stabilized Earth Abutments

Mechanically Stabilized Earth (MSE) Support Abutment typically consists of precast concrete panels, metallic soil reinforcing strips (flat strips or welded bar grids), and backfill to support the superstructure and support the roadway approach roadway embankment (see Figure 10.1.8). "Reinforced Earth" and "Retained Earth" are trademarked names given to these systems by suppliers of the components. Two MSE Abutment design concepts have been used. The first utilizes an MSE wall supporting a slab, or coping, on which the bridge bearings rest. Vertical loads are transmitted through the reinforced fill. The second concept utilizes piles or columns to support a stub abutment at the top of the reinforced fill. The piles provide vertical support for the bridge. The MSE provides lateral support for the approach roadway embankment.

Precast concrete panels are erected first, followed by the placement and compaction of a layer of backfill. The layers of backfill are sometimes referred to as "lifts." Soil reinforcement is then placed and bolted into the panels and covered with more backfill (see Figure 10.1.9). This process, which allows the wall to remain stable during construction, is repeated until the designed height is attained.

Advantages of this substructure are its internal stability and its ability to counteract shear forces, especially during earthquakes. It is generally lower in cost and has favorable esthetics when compared to a reinforced concrete full height abutment. Disadvantages include difficulty in repairing failed soil reinforcement and limited site applications. Another disadvantage is the possible settlement of an MSE wall that directly supports the superstructure (i.e. no stub abutment with piles).

Figure 10.1.8 Mechanically Stabilized Earth Abutment (Note Precast Concrete Panels)

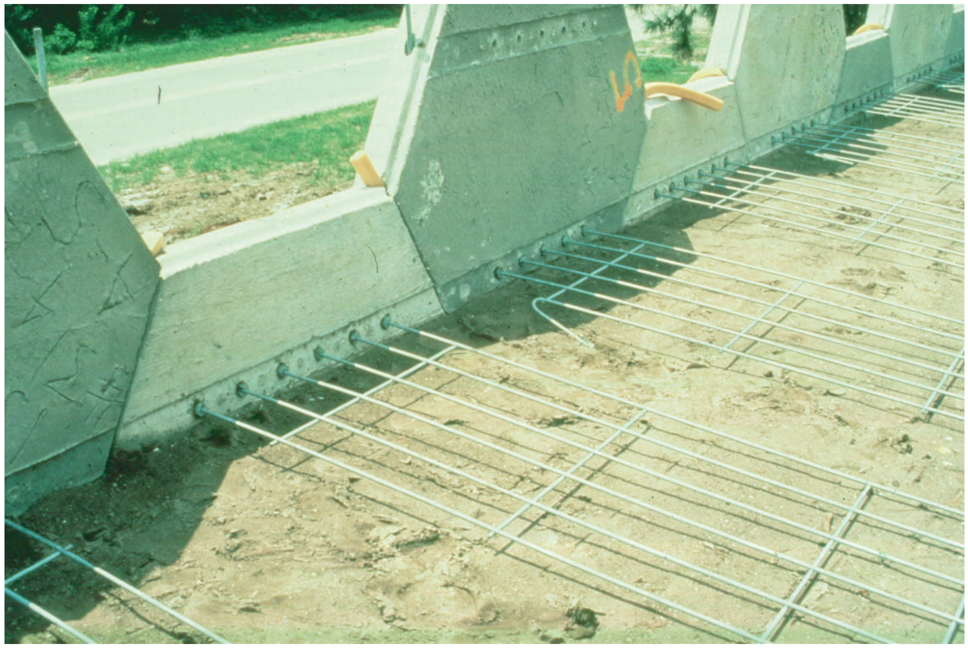


Figure 10.1.9 Mechanically Stabilized Earth Wall Under Construction

Geosynthetic Reinforced Soil Abutments

Another less common, fairly new type of abutment is the geosynthetic reinforced soil (GRS) abutment, developed by the Federal Highway Administration. GRS abutments are basically constructed on a level surface starting with a base structure of common, but high quality, cinder blocks. Fill is then placed and compacted with a sheet of geosynthetic reinforcement, which can be a series of polymer sheets or grids. These materials are layered until the designed height is attained. GRS abutments, which are internally supported, use friction to hold the blocks together and obtain their strength through proper spacing of the layers of reinforcement. Advantages of GRS abutments are their simplicity to construct, their durability, and their aesthetic appearance. GRS technology works well with simple overpasses; however, they are not ideal where severe flooding could occur (see Figures 10.1.10 and 10.1.11).

Figure 10.1.10 GRS Bridge Abutment Developed at the Turner-Fairbank Highway Research Center

The stabilized earth concepts, using metallic or geosynthetic reinforcement, are more commonly used as retaining walls or wing walls than as abutments. See Report No. FHWA-SA-96-071 (Demo 82 Manual) for a detailed description of these systems.

Figure 10.1.11 View of the Founders/Meadows Bridge Supported by GRS Abutments

Primary Materials

The primary materials used in abutment construction are plain cement concrete, reinforced concrete, stone masonry, steel (although not very common), timber, or a combination of these materials.

Figure 10.1.12 Plain Unreinforced Concrete Gravity Abutment

Figure 10.1.13 Reinforced Concrete Cantilever Abutment

Figure 10.1.14 Stone Masonry Gravity Abutment

Figure 10.1.15 Combination: Timber Pile Bent Abutment with Reinforced Concrete Cap

Figure 10.1.16 Steel Abutment

Primary and Secondary Reinforcement

The pattern of primary steel reinforcement used in concrete abutments depends on the abutment type (see Figure 10.1.17). In a cantilever abutment, primary tension reinforcement include: vertical bars in the rear face of the stem and backwall, horizontal bars in the bottom of the footing (toe steel), and horizontal bars in the top of the footing (heel steel). In a concrete open or spill-through abutment, the primary reinforcement consists of both tension and shear steel reinforcement. Tension steel reinforcement generally consists of vertical bars in the rear face of the backwall and cap beam, horizontal bars in the bottom face of the cap beam, vertical bars in the columns and horizontal bars in the bottom of the footing. Stirrups are used to resist shear in the cap beam. The column spirals or ties are generally considered to be secondary reinforcement to reduce the un-braced length of the vertical bars in the column. The spirals or ties may be considered primary reinforcement in seismic zones. All other bars would be temperature and shrinkage reinforcement, which is secondary reinforcement.

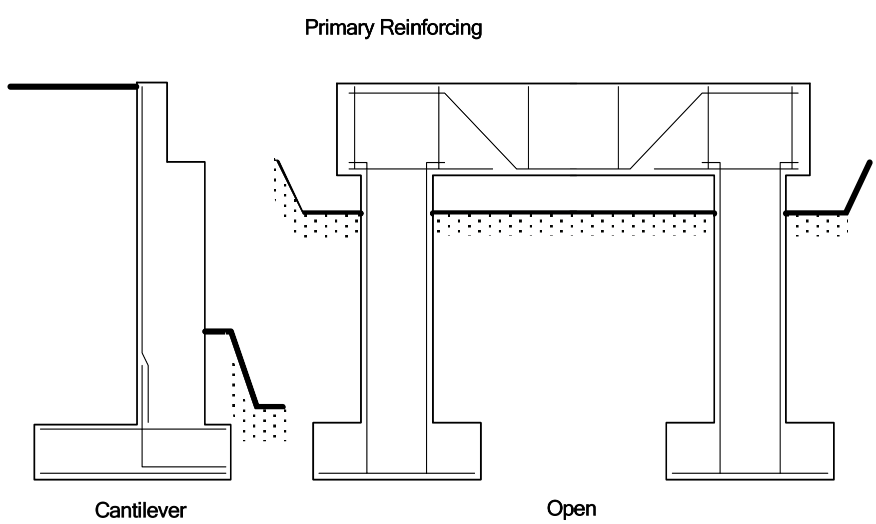


Figure 10.1.17 Primary Reinforcement in Concrete Abutments

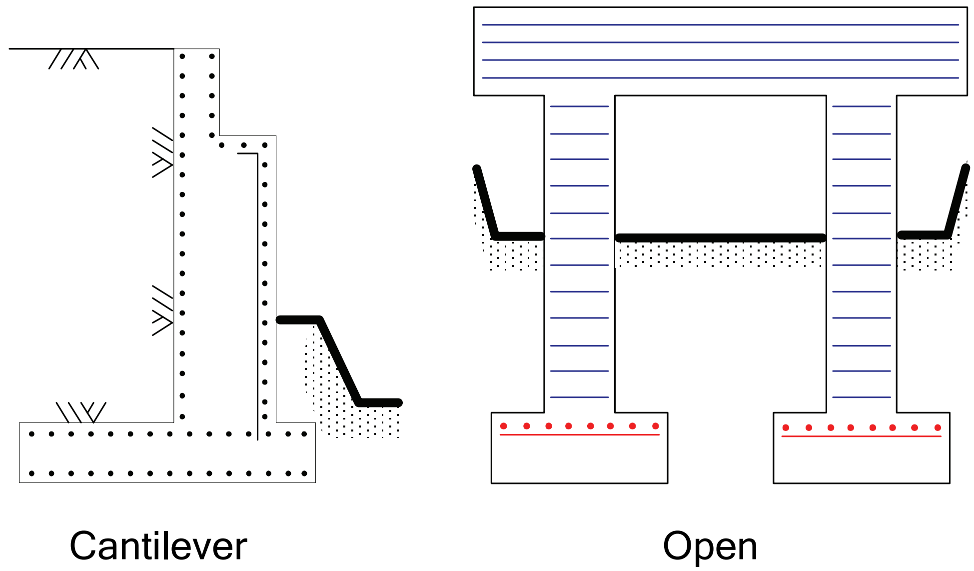


Figure 10.1.18 Secondary Reinforcement in Concrete Abutments

Abutment Elements

Common abutment elements include:

- Bridge seat
- Backwall
- Footing/Pile cap
- Cheek wall
- Abutment stem (breast wall)
- Tie backs
- Soil reinforcing strips
- Precast panels
- Deep foundations
- Geotextiles

The basic abutment elements are shown in Figure 10.1.1, Figure 10.1.2 and described below.

The bridge seat provides a bearing area that supports the bridge superstructure. The backwall retains the approach roadway subbase and keeps it from sliding onto the bridge seat. It also provides support for the approach slab and for the expansion joint, if one is present. The cheek wall is mostly cosmetic but also protects the end bearings from the elements, (see Figure 10.1.19). A cheek wall is not always present.

The abutment stem or breast wall supports the bridge seat and retains the soil behind the abutment. The foundation either spread footing or deep foundation (piles, drilled shafts, etc.), transmits the weight of the abutment, the soil backfill loads, and the bridge reactions to the supporting soil or rock. It also provides stability against overturning and sliding forces. The portion of the footing in front of the wall is called the toe, and the portion behind the wall, under the approach embankment, is called the heel.

Mechanically stabilized earth (MSE) walls consist of a reinforced soil mass and a concrete facing which is vertical or near vertical. The facing is often precast panels which are used to hold the soil in position at the face of the wall. The reinforced soil mass consists of select granular backfill. The tensile reinforcements and their connections may be proprietary, and may employ either metallic (i.e., strip- or grid-type) or polymeric (i.e., sheet-, strip-, or grid-type) reinforcement. The soil reinforcing strips hold the wall facing panels in position and provide reinforcement for the soil. Geotextiles are used to cover the joint between the panels. Geotextiles are placed behind the precast panels to keep the soil from being eroded through the joints and allow excess water to flow out. Tie backs are steel bars or strands grouted into the soil or rock behind the abutment stem. Tie backs, if present, are used when lateral earth forces cannot be resisted by the footing alone.

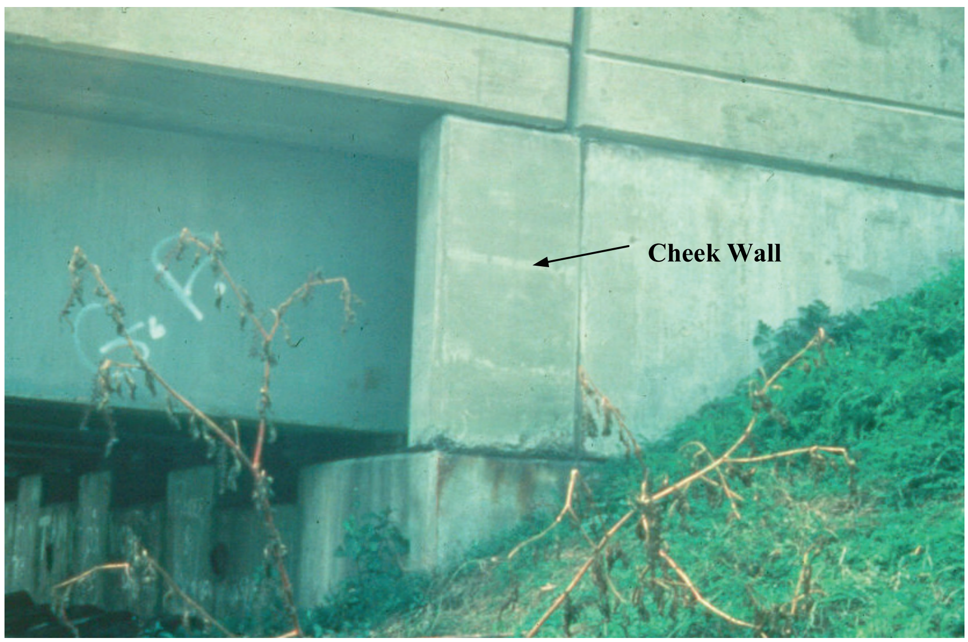


Figure 10.1.19 Cheek Wall

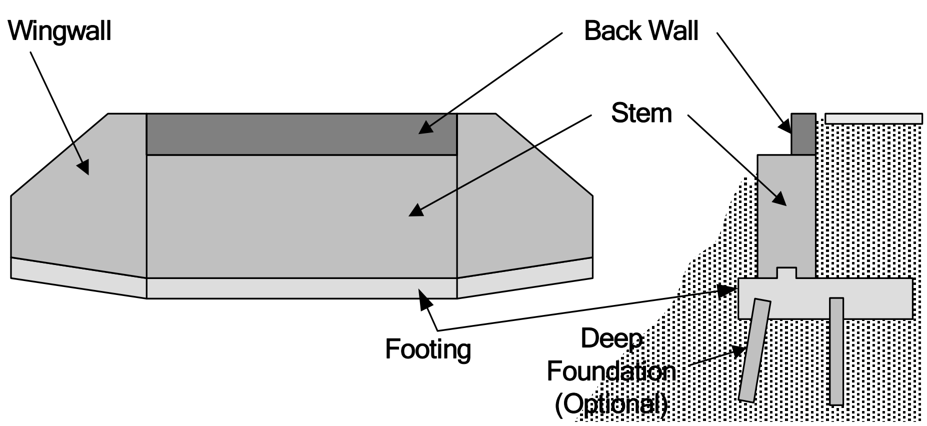


Figure 10.1.20 Spread Footing/Deep Foundations

Foundation Types

Foundations are critical to the stability of the bridge since the foundation ultimately supports the entire structure. The two basic types of bridge foundations shown in Figure 10.1.20 are:

- Spread footings
- Deep foundations

A spread footing is used when the bedrock layers are close to the ground surface or when the soil is capable of supporting the bridge. A spread footing is typically a rectangular reinforced concrete slab. This type of foundation "spreads out" or distributes the loads from the bridge to the underlying rock or soil. While a spread footing is usually buried, it is generally covered with a minimal amount of soil. In cold regions, the bottom of a spread footing will be placed below the recognized maximum frost line depth for that area.

A deep foundation is used when the soil is not suited for supporting the bridge. A pile is a long, slender support which is typically driven into the ground but can be placed in predrilled holes. Piles can be partially exposed and are made of steel, concrete (cast-in-place or precast), or timber. Various numbers and configurations of piles can be used to support a bridge foundation. This type of foundation transfers load to sound material well below the surface or, in the case of friction piles, to the surrounding soil.

"Caisson", "drilled shafts", or "bored pile" is another type of deep foundation typically used when the soil stratum is typically less than 3 meters (10 feet) from the footing bottom to bedrock. Holes are drilled through the soil and filled with reinforced concrete. Temporary or permanent steel casing is utilized during the construction process to support and retain the sides of a borehole. Temporary steel casing is removed after the concrete is placed and is capable of withstanding the surrounding pressures. The minimum diameter used for bridge substructure construction is normally 0.75 meters (30"). Caissons, drilled shafts or bored piles may be extended beyond 3 meters (10 feet) if economically feasible or if there are voids such as caverns or mines within the bedrock under the bridge.

Figure 10.1.21 Stub Abutment on Piles with Piles Exposed

10.1.3 Inspection Procedures and Locations for Abutments

Inspection procedures for abutments 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), 2.3 and 13.3 (Steel), or Topic 2.4 (Stone Masonry) for specific material defects and inspection procedures. However, because stability is a paramount concern, checking for various forms of movement is required during the inspection of abutments.

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

The most common problems observed during the inspection of abutments are:

- Vertical movement
- Lateral movement
- Rotational movement
- Material defects
- Scour and undermining of the foundation
- Drainage system malfunction
- Areas subjected to high stresses
- Areas exposed to traffic
- Fatigue prone details and fracture critical members

Vertical Movement

Vertical movement can occur in the form of uniform settlement or differential settlement. A uniform settlement of all bridge substructure units, including abutments and piers/bents, will have little effect on the structure. Uniform settlements of 0.3 m (1 foot) have been detected on small bridges with no signs of distress.

Differential settlement can produce serious distress in a bridge. Differential settlement may occur between different substructure units, causing damage of varying magnitude depending on span length and bridge type (see Figure 10.1.22). It may also occur under a single substructure unit (see Figure 10.1.23). This may cause an opening of the expansion joint between the abutment and wingwall, or it may cause cracking or tipping of the abutment, pier, or wall.

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

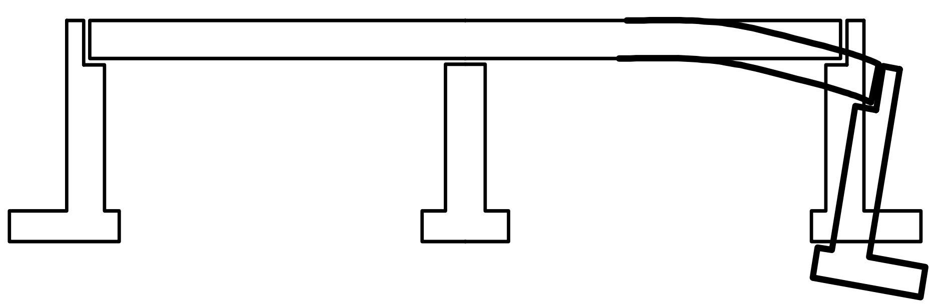


Figure 10.1.22 Differential Settlement Between Different Substructure Units

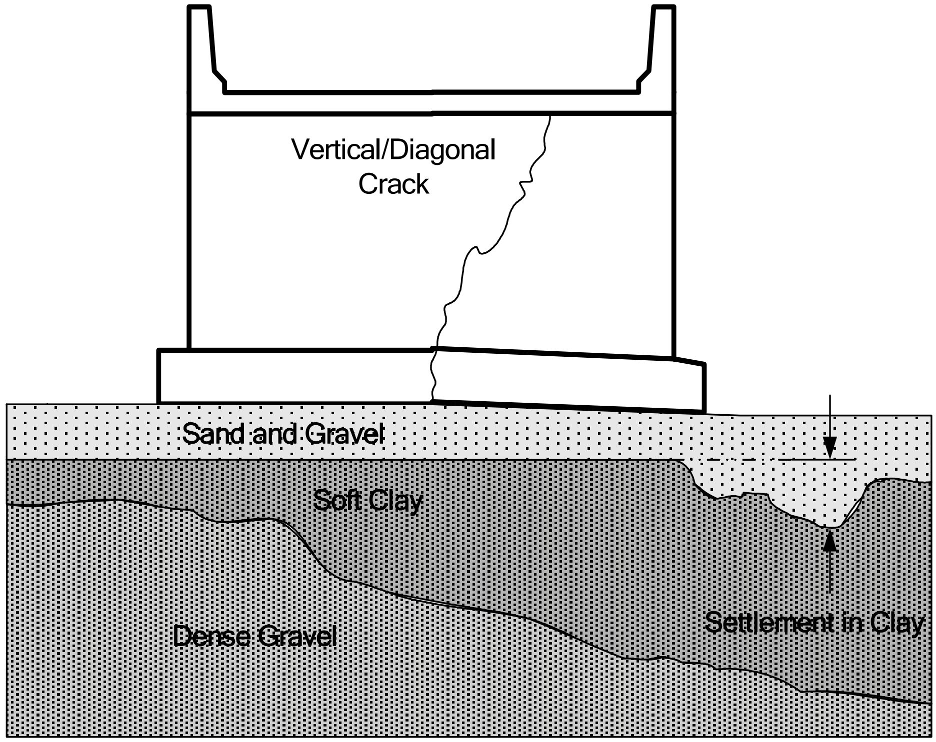


Figure 10.1.23 Differential Settlement Under an Abutment

Inspection for vertical movement, or settlement, should include:

- Inspect the joint opening between the end of the approach slab and the deck. In some cases, pavement expansion or approach fill expansion could conceivably cause vertical movement in the approach slab.
- Investigate existing and new cracks for signs of settlement (see Figure 10.1.24).
- Examine the superstructure alignment for evidence of settlement (particularly the bridge railing and deck joints).
- Check for scour and undermining around the abutment footing or foundation.
- Inspect the joint that separates the wingwall and abutment for proper alignment.

Figure 10.1.24 Crack in Abutment due to Settlement

Lateral Movement

Earth retaining structures, such as abutments and retaining walls, are susceptible to lateral movements, or sliding (see Figure 10.1.25). Lateral movement occurs when the horizontal earth pressure acting on the wall exceeds the friction forces that hold the structure in place.

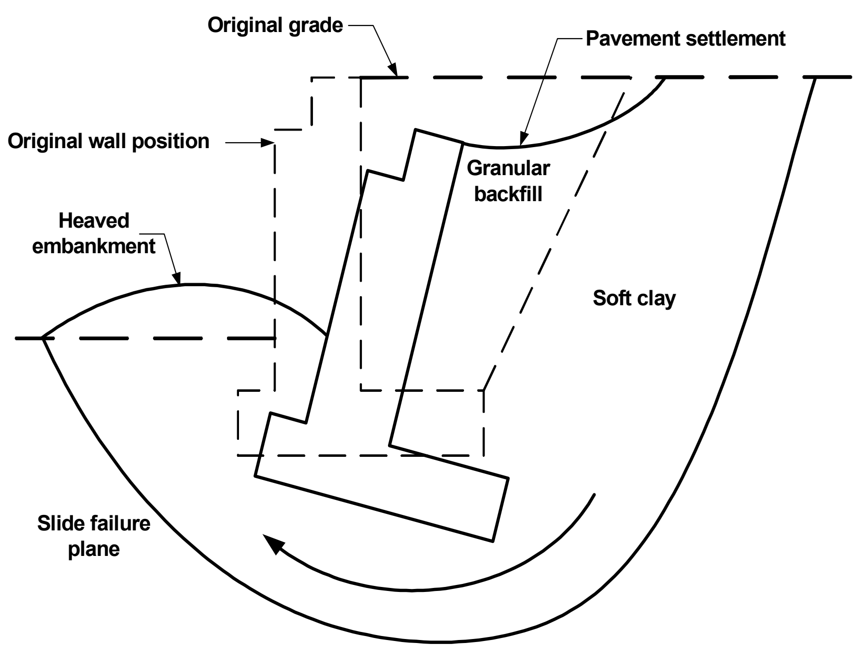


Figure 10.1.25 Lateral Movement of an Abutment due to Slope Failure

The most common causes of lateral movement are slope failure, seepage, changes in soil characteristics (e.g., frost action and ice), and time consolidation of the original soil.

Inspection for lateral movement, or sliding, should include:

- Inspect the general alignment of the abutment.
- Check the bearings for evidence of lateral displacement (see Figure 10.1.26).
- Examine the opening in the construction joint between the wingwall and the abutment.
- Investigate the joint opening between the deck and the approach slab (see Figure 10.1.27).
- Check the approach roadway for settlement.
- Check the distance between the end of the superstructure and the backwall.
- Examine for clogged drains (approach roadway, weep holes, and substructure drainage).
- Inspect for erosion, scour or undermining of the embankment material in front of the abutment (see Figure 10.1.28).

Figure 10.1.26 Excessive Rocker Bearing Displacement Indicating Possible Lateral Displacement of Abutment

Figure 10.1.27 Depressed Approach Slab due to Rotating Abutment

Figure 10.1.28 Erosion at Abutment Exposing Footing

Rotational Movement

Rotational movement, or tipping, of substructure units is generally the result of unsymmetrical settlements and / or lateral movements due to horizontal earth pressure (see Figure 10.1.29). Abutments and walls are subject to this type of movement.

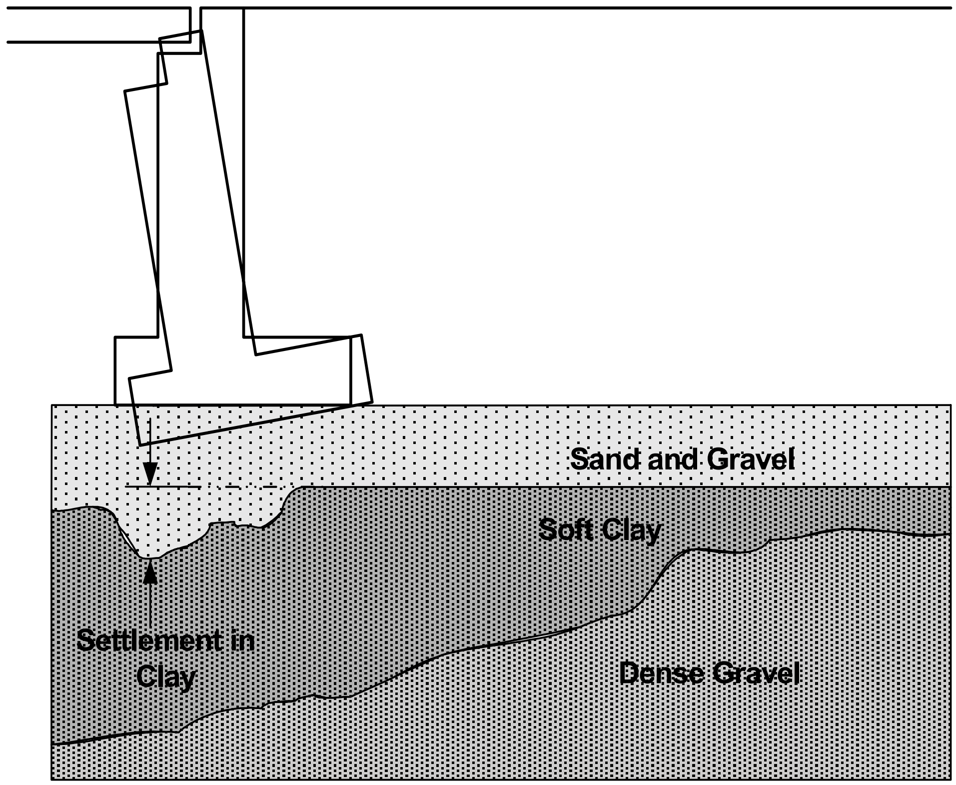


Figure 10.1.29 Rotational Movement of an Abutment

The most common causes of rotational movement are undermining, scour, saturation of backfill, soil bearing failure, erosion of backfill along the sides of the abutment, and improper design.

Inspection for rotational movement, or tipping, should include:

- Check the vertical alignment of the abutment using a plumb bob or level; keep in mind that some abutments are constructed with a battered or sloped front face (see Figures 10.1.30 and 10.1.31).
- Examine the clearance between the beams and the backwall.
- Inspect for clogged drains or weep holes.
- Investigate for unusual cracks or spalls.
- Check for scour or undermining around the abutment footing. See Topic 11.2 for a detailed description of scour and undermining. See Topic 11.3 for a detailed description of underwater inspection.

Figure 10.1.30 Rotational Movement at Abutment

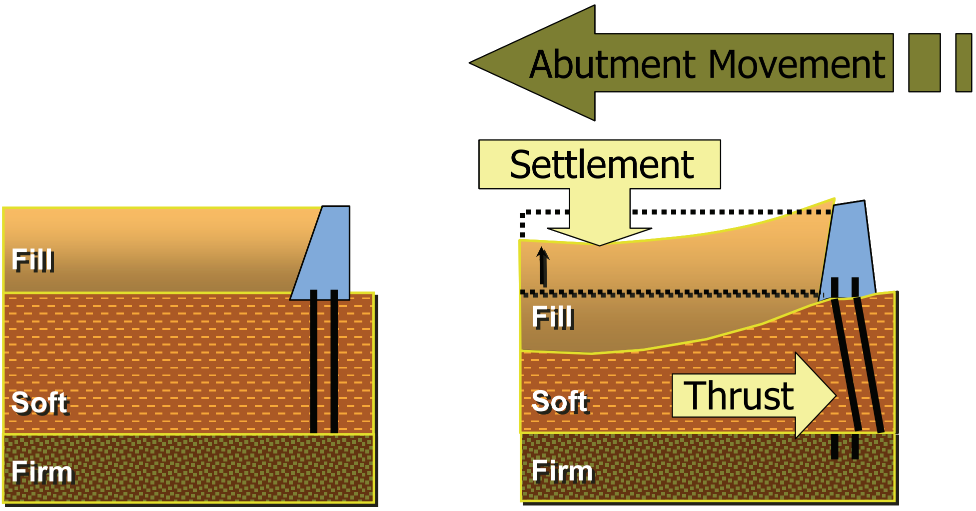


Figure 10.1.31 Rotational Movement due to "Lateral Squeeze" of Embankment Material

Material Defects

A common problem observed during the inspection of abutments is the presence of construction material defects. Refer to Topics 2.1 – 2.4 for a more detailed description of the types and causes of deterioration observed in timber, concrete, steel and stone masonry.

Concrete and Stone Masonry

Inspection for concrete and stone masonry material defects in abutments should include:

- Examine the bearing seats for cracking and spalling, particularly near the edges; this is particularly critical where concrete beams bear directly on the abutment seat (see Figure 10.1.32).
- Inspect for the presence of debris and standing water on the bearing seats.
- Investigate for deteriorated concrete in areas that are exposed to roadway drainage, particularly below the joint between the backwall and the deck (see Figure 10.1.33).
- Check the backwall for cracking and possible movement.
- Examine the construction joint between the backwall and the abutment stem.
- Inspect stone masonry for mortar cracks or loss of mortar in the joints (see Figure 10.1.34).
- Examine stone masonry for vegetation, water seepage through cracks, loose or missing stones, weathering, split, spalled, loose or missing blocks.

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

Figure 10.1.32 Cracking in Bearing Seat of Concrete and Stone Abutment

Figure 10.1.33 Deteriorated Concrete in Abutment Backwall

Figure 10.1.34 Deteriorated Stone Masonry Abutment

Steel

Although a steel abutment is uncommon (see Figure 10.1.35), the following items should be inspected if one is encountered:

- Examine bearing seat area for buildup of dirt and debris.
- After cleaning, check bearing seat area for corrosion and section loss.
- Inspect cap beam, piles, and any other steel elements for corrosion, cracking, and section loss.
- Investigate piles closely at the ground line.
- Check for scour and erosion around the piles.
- Examine all fasteners and connections for condition and tightness.

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

Figure 10.1.35 Steel Abutment

Timber

Inspection for timber defects in abutments should include:

- Examine bearing seat for accumulated dirt and debris and prolonged exposure to moisture.
- Inspect for decay, insect damage, and crushing of the cap beam.
- Investigate for local failures in lagging or piles due to lateral movement (see Figure 10.1.36).
- Check crib timbers, timber lagging, and piles for splits, cracks, decay, insect damage, fire damage, and chemical attack (see Figure 10.1.37).
- Inspect for scour around the piles (see Figure 10.1.38).
- Examine piles very closely for decay at or near the ground line or

waterline.

- Investigate splices and connections for tightness and for loose bolts.
- In marine environments, examine piles for the presence of marine borers and caddis flies.

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

Figure 10.1.36 Local Failure in Timber Pile due to Lateral Movement of Abutment

Figure 10.1.37 Decay in Lagging of Timber Crib Abutment

Figure 10.1.38 Decayed Lagging and Scour at a Timber Pile Bent Abutment

Scour and Undermining

Scour is the removal of material from a streambed as a result of the erosive action of running water (see Figure 10.1.39). Scour can cause undermining or the removal of supporting foundation material from beneath the abutments when streams or rivers flow adjacent to them. Refer to Topic 11.2 for a more detailed description of scour and undermining.

Figure 10.1.39 Abutment with Undermining due to Scour

Inspection for scour should include probing around the abutment footing for signs of undermining (see Figure 10.1.40). Sometimes silt loosely fills in a scour hole and offers no protection or bearing capacity for the abutment footing.

Figure 10.1.40 Inspector Checking for Scour

Drainage Systems

Water can build up horizontal pressure behind an abutment. Allowing the water to exit from behind the abutment relieves this pressure. Weep holes, normally 100 mm (4 inches) in diameter, allow water to pass through the abutment. Sometimes abutments have subsurface drainage pipes that are parallel to the rear face of the abutment stem. These pipes are sloped to drain the water out at the end of the abutment.

Check weep holes and subsurface drainage pipes to see that they are clear and functioning. Be careful of any animal or insect nests that may be in the weep holes. Look for signs of discoloration under the weep holes, which may indicate that the weep holes or substructure drainage pipes are functioning properly. Check the condition of any drainage system that is placed adjacent to the abutment that may result in deterioration of the abutment.

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 abutment stem/footing connection, and the area where the footing is supported by earth or deep foundations. In timber abutments, 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 at the bottom of the backwall, and bottom of abutment stem. In timber abutments, 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 backwall and abutment stem connection. High flexural moments may be occurring at the footing toe/abutment stem. 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 abutments may include spalls and exposed reinforcement and possibly steel reinforcement section loss.

Steel abutments may experience cracks, section loss, or distortion which must be documented.

Fatigue Prone Details and Fracture Critical Members

Steel abutments may contain fatigue prone details. Closely examine these details for section loss due to corrosion and cracking. The members of a steel abutment may be fracture critical. See Topic 8.1 for a detailed description of fatigue prone details and fracture critical members.

10.1.4 Design Characteristics of Wingwalls

General

Wingwalls are located on the sides of an abutment and enclose the approach fill. Wingwalls are generally considered to be retaining walls since they are designed to maintain a difference in ground surface elevations on the two sides of the wall (see Figure 10.1.41).

A wingwall is similar to an abutment except that it is not required to carry any loads from the superstructure. The absence of the vertical superstructure load usually necessitates a wider footing to resist the overturning moment or horizontal sliding.

Figure 10.1.41 Typical Wingwall

Geometrical Classifications

There are several geometrical classifications of wingwalls, and their use is dependent on the design requirements of the structure:

- **Straight** - extensions of the abutment wall (see Figure 10.1.42)
- **Flared** - form an acute angle with the bridge roadway (see Figure 10.1.43)
- **U-wings** - parallel to the bridge roadway (see Figure 10.1.44)

Figure 10.1.42 Straight Wingwall

Figure 10.1.43 Flared Wingwall

Figure 10.1.44 U-wingwall

Construction Classifications

There are several construction classifications of wingwalls:

- **Integral** - constructed monolithically with the abutment (see Figure 10.1.45) normally cast-in-place concrete
- **Independent** - constructed separately from the abutment; usually an expansion or mortar joint separates them from the abutment stem (see Figure 10.1.46)

Figure 10.1.45 Integral Wingwall

Figure 10.1.46 Independent MSE Wingwall

Primary Materials

Wingwalls may be constructed of concrete, stone masonry, steel, or timber or a combination of these materials.

Figure 10.1.47 Masonry Wingwall

Primary and Secondary Reinforcement

In a concrete cantilever wingwall, the primary reinforcing steel consists of vertical bars in the rear face of the stem, horizontal bars in the bottom of the footing (toe steel), and horizontal bars in the top of the footing (heel steel) (see Figure 10.1.48). Secondary reinforcement is used to resist temperature and shrinkage.

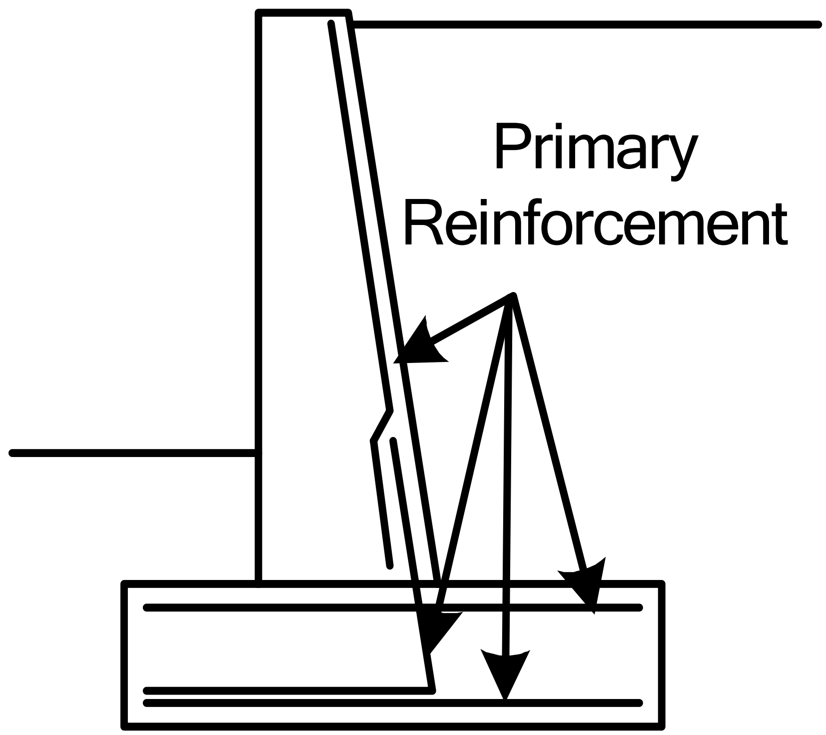


Figure 10.1.48 Primary Reinforcement in Concrete Cantilever Wingwall

10.1.5 Inspection Procedures and Locations for Wingwalls

The inspection procedures and locations for most wingwalls are similar to those for abutments (see Topic 10.1.3). Many of the problems that occur in abutments are common in wingwalls also, including:

- Vertical movement
- Lateral movement
- Rotational movement (see Figure 10.1.49)
- Material defects (see Figure 10.1.50)
- Scour/undermining (see Figure 10.1.51)
- Drainage systems
- Areas subjected to high stresses
- Areas exposed to traffic

Figure 10.1.49 Rotational Movement at Concrete Wingwall

Figure 10.1.50 Deteriorated Concrete Wingwall

Figure 10.1.51 Scour and Possible Undermining of Concrete Wingwall

Material defects to look for include shoulder erosion, cracks, concrete deterioration, stone masonry deterioration, timber decay, and steel buckling (see Figures 10.1.52 to 10.1.55).

Figure 10.1.52 Roadway Shoulder Erosion Behind Wingwall

Figure 10.1.53 Settlement Cracks at Integral Concrete Wingwalls

Figure 10.1.54 Deteriorating Stone Masonry Wingwall

Figure 10.1.55 Timber Wingwall

Wingwall problems are similar to problems in abutments. Refer to Topic 10.1.3 for a detailed description of common abutment problems.

Integral wingwalls should be inspected with the abutments, and they are included in the substructure evaluation and condition rating. However, only that portion up to the first construction or expansion joint is considered. Independent wingwalls should also be inspected, but their condition does not affect the evaluation and condition rating of the substructure. The condition of integral and independent wingwalls should be noted on the inspection form.

10.1.6 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 an abutment or wingwall structure, the AASHTO CoRe element typically is one of the following:

Element No.	**Description**
215	Abutment – Reinforced Concrete
216	Abutment – Timber
217	Abutment – Other (masonry, steel, etc.)

Some bridge owners use the following CoRe elements for abutments similar to those shown in Figures 10.1.5, 10.1.15, 10.1.16, 10.1.36, and 10.1.38,

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)
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)

The unit quantity for the substructure elements is meters or feet, measured horizontally across the abutment 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 abutment or wingwall, the "Settlement" Smart Flag, Element No. 360, can be used and one of three condition states assigned. For scour at the abutments or wingwalls, the "Scour" Smart Flag, Element No. 361, can be used and one of three condition states assigned.

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.

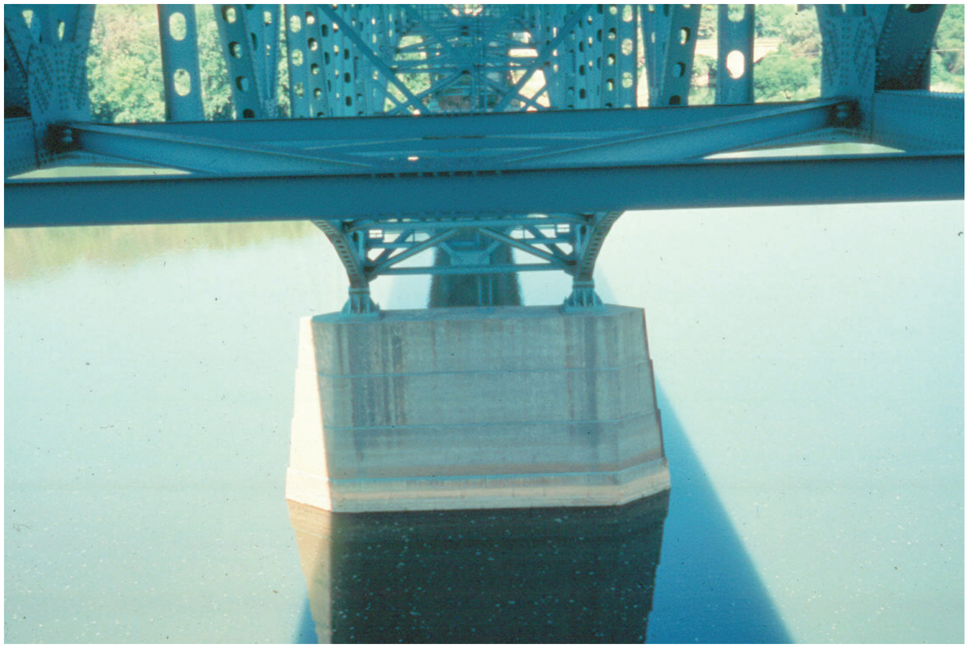


Figure 10.2.2 Solid Shaft Pier

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.

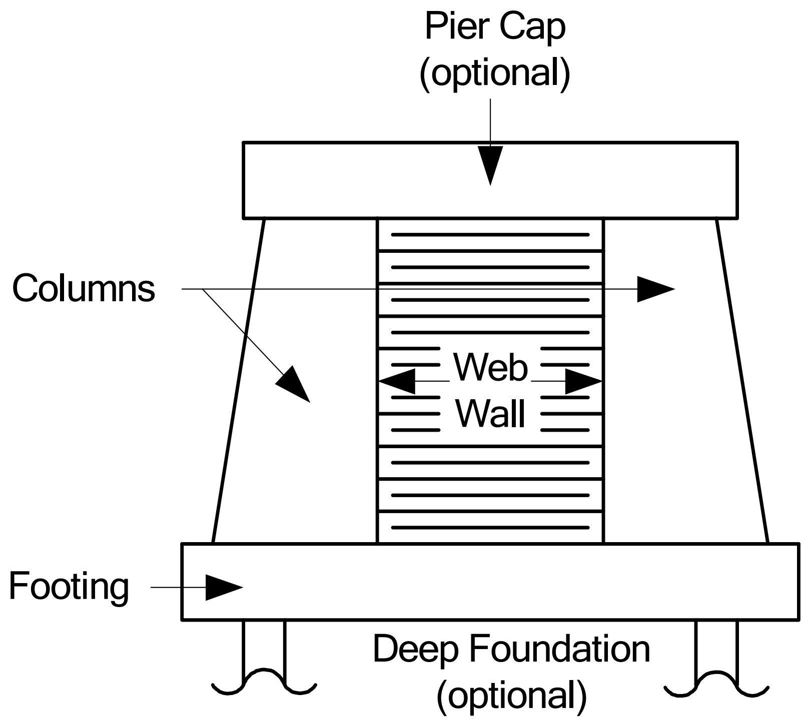


Figure 10.2.4 Column Pier with Web Wall

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

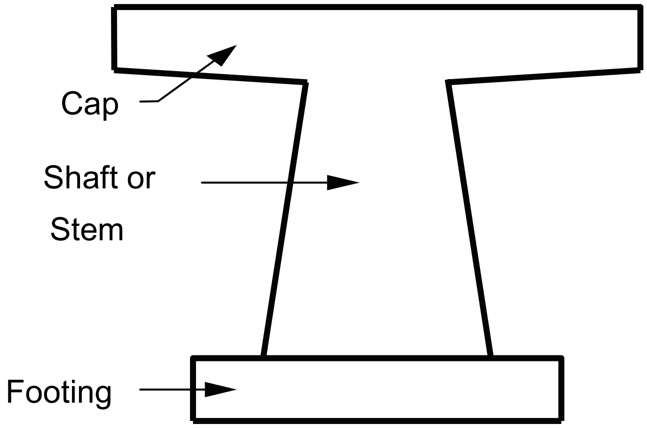


Figure 10.2.6 Single Stem Pier (Cantilever or Hammerhead)

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

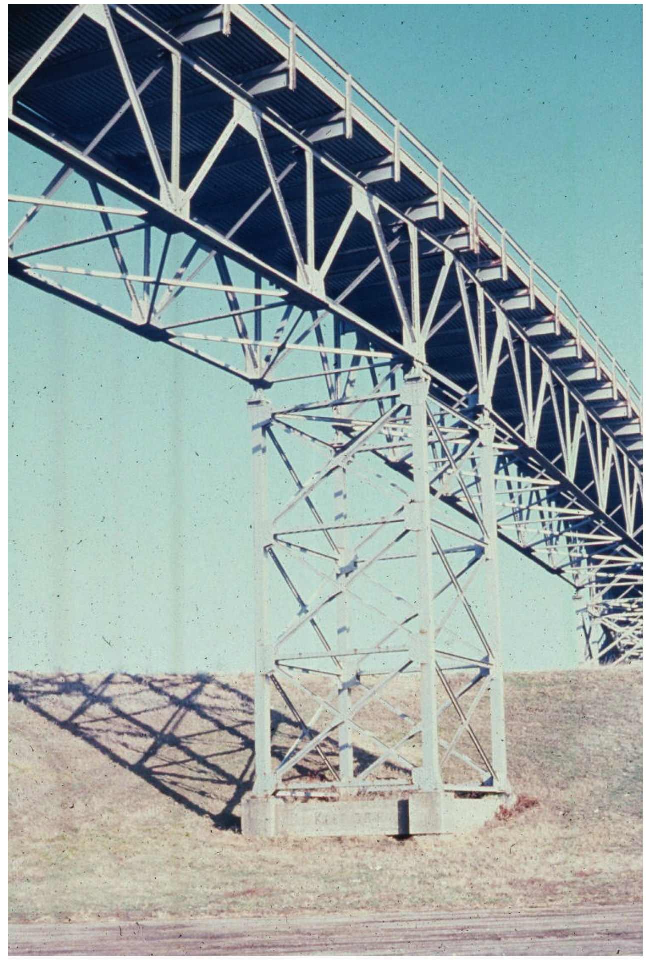


Figure 10.2.15 Steel Bent

Figure 10.2.16 Timber Pile Bent

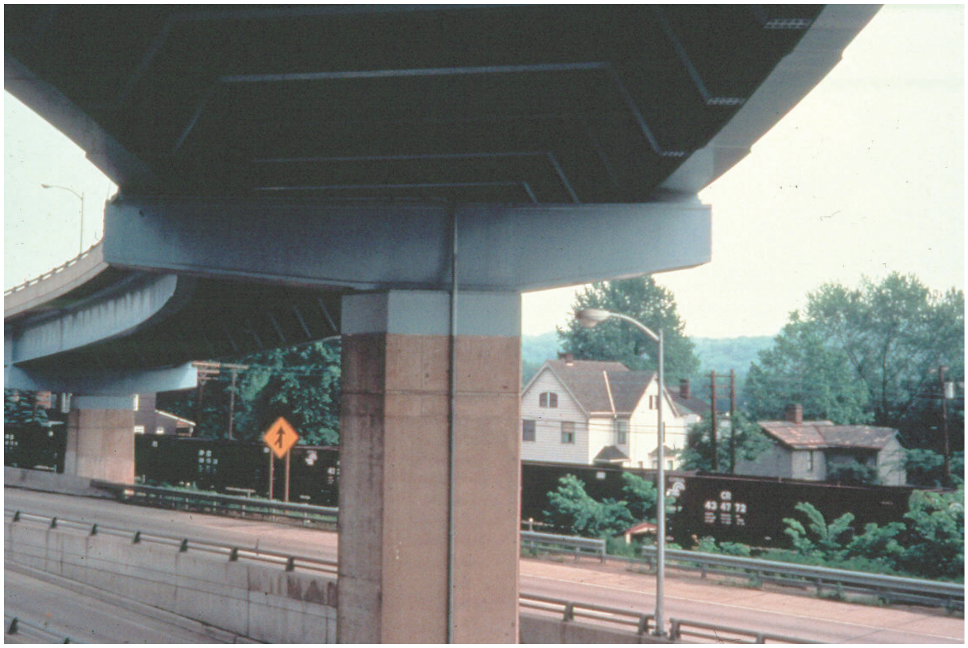


Figure 10.2.17 Combination: Reinforced Concrete Column with Steel Pier Cap

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.

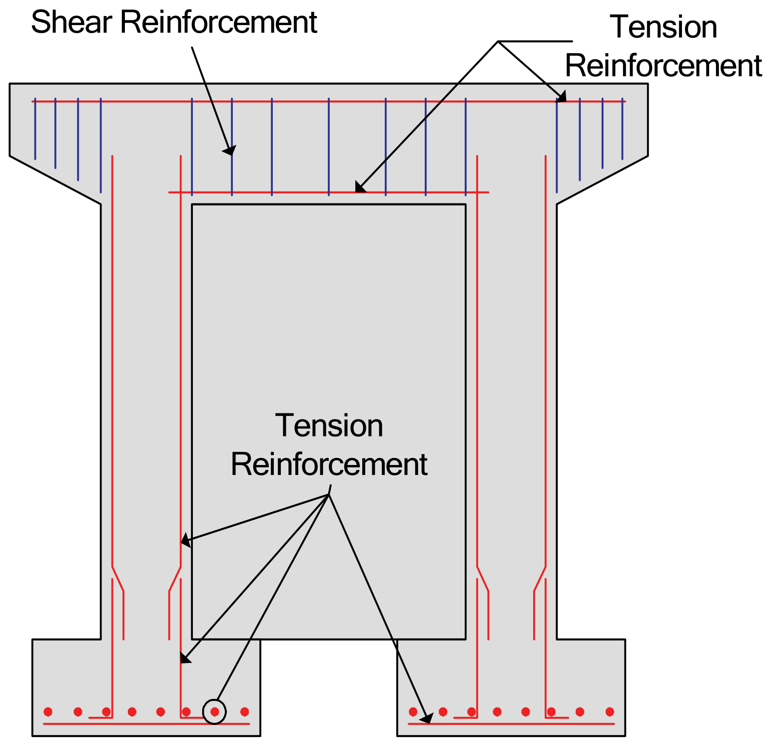


Figure 10.2.18 Primary Reinforcement in Column Bent with Web Wall

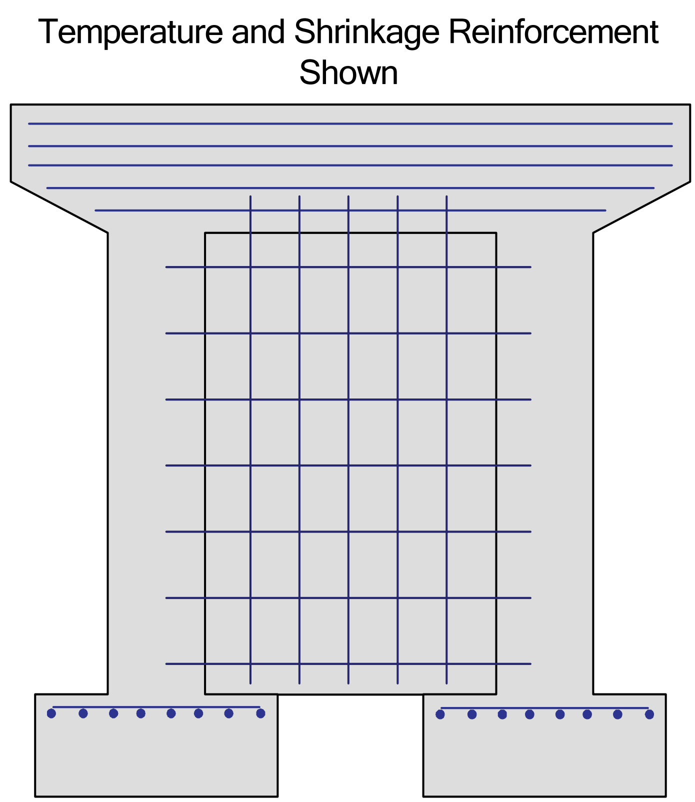


Figure 10.2.19 Secondary Reinforcement in Column Bent with Web Wall

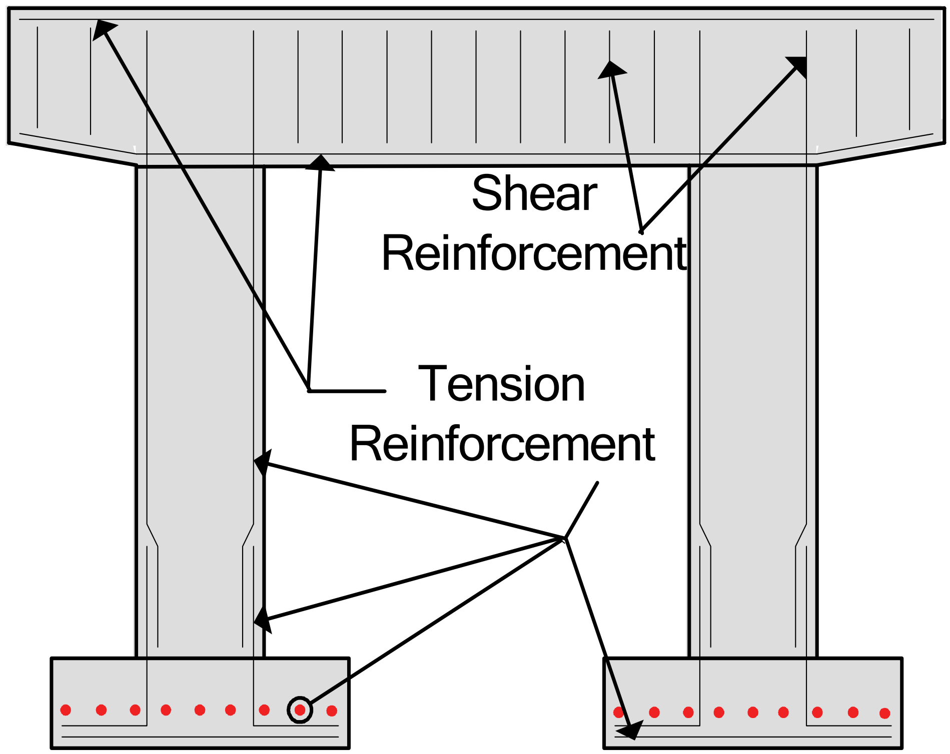


Figure 10.2.20 Primary Reinforcement in Column Bents

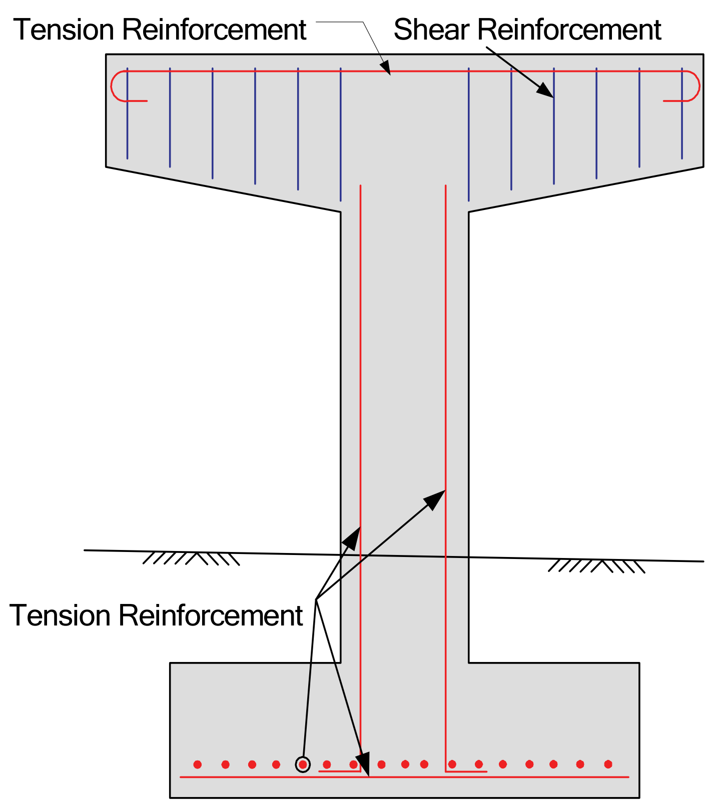


Figure 10.2.21 Primary Reinforcement for a Cantilevered Pier

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

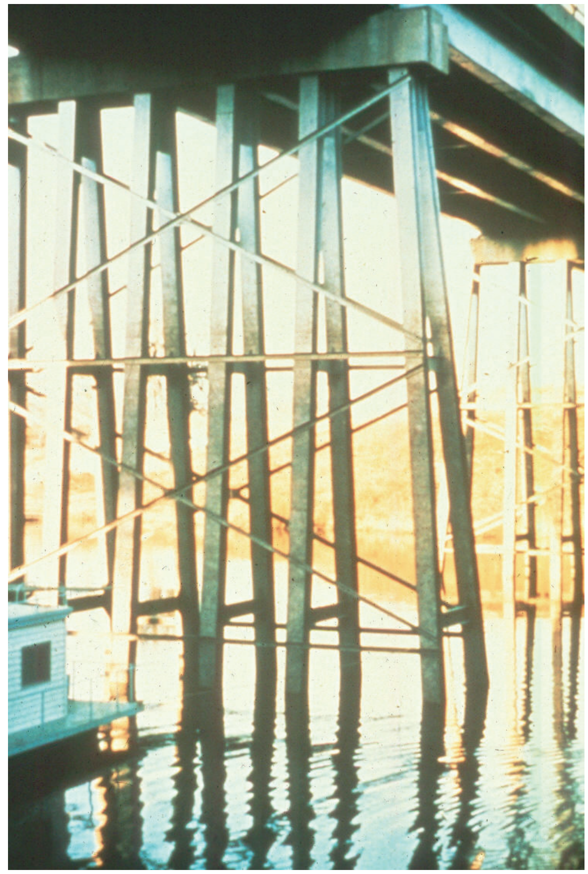


Figure 10.2.23 Pile Bent

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).

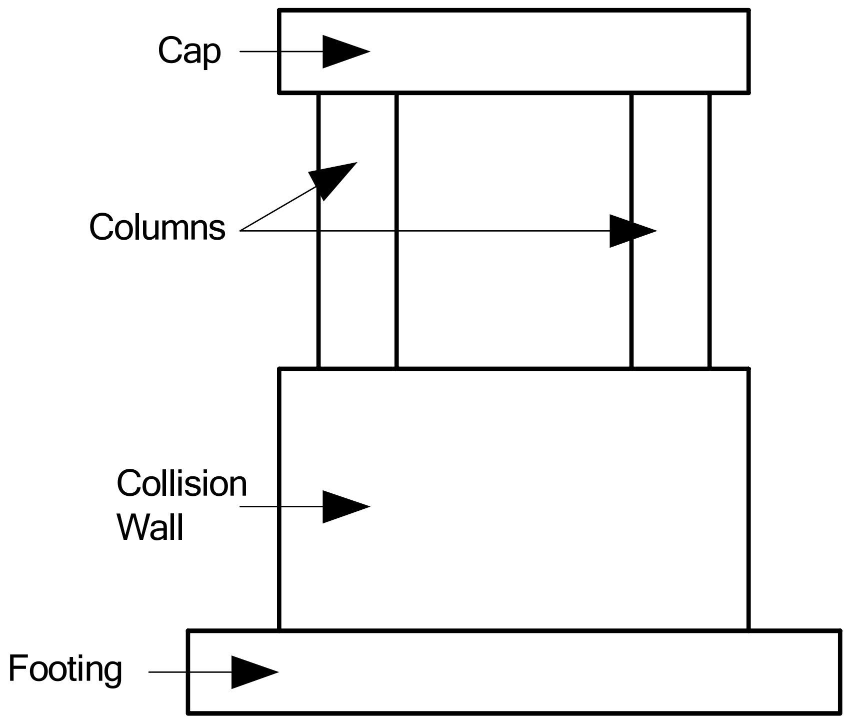


Figure 10.2.24 Collision Wall

Figure 10.2.25 Collision Wall

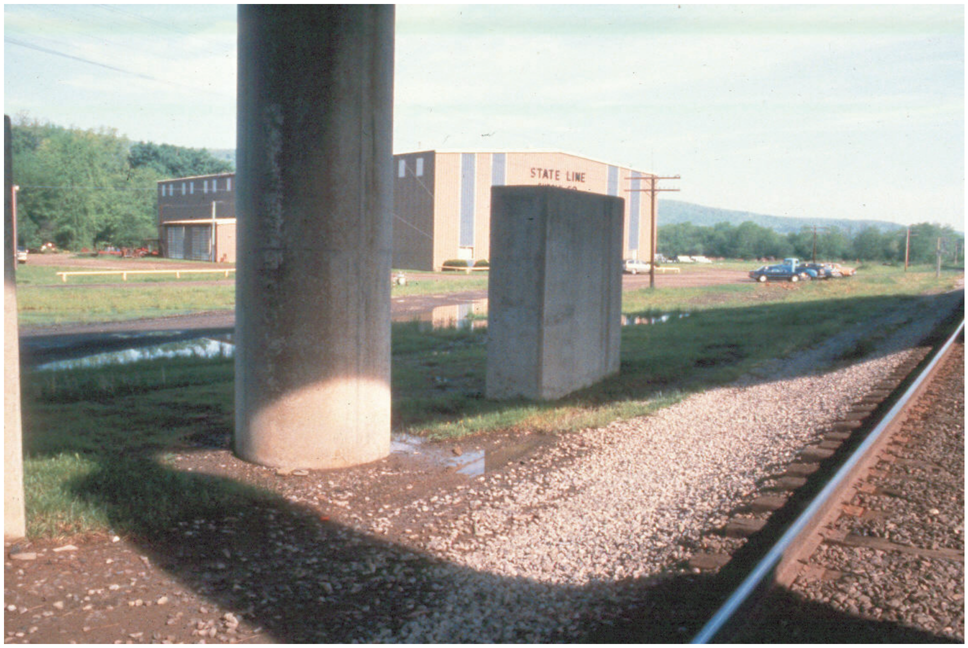


Figure 10.2.26 Concrete Block Dolphin

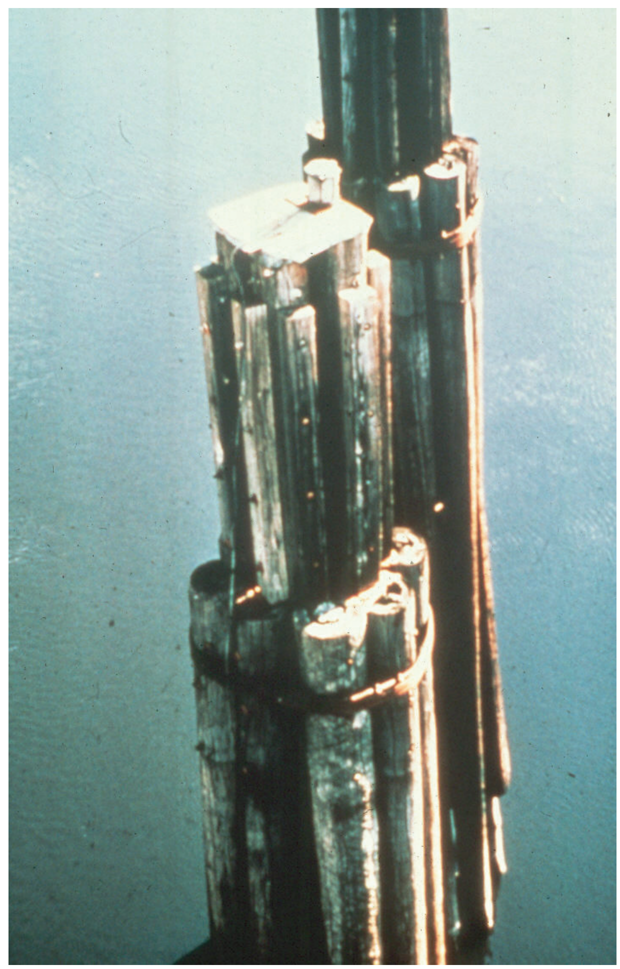


Figure 10.2.27 Timber Dolphin

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.

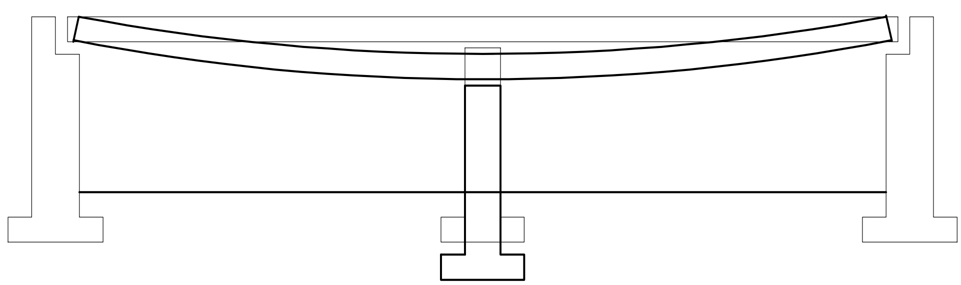


Figure 10.2.30 Differential Settlement Between Different Substructure Units

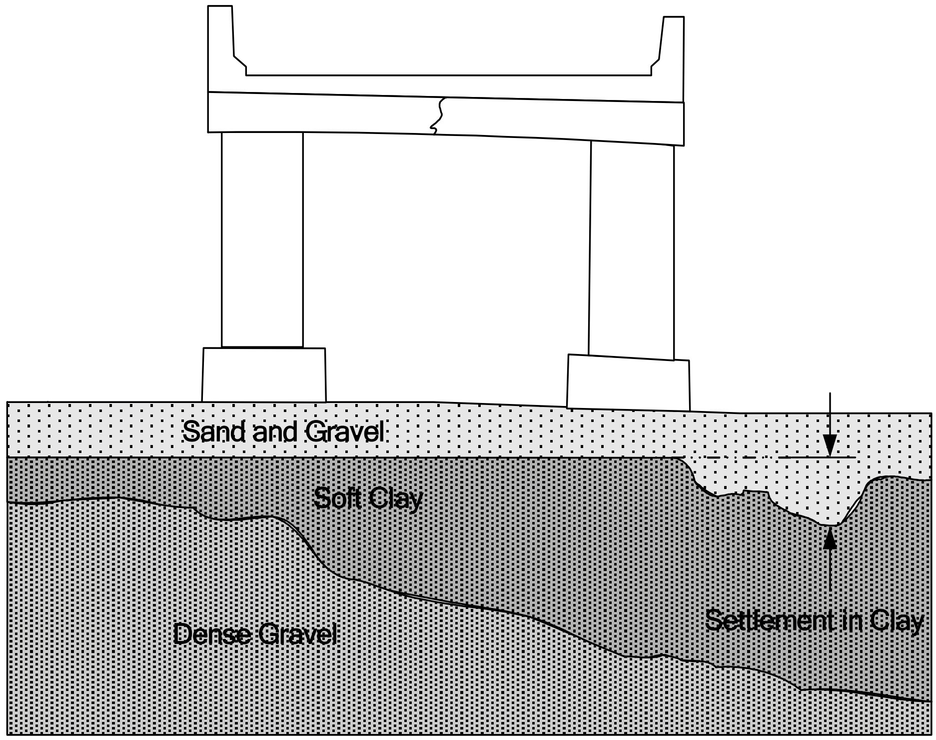


Figure 10.2.31 Differential Settlement Under a Pier

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.

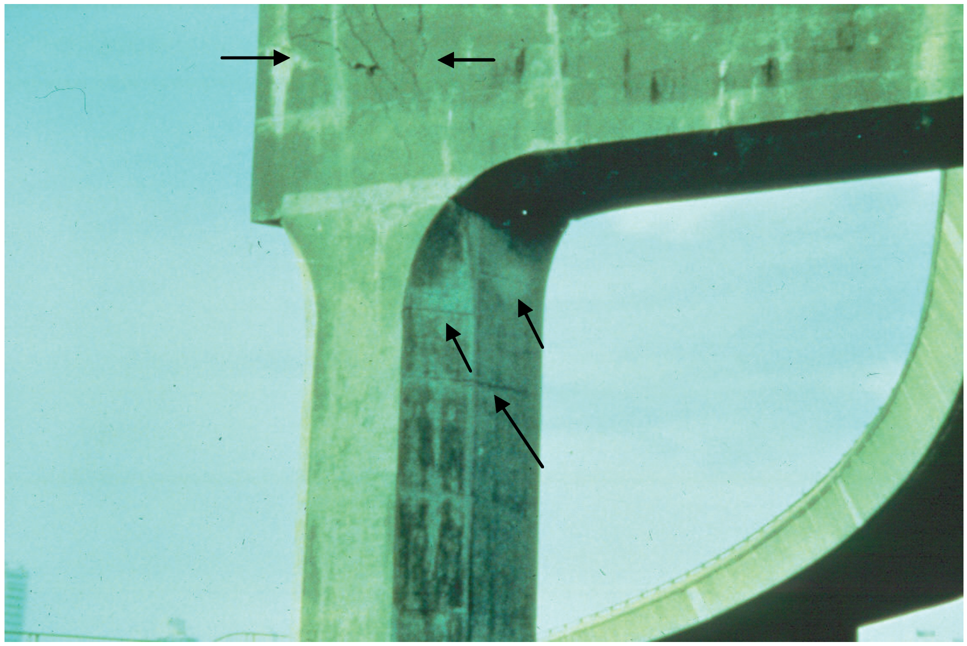


Figure 10.2.33 Cracks in Bent Cap due to Lateral Movement of Bent during Earthquake

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

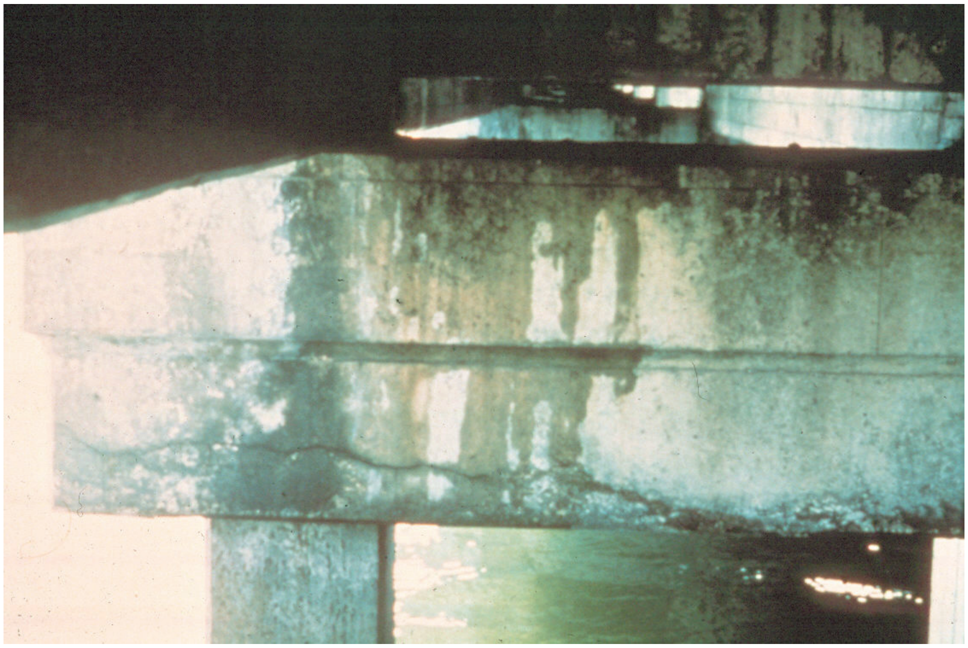


Figure 10.2.37 Crack in Concrete Bent Cap

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.

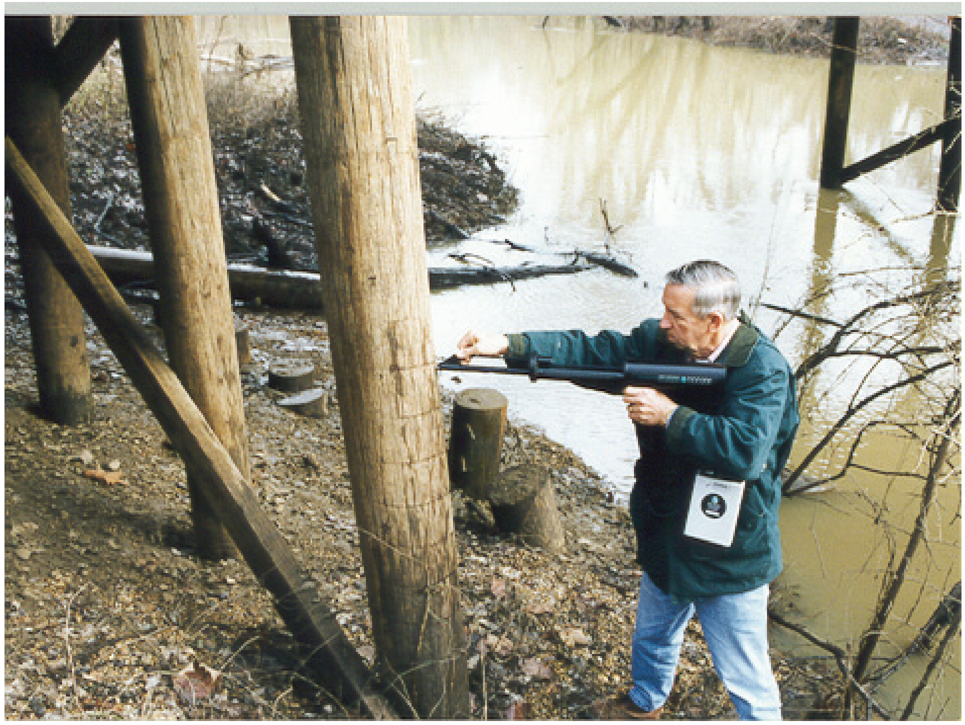


Figure 10.2.44 Drilling a Timber Bent Column for a Core Sample

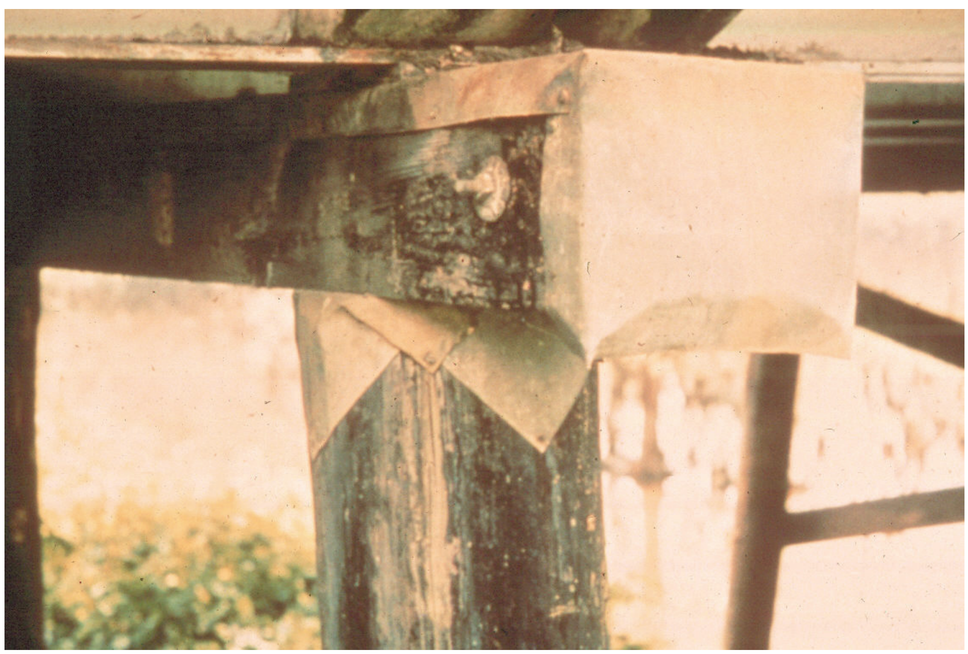


Figure 10.2.45 Decay in Timber Bent Cap (Note "Protective" Cover / Flashing)

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.

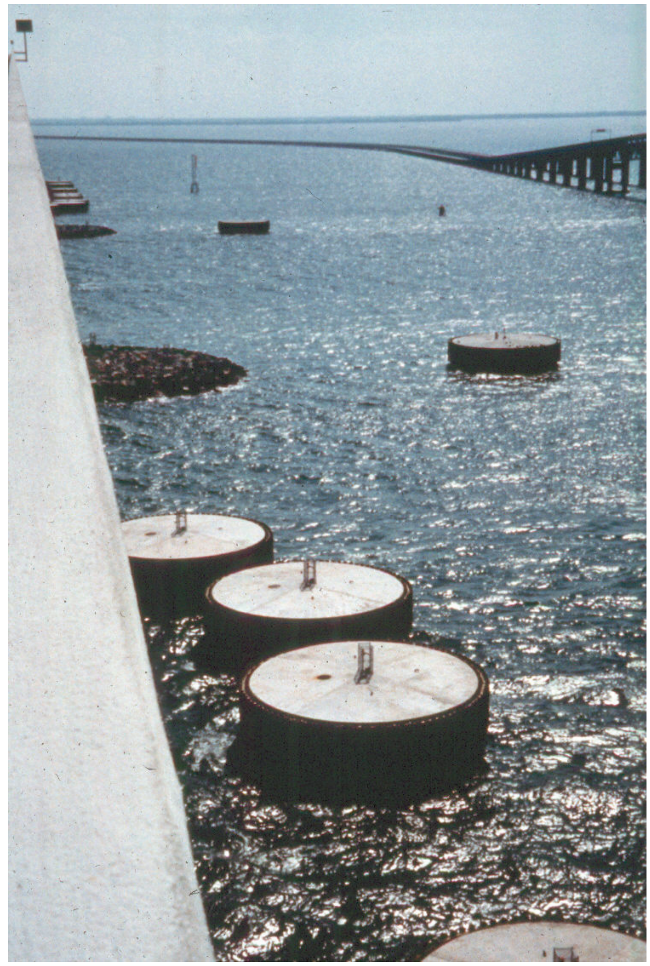


Figure 10.2.53 Concrete Dolphins

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.