Table of Contents

Chapter 12
Inspection and Evaluation of Substructures

12.1 Abutments and Wingwalls 12.1.1

12.1.1 Introduction 12.1.1

12.1.2 Design Characteristics of Abutment 12.1.2
Common Abutment Types 12.1.2
Full Height Abutments and Stub Abutments 12.1.6
Open Abutments 12.1.7
Integral Abutments and Semi-Integral Abutments 12.1.7
Less Common Abutment Types 12.1.9
Mechanically Stabilized Earth Abutments 12.1.9
Geosynthetic Reinforced Soil Abutments 12.1.10
Primary Materials 12.1.12
Primary and Secondary Reinforcement 12.1.14
Abutment Members 12.1.15
Foundation Types 12.1.17

12.1.3 Design Characteristics of Wingwalls 12.1.18
General 12.1.18
Geometrical Classifications 12.1.19
Construction Classifications 12.1.20
Primary Materials 12.1.21
Primary and Secondary Reinforcement 12.1.22

12.1.4 Inspection Methods and Locations 12.1.23
Methods 12.1.23
Visual 12.1.23
Physical 12.1.29
Advanced Inspection Methods 12.1.30
Locations 12.1.32
Areas Subjected to Movement 12.1.32
Bearing Areas 12.1.39
Shear Zones 12.1.39
Flexural Zones 12.1.39
Areas Exposed to Drainage 12.1.40
Areas Exposed to Traffic 12.1.40
Areas Previously Repaired 12.1.40
Scour and Undermining 12.1.40
Problematic Details and Fracture Critical Members 12.1.42

12.1.5 Evaluation 12.1.42
NBI Component Condition Rating Guidelines 12.1.42
Element Level Condition State Assessment 12.1.43

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Chapter 12
Inspection and Evaluation of Substructures

Topic 12.1 Abutments and Wingwalls

12.1.1 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.

12.1.2 Design Characteristics of Abutments

Common 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 12.1.1 and include:

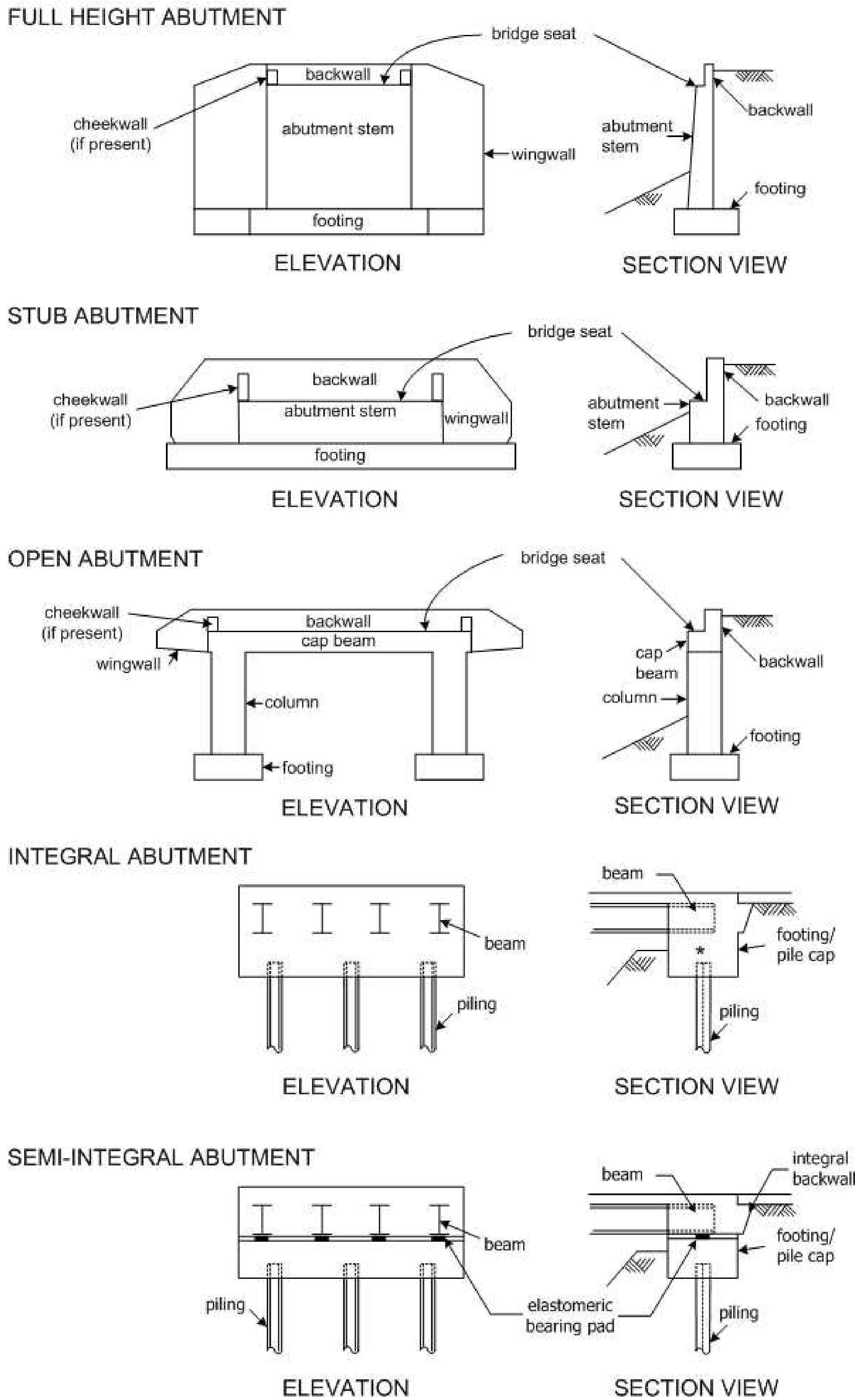
- Full height or closed type
- Stub, semi-stub, or shelf type
- Open or spill-through type
- Integral
- Semi-integral

Foundations consist of either spread footings or deep foundations. See page 12.1.16 for a detailed description of abutment foundation types.

Less common abutments used to support highway bridges are shown in Figures 12.1.2 and 12.1.3, and include:

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

Detailed descriptions of abutment elements are provided on page 12.1.15.



* Some agencies weld beam and piles together prior to concrete placement

Figure 12.1.1 Schematic of Common Abutment Types

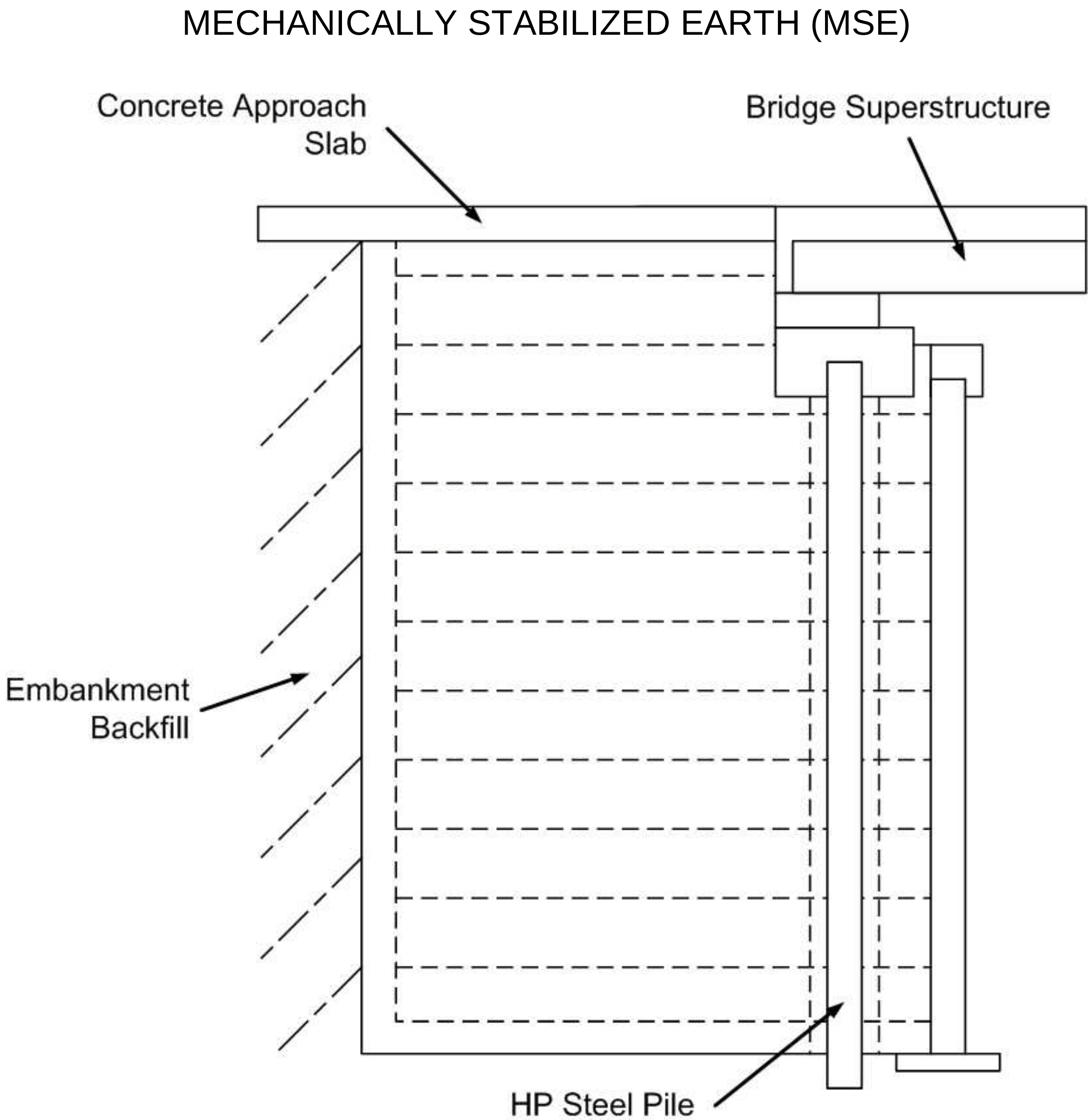


Figure 12.1.2 Section View of Less Common Abutment Types (Mechanically Stabilized Earth)

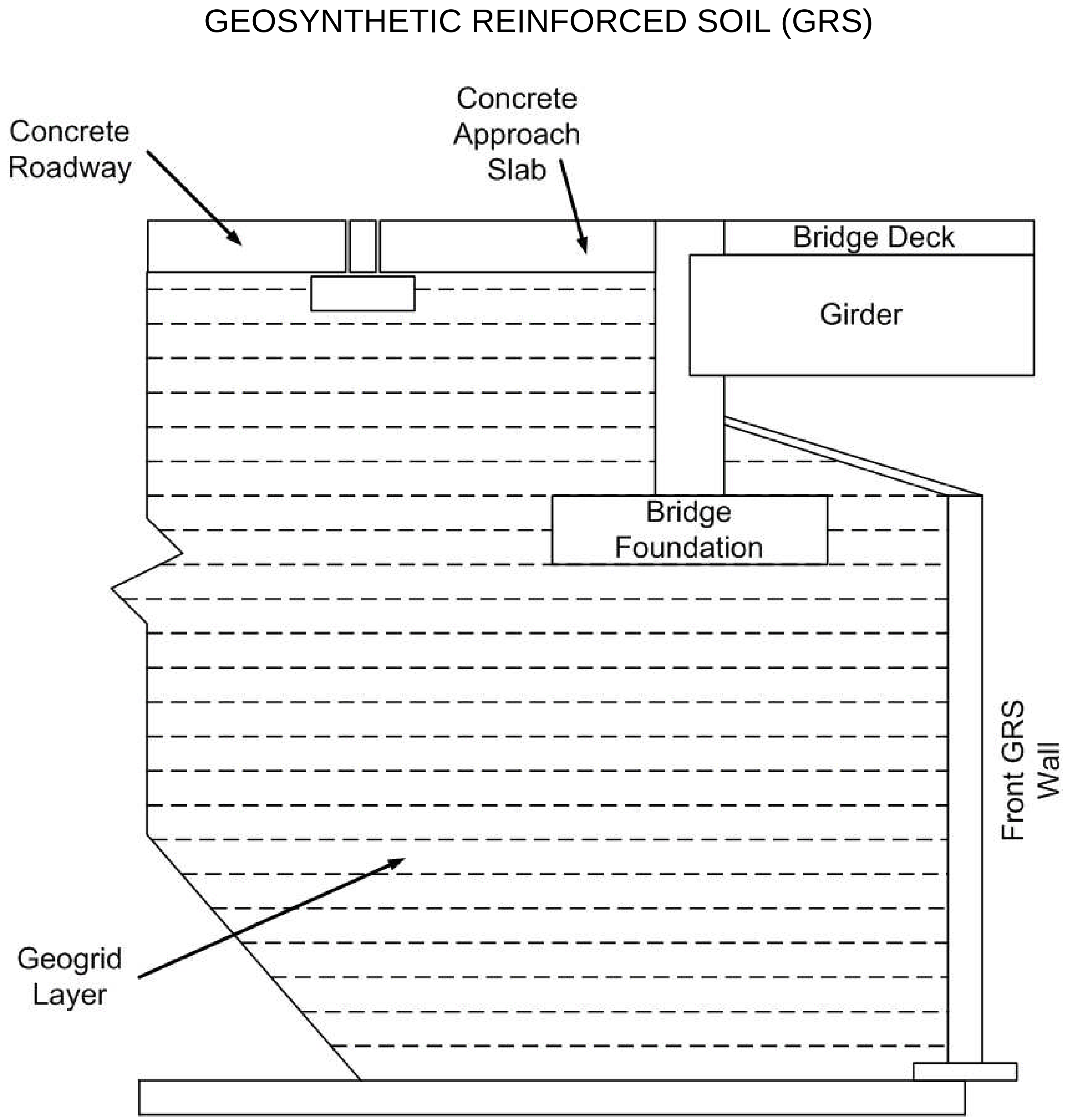


Figure 12.1.3 Section View of Less Common Abutment Types (Geosynthetic Reinforced Soil)

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 (see Figure 12.1.4). 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 (see Figure 12.1.5). 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 12.1.4 Full Height Abutment

Figure 12.1.5 Stub 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 (see Figure 12.1.6).

The advantages of the open abutment are lower construction 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.

Figure 12.1.6 Open Abutment

Integral Abutments and Semi-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 12.1.7). 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 (see Figure 12.1.8). 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 or superstructure rotations due to heavy skews.

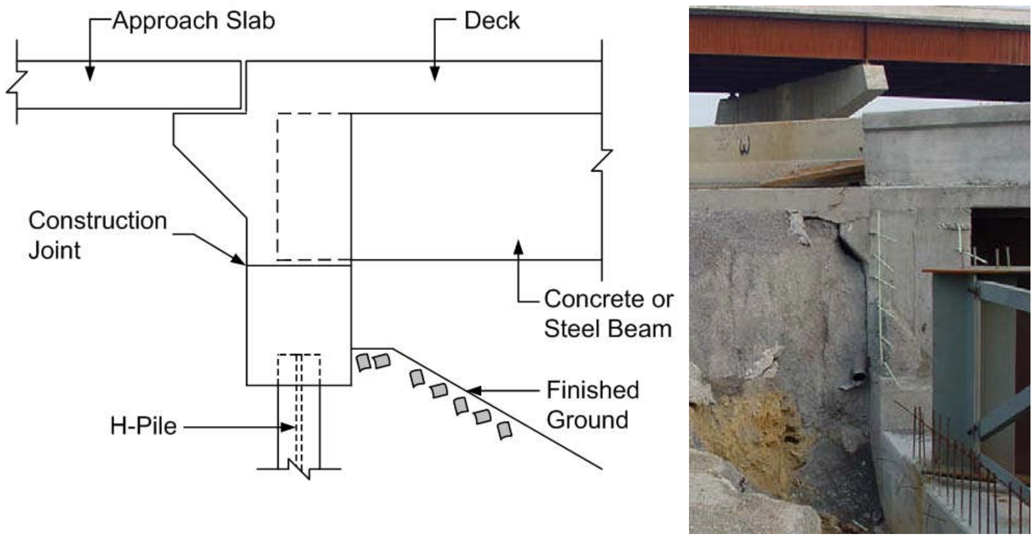


Figure 12.1.7 Integral Abutment

Figure 12.1.8 Integral Abutment

Semi-integral abutments are similar to integral abutments, however, the superstructure and the top of the abutment act as one unit, but the bottom portion act independently of the superstructure. This is achieved by a joint between the top and bottom portions of the abutment which will allow for un-restrained rotation and thermal movement.

Less Common Abutment Types

Some Agencies utilize additional, less common abutment types.

Mechanically Stabilized Earth Abutments

Mechanically Stabilized Earth (MSE) 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 12.1.9). 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. Problems have occurred when the MSE wall supports the bearings, since the MSE walls bulge out when they support vertical superstructure loads, which are transmitted through the bearings. Current construction practices call for stub abutments behind the MSE wall.

Precast vertical 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.” Horizontal soil reinforcement is then placed and bolted to the panels and covered with more backfill (see Figure 12.1.10). 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 12.1.9 Mechanically Stabilized Earth Abutment (Note Precast Concrete Panels)

Figure 12.1.10 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. 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 and their aesthetic appearance. GRS technology works well with simple overpasses; however, they are not ideal where severe flooding or scour could occur (see Figures 12.1.11 and 12.1.12).

Figure 12.1.11 GRS Bridge Abutment at the FHWA 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 12.1.12 View of the Founders/Meadows Bridge Supported by GRS Abutments

Primary Materials

The primary materials used in abutment construction are unreinforced concrete, reinforced concrete, stone masonry, steel (although not very common), timber, reinforcing strips (either metallic or geosynthetic), or a combination of these materials (see Figures 12.1.13 thru 12.1.17).

Figure 12.1.13 Plain Unreinforced Concrete Gravity Abutment

Figure 12.1.14 Reinforced Concrete Cantilever Abutment

Figure 12.1.15 Stone Masonry Gravity Abutment

Figure 12.1.16 Combination: Timber Pile Bent Abutment with Reinforced Concrete Cap

Figure 12.1.17 Steel Abutment

Primary and Secondary Reinforcement

The pattern of primary steel reinforcement used in concrete abutments depends on the abutment type (see Figure 12.1.18). 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 (see Figure 12.1.19). The spirals or ties may be considered primary reinforcement in seismic zones. Bars used for temperature and shrinkage reinforcement are considered secondary reinforcement.

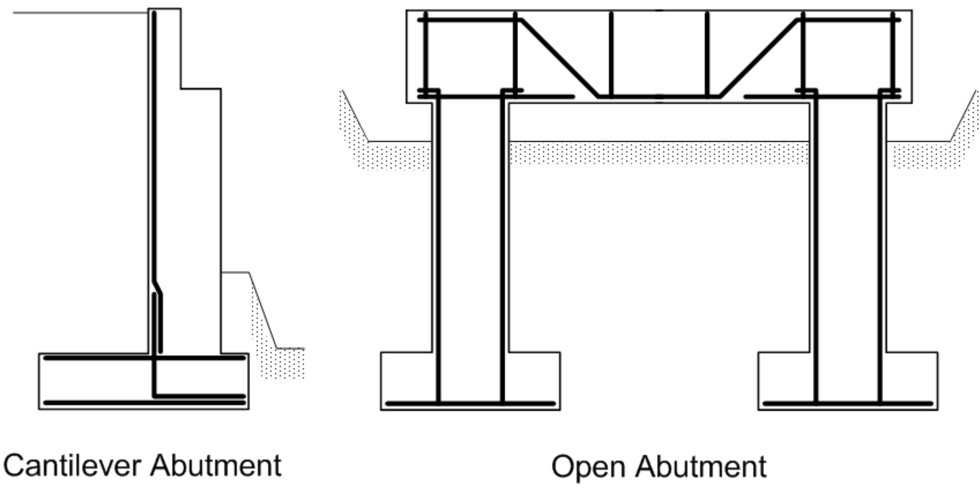


Figure 12.1.18 Primary Reinforcement in Concrete Abutments

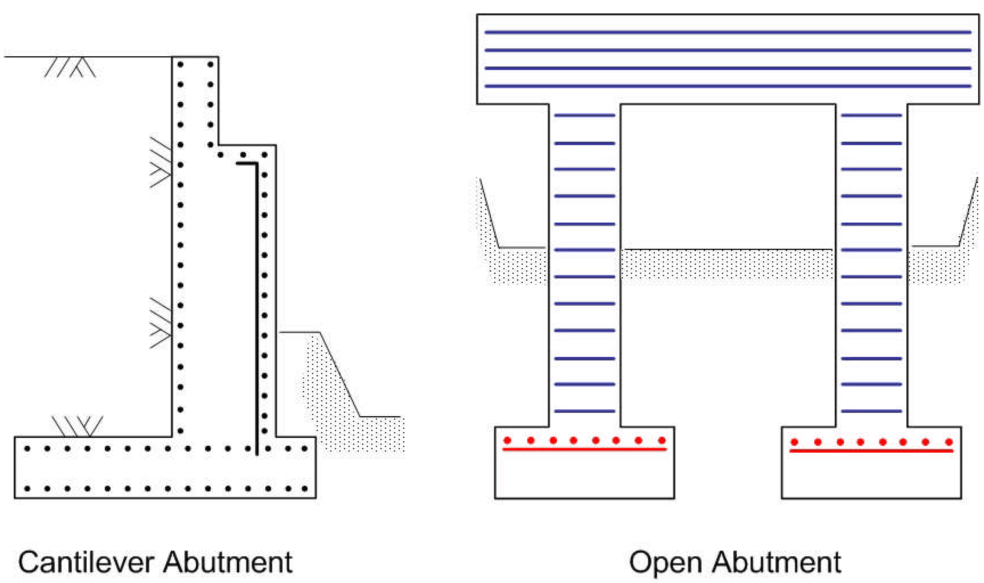


Figure 12.1.19 Secondary Reinforcement in Concrete Abutments

Abutment Members

Common abutment members include:

- Bridge seat
- Backwall
- Footing and pile cap
- Cheek wall
- Abutment stem (breast wall)
- Tie backs
- Soil reinforcing strips

- Precast panels
- Spread footings
- Deep foundations
- Geotextiles

The basic abutment elements are shown in Figure 12.1.1 through Figure 12.1.3 and described below.

The bridge seat provides a bearing area that supports the bridge superstructure. The backwall retains the approach roadway sub-base 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 12.1.20). 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 (see Figure 12.1.21). 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.

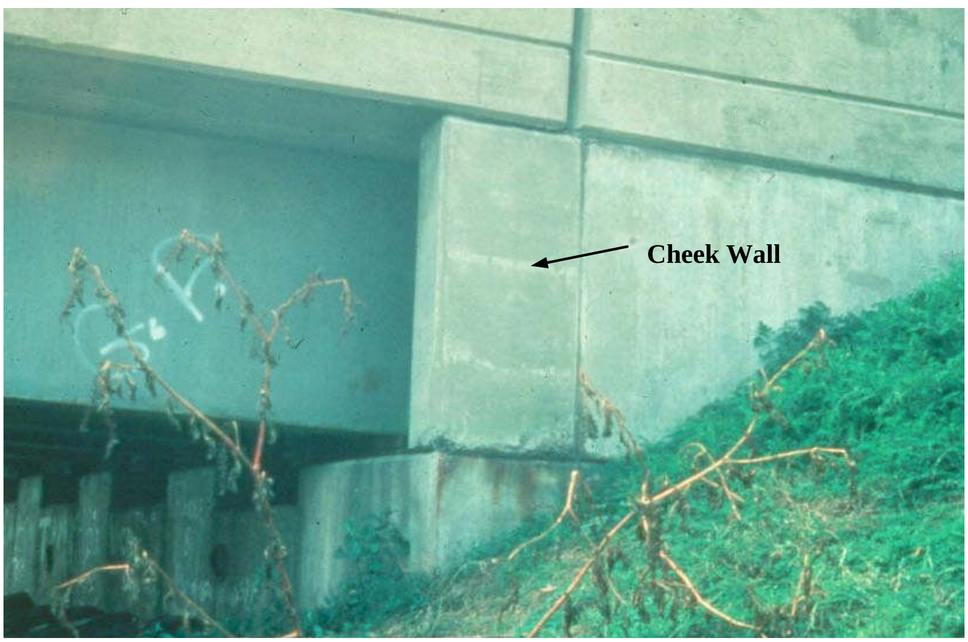


Figure 12.1.20 Cheek Wall

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.

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 12.1.21 are:

- Spread footings
- Deep foundations

A spread footing is used when bedrock is 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 is placed below the recognized maximum frost line depth for that area.

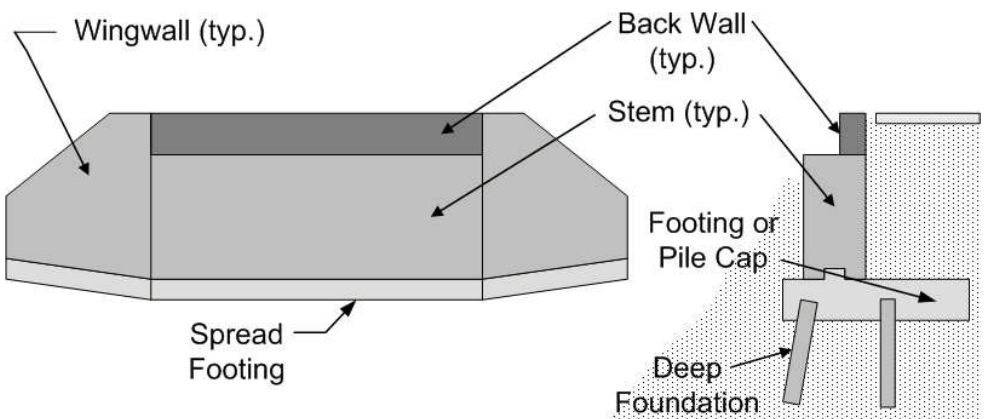


Figure 12.1.21 Spread Footing and Deep Foundations

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 (see Figure 12.1.22). 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 shaft", or "bored pile" is another type of deep foundation used when the soil is not competent to support a spread footing. 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 caisson diameter used for bridge substructure construction is normally 30 inches. Caissons, drilled shafts or bored piles may be extended through voids such as caverns or mines to reach bedrock under the bridge.

Figure 12.1.22 Stub Abutment on Piles with Piles Exposed

12.1.3 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 12.1.23).

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 due to lateral earth pressure.

Figure 12.1.23 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 12.1.24)
- Flared - form an acute angle with the bridge roadway (see Figure 12.1.25)
- U-wings - parallel to the bridge roadway (see Figure 12.1.26)

Figure 12.1.24 Straight Wingwall

Figure 12.1.25 Flared Wingwall

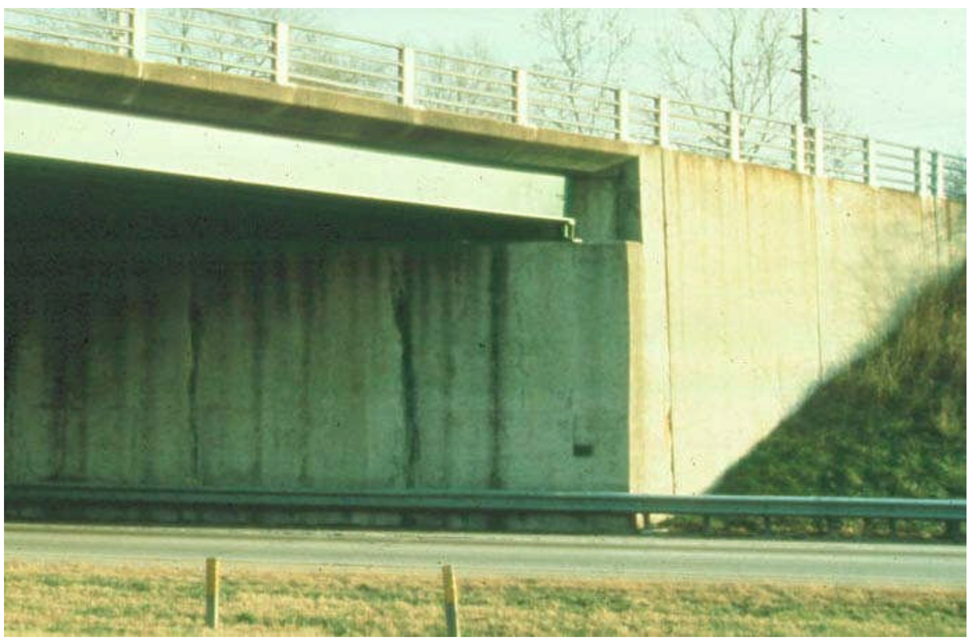


Figure 12.1.26 U-wingwall

Construction Classifications

There are several construction classifications of wingwalls:

- Integral - constructed monolithically with the abutment (see Figure 12.1.27) normally cast-in-place concrete with no expansion or construction joint between the abutment and wingwall
- Independent - constructed separately from the abutment; usually an expansion or construction joint separates the wingwall from the abutment (see Figure 12.1.28)

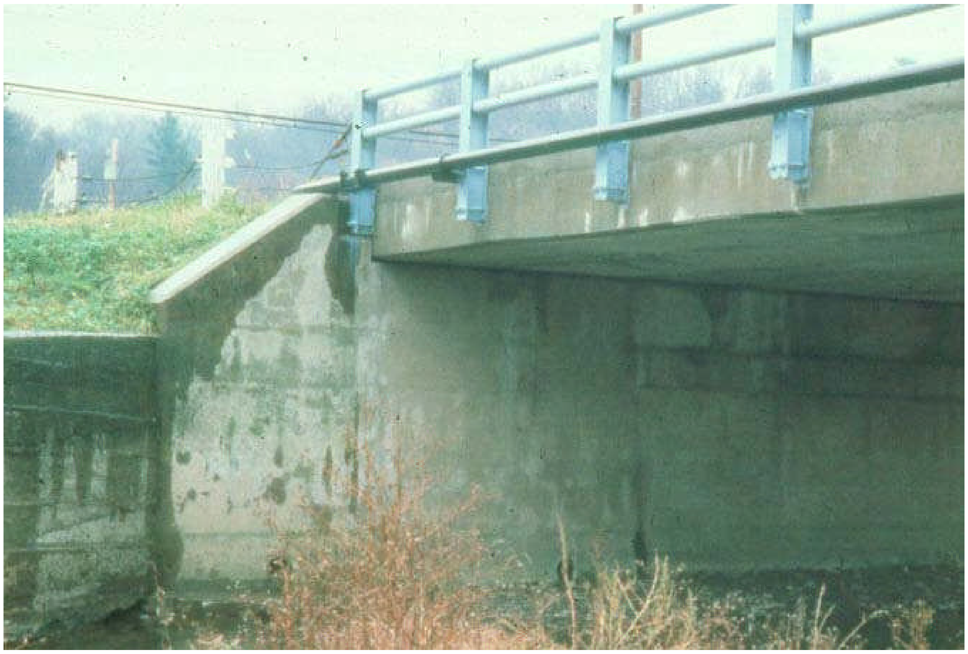


Figure 12.1.27 Integral Wingwall

Figure 12.1.28 Independent MSE Wingwall

Primary Materials

Wingwalls may be constructed of concrete, stone masonry, steel, or timber or a combination of these materials (see Figure 12.1.29).

Figure 12.1.29 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 12.1.30). Secondary reinforcement is used to resist temperature and shrinkage.

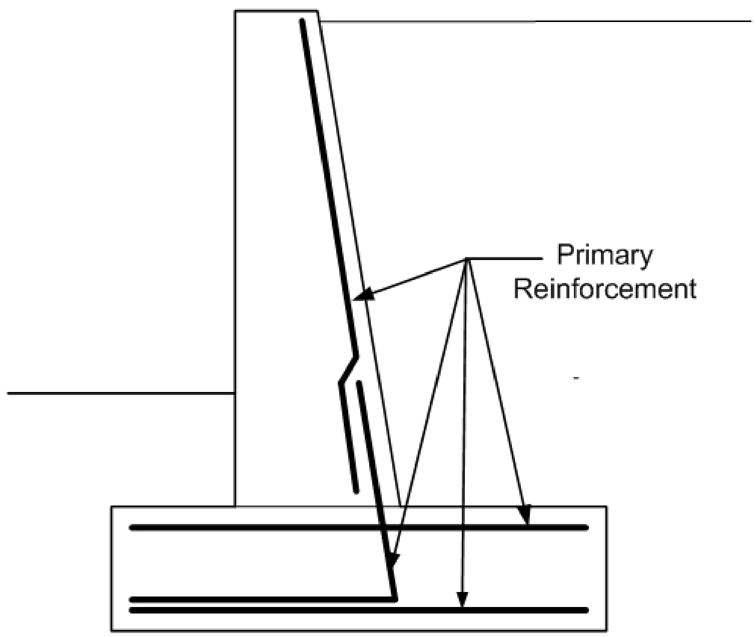


Figure 12.1.30 Primary Reinforcement in Concrete Cantilever Wingwall

12.1.4 Inspection Methods and Locations

The inspection methods and locations for most wingwalls are similar to those for abutments. Many of the problems that occur in abutments are also common in wingwalls.

Methods

The specific visual, physical and advanced inspection methods are dependent upon the type of material used in the abutment and wingwalls. The inspection method used is based on the type of material the abutment or wingwall is made of and the methods are similar to the inspection of superstructures. See Topics 6.1 and 15.1 (Timber), Topics 6.2 and 15.2 (Concrete), 6.3 and 15.3 (Steel), or Topic 6.4 (Stone Masonry) for specific material defects and inspection methods.

Visual

There are two types of visual inspections that may be required of an inspector. The first, called a routine inspection, involves reviewing the previous inspection report and visually examining the members of the bridge. A routine inspection involves a visual assessment to identify obvious defects.

The second type of visual inspection is called an in-depth inspection. An in-depth inspection is an inspection of one or more members above or below the water level to identify any deficiencies not readily detectable using routine methods. Hands-on inspection may be necessary at some locations. This type of visual inspection requires the inspector to visually assess every defective surface at a distance no further than an arm’s length. Surfaces are given close visual attention to quantify and qualify any defects.

As presented in Topic 6.2.6, visually inspect for the following concrete deficiencies:

- Cracking (structural, flexure, shear, crack size, nonstructural, crack orientation) (See Figure 12.1.31)
- Scaling (See Figure 12.1.32)
- Delamination
- Spalling
- Chloride contamination
- Freeze-thaw
- Efflorescence (See Figure 12.1.33)
- Alkali-Silica Reactivity (ASR)
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion

- Overload damage
- Internal steel corrosion
- Loss of prestress
- Carbonation
- Other causes (temperature changes, chemical attack, moisture absorption, differential foundation movement, design and construction deficiencies, unintended objects in concrete, fire damage)

As presented in Topic 6.5.4, visually inspect for the following masonry deficiencies:

- Weathering – hard surfaces degenerate in to small granules, giving stones a smooth, rounded look; mortar disintegrates (See Figure 12.1.34)
- Spalling – small pieces of rock break out
- Splitting – seams or cracks open up in rocks, eventually breaking them into smaller pieces
- Fire – masonry is not flammable but can be damaged by high temperatures

Figure 12.1.31 Cracking in Bearing Seat of Concrete and Stone Abutment

Figure 12.1.32 Spalled Concrete Wingwall

Figure 12.1.33 Cracking and Efflorescence in Abutment Backwall

Figure 12.1.34 Stone Masonry Abutment with Deteriorated Joints

As presented in Topic 6.3.5, visually inspect for the following steel deficiencies (see Figure 12.1.35):

- Corrosion
- Fatigue cracking
- Overloads
- Collision damage
- Heat damage
- Coating failures

Figure 12.1.35 Steel Abutment

As presented in Topic 6.1.5, visually inspect for the following timber deficiencies:

- Inherent defects: checks, splits, shakes, knots
- Fungi
- Insects (see Figure 12.1.36)
- Marine borers
- Chemical attack
- Delaminations
- Loose connection (see Figure 12.1.37)
- Surface depressions
- Fire
- Collision damage
- Wear
- Abrasion (see Figure 12.1.38)
- Overstress (see Figure 12.1.37)
- Protective coating failure

Figure 12.1.36 Decay caused by insects in Timber Abutment

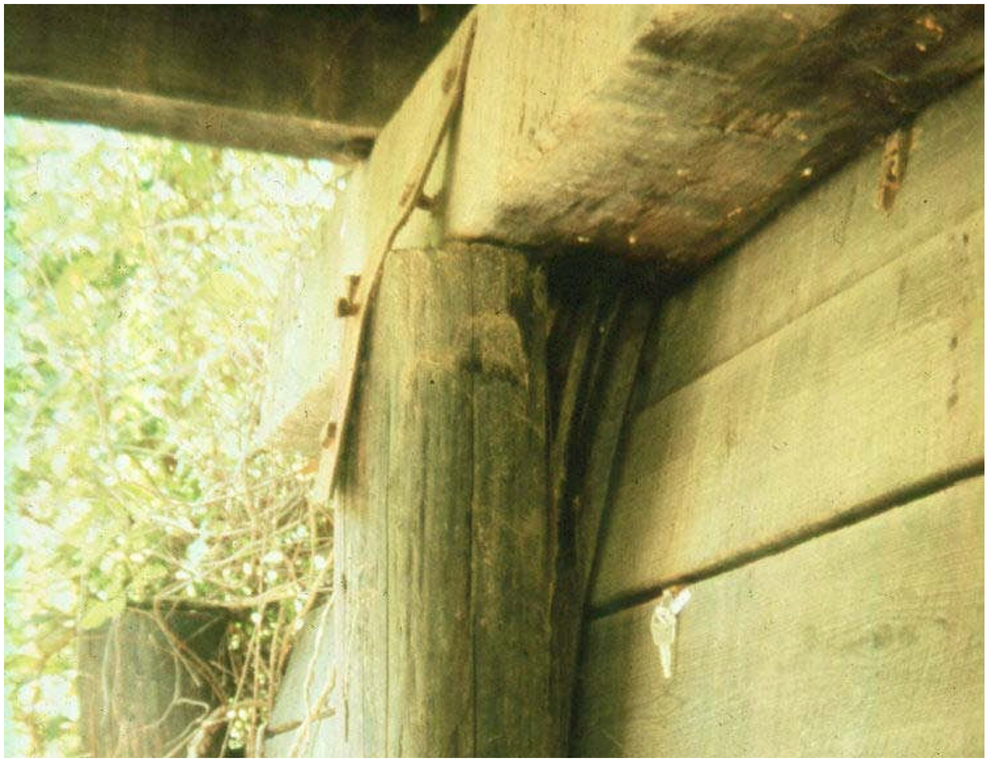


Figure 12.1.37 Local Failure in Timber Pile due to Lateral Movement of Abutment

Figure 12.1.38 Decayed Lagging and Abrasion Caused by Scour at a Timber Pile Bent Abutment

Physical

Once the defects are identified visually, physical methods are used to verify the extent of the defect. Carefully measure and record deficiencies found during physical inspection methods.

Areas of concrete or rebar deterioration identified visually need to be examined physically using an inspection hammer. This hands-on effort verifies the extent of the deficiency and its severity. A delaminated area has a distinctive hollow “clacking” sound when tapped with a hammer. The location, length and width of cracks found during the visual inspection need to be measured and recorded.

For steel members, the main physical inspection methods involve the use of an inspection hammer or wire brush. Excessive hammering, brushing or grinding may close surface cracks and make the cracks difficult to find. Corrosion results in loss of member material. This partial loss of cross section due to corrosion is known as section loss. Section loss may be measured using a straight edge and a tape measure. However, a more exact method of measurement, such as calipers or an ultrasonic thickness gauge (D-meter), are used to measure the remaining section of steel. The inspector removes all corrosion products (rust scale) prior to taking measurements.

For timber members, an inspection hammer is used to tap on areas and determine the extent of internal decay. This is done by listening to the sound the hammer makes. If it sounds hollow, internal decay may be present.

Advanced Inspection Methods

If the extent of the deficiency cannot be determined by the visual and physical inspection methods described above, advanced inspection methods are used.

For concrete inspections, non-destructive methods, described in Topic 15.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Electrical methods
- Delamination detection machinery
- Ground-penetrating radar
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing
- Smart concrete
- Carbonation

Other advanced methods for concrete members, described in Topic 15.2.3, include:

- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Petrographic examination
- Reinforcing steel strength
- Chloride test
- Matrix analysis
- ASR evaluation

For steel inspections, non-destructive methods, described in Topic 15.3.2, include:

- Acoustic emissions testing
- Corrosion sensors
- Smart coatings
- Dye penetrant
- Magnetic particle
- Radiography testing
- Computed tomography
- Robotic inspection
- Ultrasonic testing
- Eddy current
- Electrochemical fatigue sensor (EFS)
- Magnetic flux leakage (external PT tendons and stay cables)
- Laser vibrometer (for stay cable vibration measurement and cable force determination)

Other advanced methods for steel members, described in Topic 15.3.3, include:

- Brinell hardness test
- Charpy impact test
- Chemical analysis
- Tensile strength test

For timber inspections, non-destructive methods, described in Topic 15.1.1, include:

- Sonic testing
- Spectral analysis
- Ultrasonic testing
- Vibration

Other advanced methods for timber members, described in Topic 15.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Field Ohmmeter

Locations

Stability is a paramount concern; therefore checking for various forms of movement is required during the inspection of abutments and wingwalls.

The locations for inspection can be related to common abutment and wingwall problems.

The most common problems observed during the inspection of abutments and wingwalls are associated with:

- Areas subjected to movement
- High stress areas
- Areas exposed to drainage
- Areas exposed to traffic
- Areas previously repaired
- Scour and undermining
- Problematic details and fracture critical members

Areas Subjected to Movement

The most common types of movement observed during the inspection of abutments and wingwalls are:

- Vertical movement
- Lateral movement
- Rotational movement

Vertical movement can occur in the form of uniform settlement or differential settlement. A uniform settlement of the bridge substructure units, including abutments, and piers and bents, has little effect on the structure. Uniform settlements of one foot have been detected on small bridges with no signs of distress.

Differential settlement can produce severe 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 12.1.39). It may also occur under a single substructure unit (see Figure 12.1.40). 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.

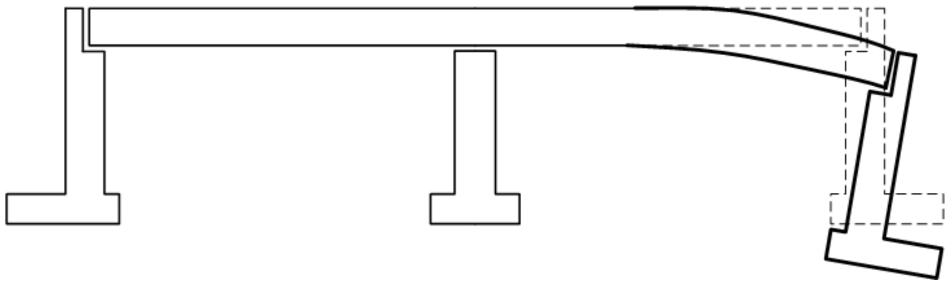


Figure 12.1.39 Differential Settlement Between Different Substructure Units

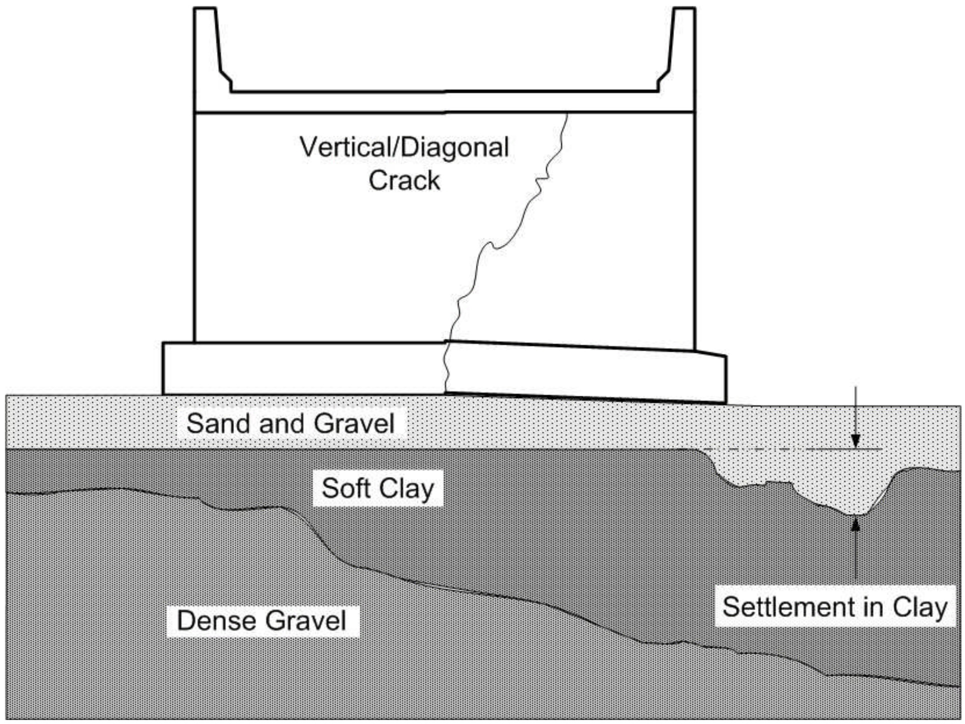


Figure 12.1.40 Differential Settlement Under an Abutment

Inspection for vertical movement, or settlement, includes:

- Inspect the joint opening between the end of the approach slab and the bridge 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 12.1.41).
- 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 12.1.41 Crack in Abutment due to Settlement

Earth retaining structures, such as abutments and retaining walls, are susceptible to lateral movements, or sliding (see Figure 12.1.42). Lateral movement occurs when the horizontal earth pressure acting on the wall exceeds the friction forces that hold the structure in place.

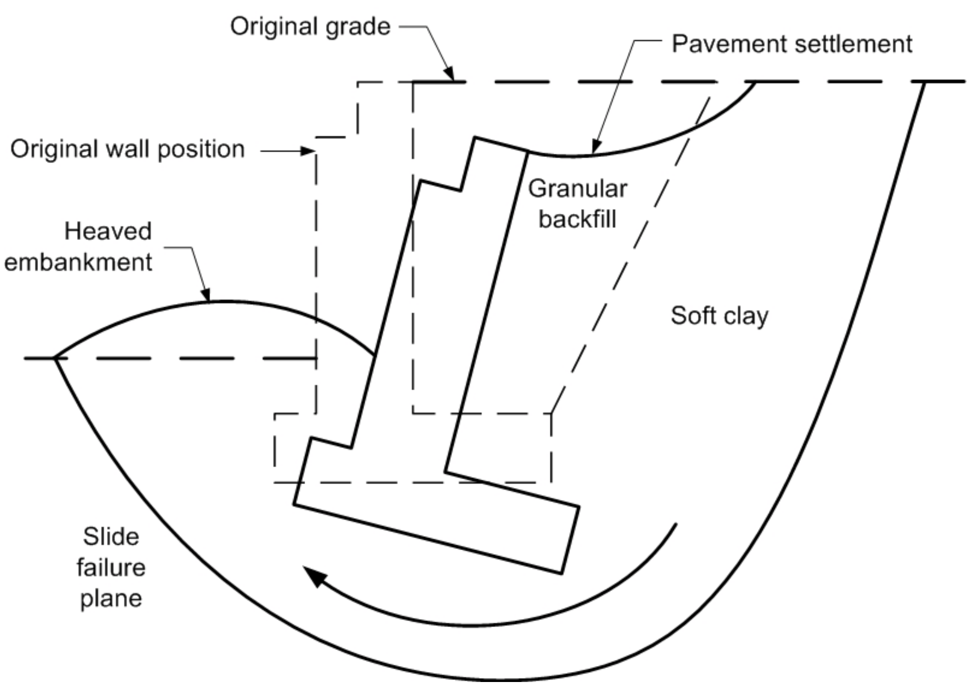


Figure 12.1.42 Lateral Movement of an Abutment due to Slope Failure

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, includes:

- Inspect the general alignment of the abutment.
- Check the bearings for evidence of lateral displacement (see Figure 12.1.43).
- 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 12.1.44).
- 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 or wingwall (see Figure 12.1.45).

Figure 12.1.43 Excessive Rocker Bearing Displacement Indicating Possible Lateral Displacement of Abutment

Figure 12.1.44 Vertical Misalignment Between Approach Slab (left) and Bridge Deck (right)

Figure 12.1.45 Erosion at Abutment Exposing Footing

Rotational movement, or tipping, of substructure units is generally the result of differential settlements, lateral movements, or a combination of both due to horizontal earth pressure (see Figure 12.1.46). Abutments and walls are subject to this type of movement.

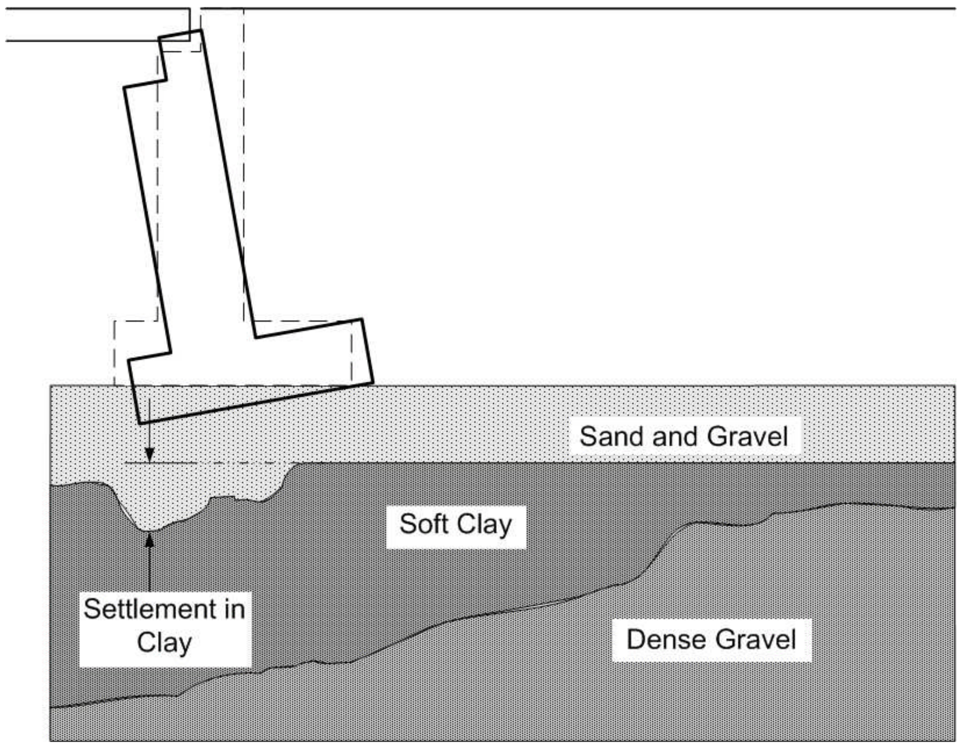


Figure 12.1.46 Rotational Movement of an Abutment

The most common causes of rotational movement are differential settlement, 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, includes:

- 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 12.1.47, 12.1.48 and 12.1.49).
- 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 13.2 for a detailed description of scour and undermining. See Topic 13.3 for a detailed description of underwater inspection.

Figure 12.1.47 Rotational Movement at Abutment

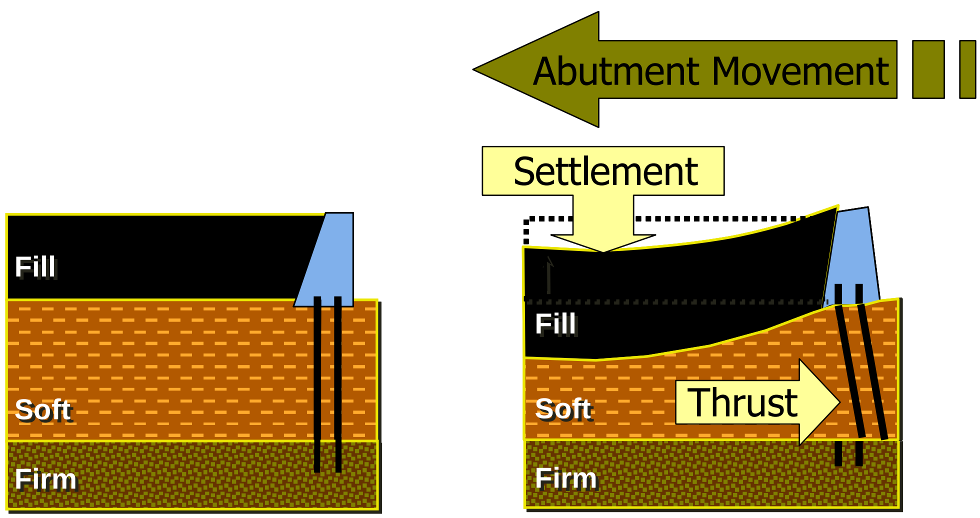


Figure 12.1.48 Rotational Movement due to "Lateral Squeeze" of Embankment Material

Figure 12.1.49 Rotational Movement at Concrete Wingwall

Bearing Areas

High bearing zones include the bridge seats, the abutment stem and 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.

Shear Zones

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.

Flexural Zones

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 and abutment stem. Moments cause compression and tension depending on the load type and location of the member neutral axis. Look for deterioration caused by overstress due to compression or tension caused by flexural moments. Check compression areas for timber splitting, concrete crushing or steel buckling. Examine tension members for cracking or distortion.

Areas Exposed to Drainage

Water can leak through the deck joints. Examine areas such as backwalls and bridge seats for signs of water leakage, and dirt and debris build-up. Look for material deficiencies caused by exposure to moisture, such as corrosion and section loss on steel, spalls and delaminations on concrete and decay on timber. Examine the abutment stem at the ground level or water level for similar deteriorations.

Water can build up horizontal pressure behind an abutment. Allowing the water to exit from behind the abutment relieves this pressure. Weep holes, normally four 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 Exposed to Traffic

Check for collision damage from vehicles or vessels 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 needs to be documented. Timber abutments may experience cracks, section loss, distortion or loose connections which need to be documented.

Areas Previously Repaired

Examine thoroughly any repairs that have been previously made. Determine if repaired areas are sound and functioning properly.

For concrete members, effective repairs and patching are usually limited to protection of exposed reinforcement. For steel members, document the location and condition of any repair plates and their connections. For timber members, document the location and condition of repaired areas and their connections.

Scour and Undermining

Scour is the removal of material from a streambed as a result of the erosive action of running water (see Figure 12.1.50). 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 13.2 for a more detailed description of scour and undermining.

Figure 12.1.50 Abutment with Undermining due to Scour

Inspection for scour includes probing around the abutment and wingwall footings for signs of undermining (see Figure 12.1.51 and 12.1.52). Sometimes silt loosely fills in a scour hole and offers no protection or bearing capacity for the abutment footing.

Figure 12.1.51 Inspector Checking for Scour

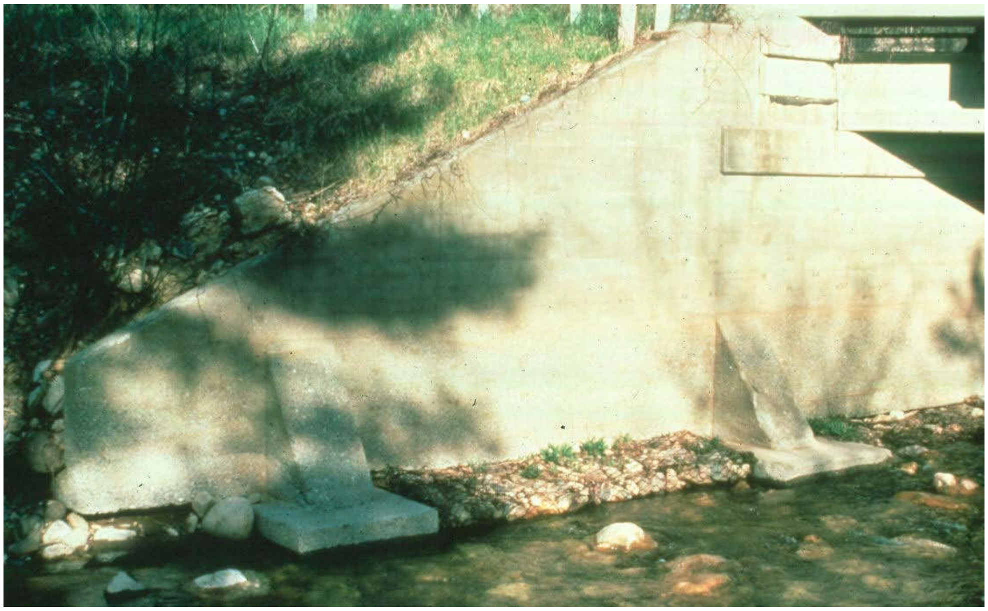


Figure 12.1.52 Scour and Possible Undermining of Concrete Wingwall

Problematic Details and Fracture Critical Members

Steel abutments may contain problematic or 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 6.4 for a detailed description of problematic details and fracture critical members.

12.1.5 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 condition rating method and the AASHTO *Guide Manual for Bridge Element Inspection* for element level condition state assessment method.

NBI Component Condition Rating Guidelines

Using NBI component condition rating guidelines, a one-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the entire substructure including abutments and piers. Component condition 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 component condition rating guidelines.

Consider previous inspection data along with current inspection findings to determine the correct component condition rating. Recognize that abutments may be affected by scour or other conditions that may only be able to be accessed and evaluated by a separate underwater inspection. Therefore, the results of both the routine and underwater inspection, if applicable, are integrated and evaluated together to arrive at the correct component condition rating for the substructure. Note the findings of the underwater inspection in the narrative portion of the routine inspection report as documentation and justification for the determined substructure component condition rating code.

Element Level Condition State Assessment

In an element level condition state assessment of an abutment, possible AASHTO Bridge Elements (NBEs) and Bridge Management Elements (BMEs) are:

NBE No.	Description
Substructure	
219	Steel Abutment
215	Reinforced Concrete Abutment
216	Timber Abutment
217	Masonry Abutment
218	Other Abutment
202	Steel Column/Pile Extension
225	Steel Submerged Pile
231	Steel Pier Cap
204	Prestressed Concrete Column/Pile Extension
226	Prestressed Concrete Submerged Pile
233	Prestressed Concrete Pier Cap
205	Reinforced Concrete Column/Pile Extension
220	Reinforced Concrete Pile Cap/Footing
227	Reinforced Concrete Submerged Pile
234	Reinforced Concrete Pier Cap
206	Timber Column/Pile Extension
228	Timber Submerged Pile
235	Timber Pier Cap

BME No.	Description
Wearing Surfaces and Protection Systems	
515	Steel Protective Coating
521	Concrete Protective Coating

The unit quantity for the substructure elements is feet, measured horizontally across the abutment. The total length is distributed among the four available condition states depending on the extent and severity of the deficiency. The unit quantity for columns and piles is each, and the total quantity is placed in one of the available condition states depending on the extent and severity of the deficiency. The unit quantity for protective coatings is square feet, with the total area distributed among the four available condition states depending on the extent and severity of the deficiency. Condition State 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

The following Defect Flags are applicable in the evaluation of abutments:

Defect Flag No.	**Description**
356	Steel Cracking/Fatigue
357	Pack Rust
358	Concrete Cracking
359	Concrete Efflorescence
360	Settlement
361	Scour
363	Steel Section Loss
364	Steel Out-of-Plane (Compression Members)
367	Substructure Traffic Impact (load capacity)

See the AASHTO *Guide Manual for Bridge Element Inspection* for the application of Defect Flags.

Table of Contents

Chapter 12
Inspection and Evaluation of Substructures

12.2 Piers and Bents ... 12.2.1

12.2.1 Introduction ... 12.2.1

12.2.2 Design Characteristics ... 12.2.1
Pier and Bent Types ... 12.2.1
Primary Materials ... 12.2.7
Primary and Secondary Reinforcement ... 12.2.10
Pier and Bent Members ... 12.2.13
Foundation Types ... 12.2.14
Pier Protection ... 12.2.14

12.2.3 Inspection Methods and Locations ... 12.2.18
Methods ... 12.2.18
Visual ... 12.2.18
Concrete ... 12.2.18
Masonry ... 12.2.21
Steel ... 12.2.22
Timber ... 12.2.24
Physical ... 12.2.28
Advanced Inspection Methods ... 12.2.28
Locations ... 12.2.30
Areas Subjected to Movement ... 12.2.31
Bearing Areas ... 12.2.34
Shear Zones ... 12.2.35
Flexural Zones ... 12.2.35
Areas Exposed to Drainage ... 12.2.35
Areas Exposed to Traffic ... 12.2.35
Areas Previously Repaired ... 12.2.35
Scour and Undermining ... 12.2.36
Problematic Details and Fracture Critical Members 12.2.36
Dolphins and Finders ... 12.2.37

12.2.4 Evaluation ... 12.2.39
NBI Component Condition Rating Guidelines ... 12.2.39
Element Level Condition State Assessment ... 12.2.40

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Topic 12.2 Piers and Bents

12.2.1 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 12.2.1). There is no functional difference between piers and bents. 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.

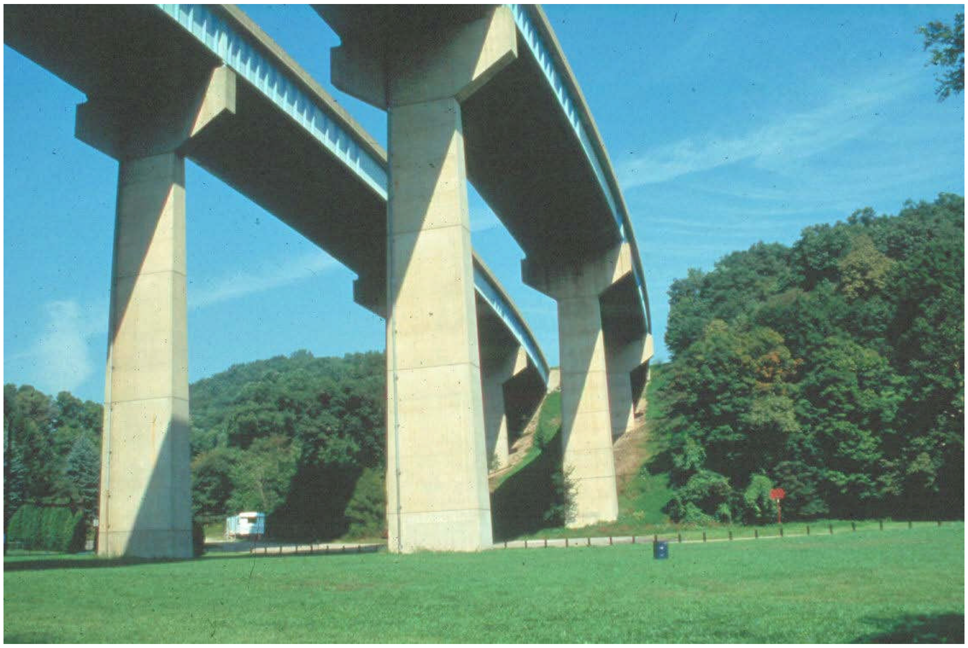

Figure 12.2.1 Example of Piers as Intermediate Supports for a Bridge

12.2.2 Design Characteristics

Pier and Bent Types

The most common pier and bent types are:

- Solid shaft pier (see Figure 12.2.2)
- Column pier (see Figure 12.2.3)
- Column pier with web wall (see Figures 12.2.4 and 12.2.5)
- Cantilever pier or hammerhead pier (see Figures 12.2.6 and 12.2.7)
- Column bent or open bent (see Figure 12.2.8)
- Pile bent (see Figure 12.2.9)

Detailed descriptions of pier and bent members are provided on page 12.2.13.

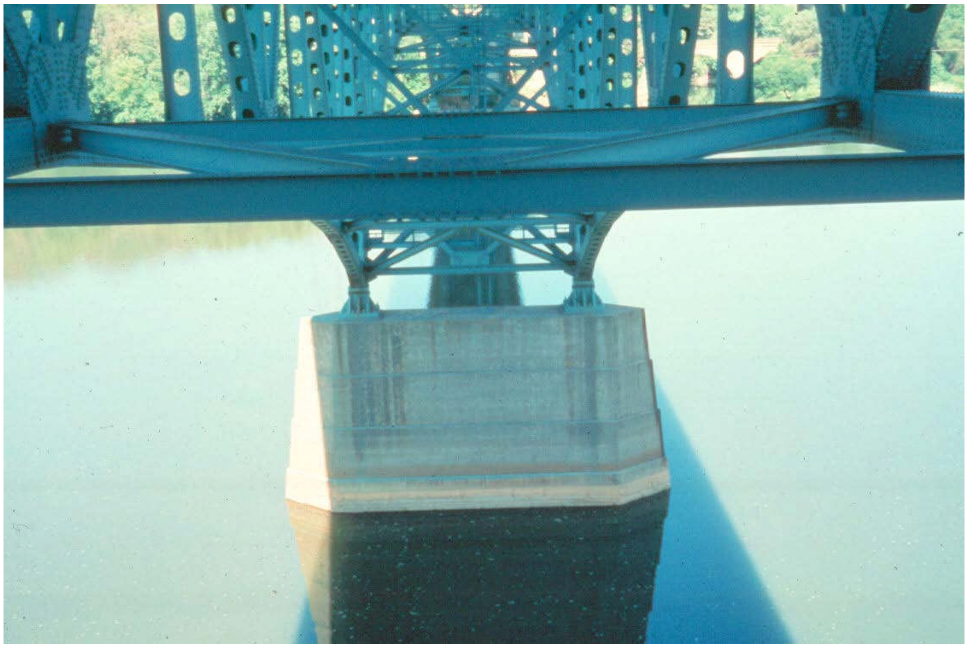

Figure 12.2.2 Solid Shaft Pier

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 12.2.3 Column Pier

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

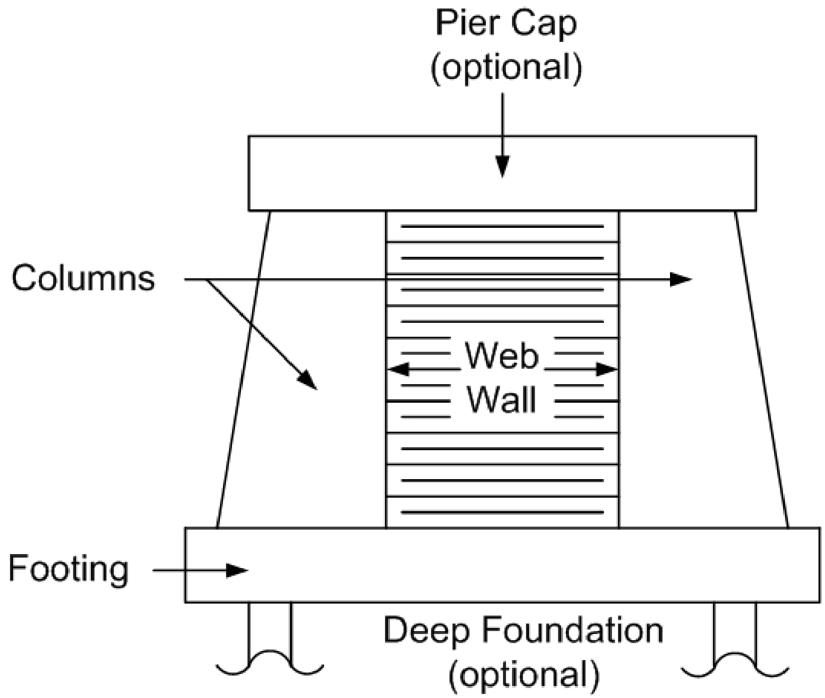

Figure 12.2.4 Column Pier with Web Wall

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 12.2.5 Column Pier with Web Wall

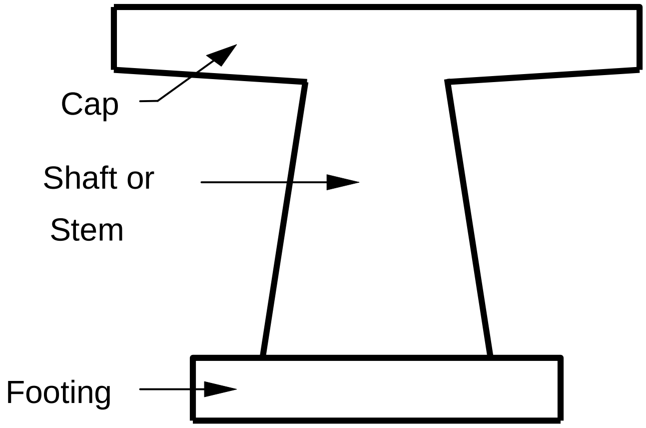

Figure 12.2.6 Single Stem Pier (Cantilever or Hammerhead)

The cantilever or hammerhead pier is a modified column pier for use with wide superstructures.

Figure 12.2.7 Cantilever Pier

Figure 12.2.8 Column Bent or Open Bent

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

Figure 12.2.9 Concrete Pile Bent

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

Two other specialized types of piers 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 its 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 eases in transporting segments 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 concrete caps within a girder superstructure. The concrete cap is likely to be post-tensioned rather than conventionally reinforced (see Figures 12.2.10 thru 12.2.12).

Figure 12.2.10 Concrete Pier with Integral Steel Pier Cap

Figure 12.2.11 Integral Concrete Pier and Pier Cap

Figure 12.2.12 Integral Concrete Pier and Pier Cap

Primary Materials

The primary materials used in pier and bent construction are unreinforced concrete, reinforced concrete, stone masonry, steel, timber, or a combination of these materials (see Figures 12.2.13 thru 12.2.17).

Figure 12.2.13 Reinforced Concrete Piers under Construction

Figure 12.2.14 Stone Masonry Pier

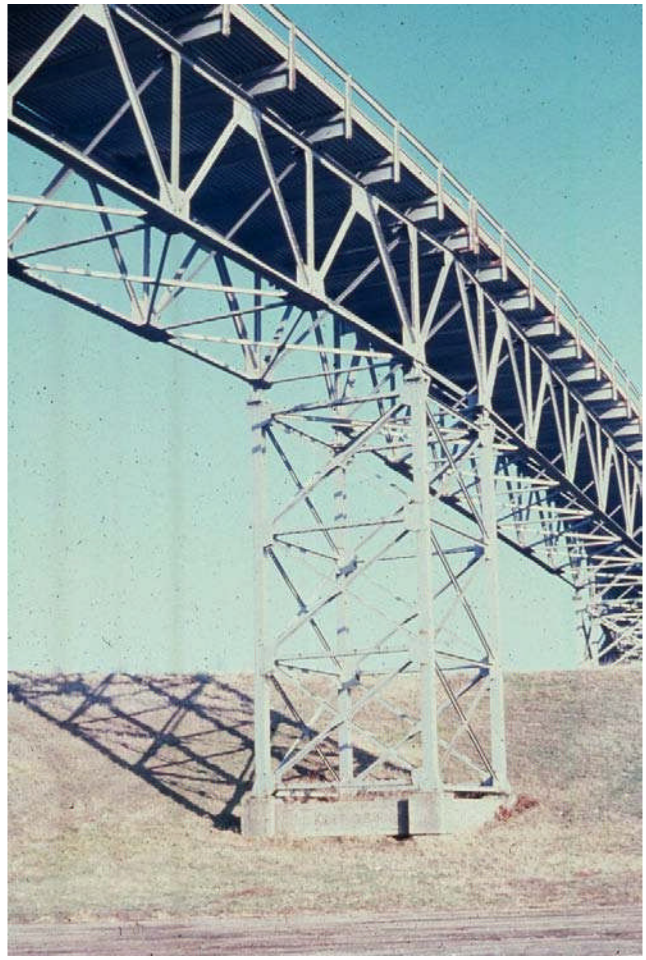

Figure 12.2.15 Steel Bent

Figure 12.2.16 Timber Pile Bent

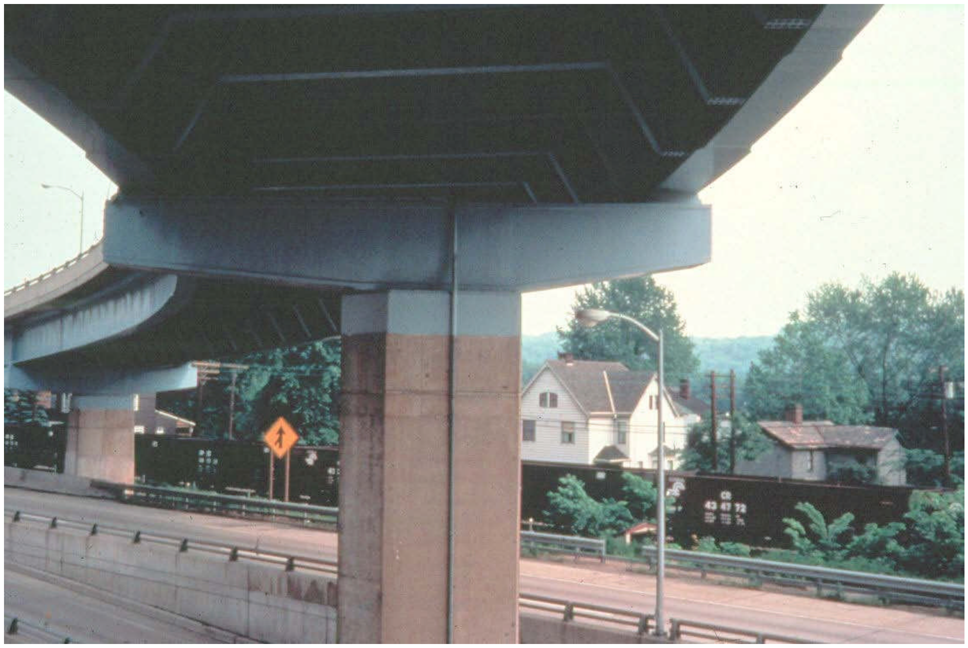

Figure 12.2.17 Combination: Reinforced Concrete Column with Steel Pier Cap

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 secondary reforcement for temperature and shrinkage is provided. Each concrete face is 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 12.2.18 thru 12.2.21 illustrate typical reinforcement patterns.

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

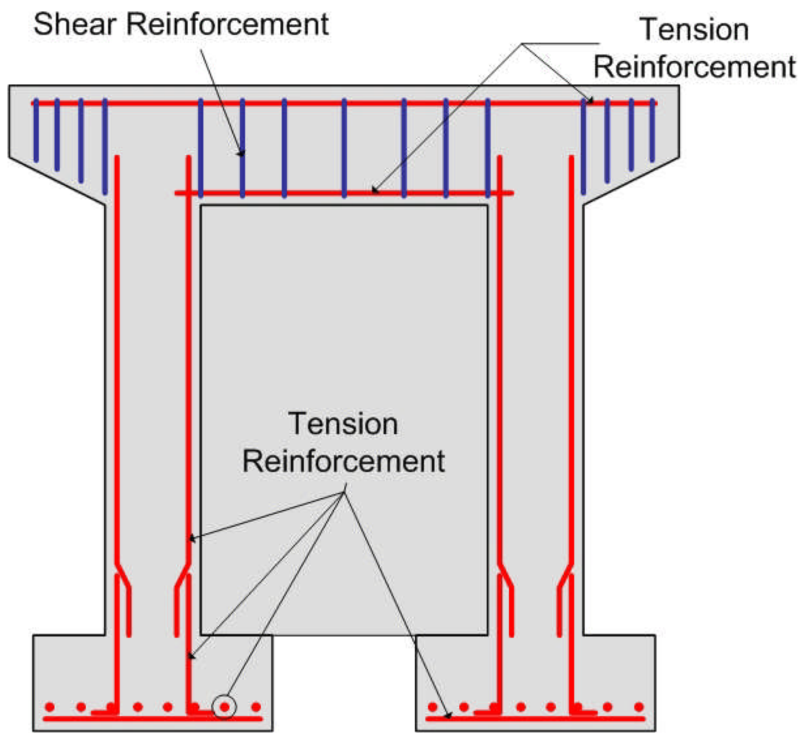

Figure 12.2.18 Primary Reinforcement in Column Bent with Web Wall

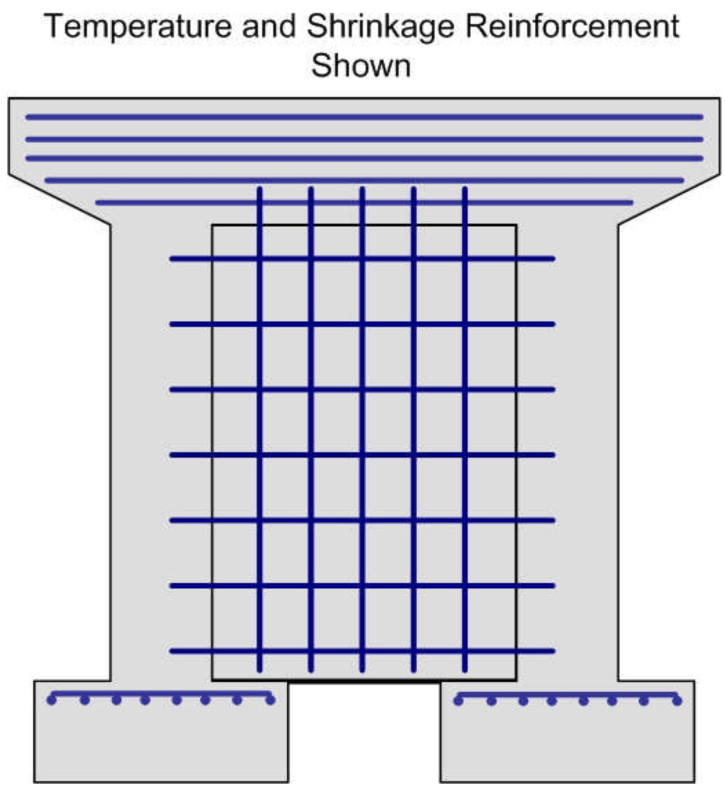

Figure 12.2.19 Secondary Reinforcement in Column Bent with Web Wall

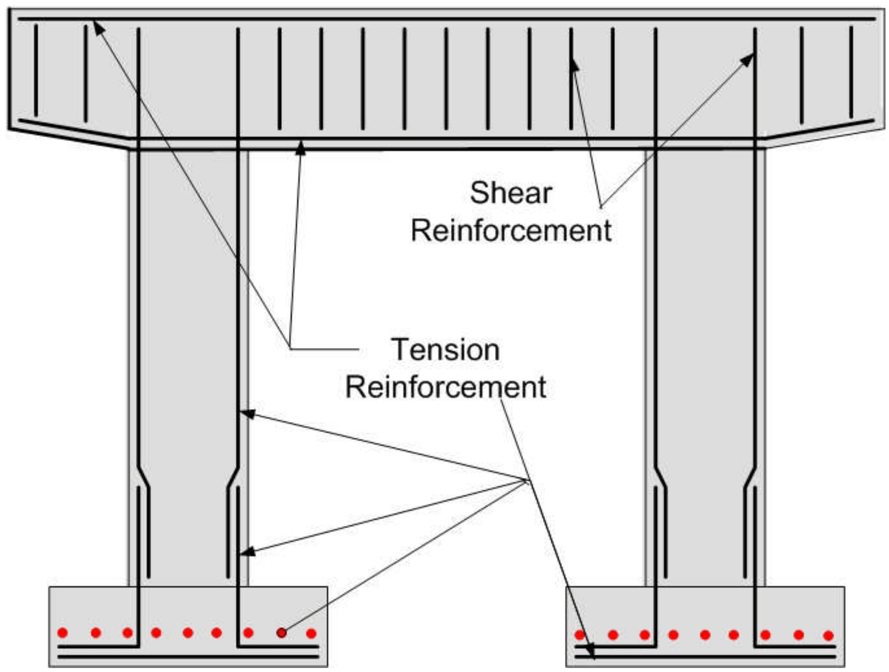

Figure 12.2.20 Primary Reinforcement in Column Bents

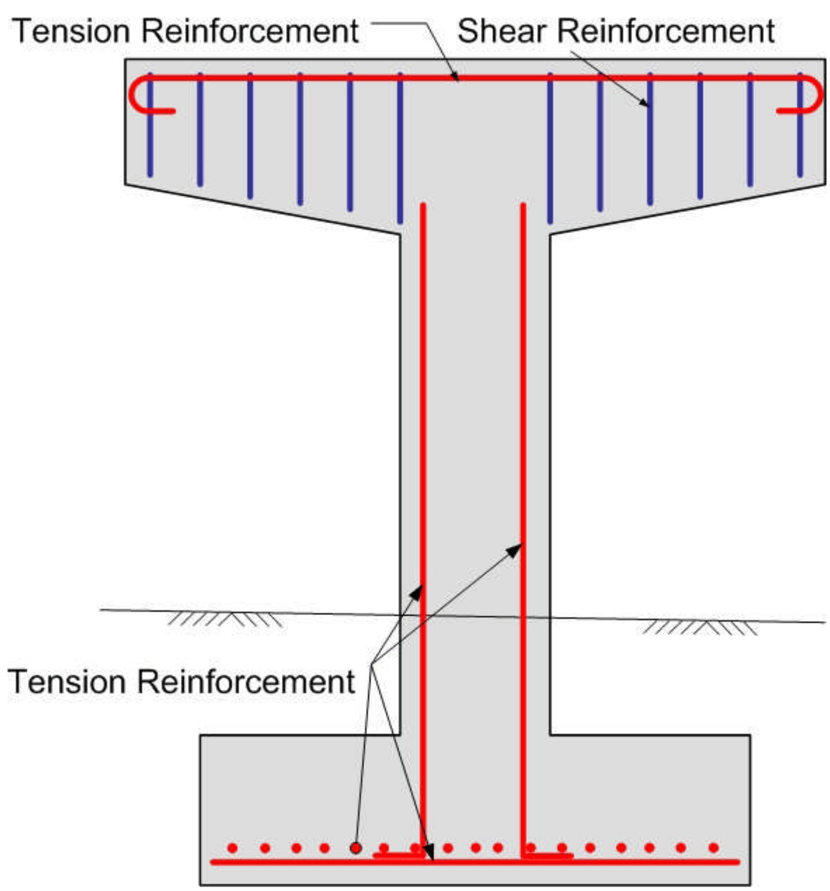

Figure 12.2.21 Primary Reinforcement for a Cantilevered Pier

Pier and Bent Members

The primary pier and bent members 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 12.2.22 and 12.2.23).

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.

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.

Figure 12.2.22 Cantilevered Piers Joined by a Web Wall

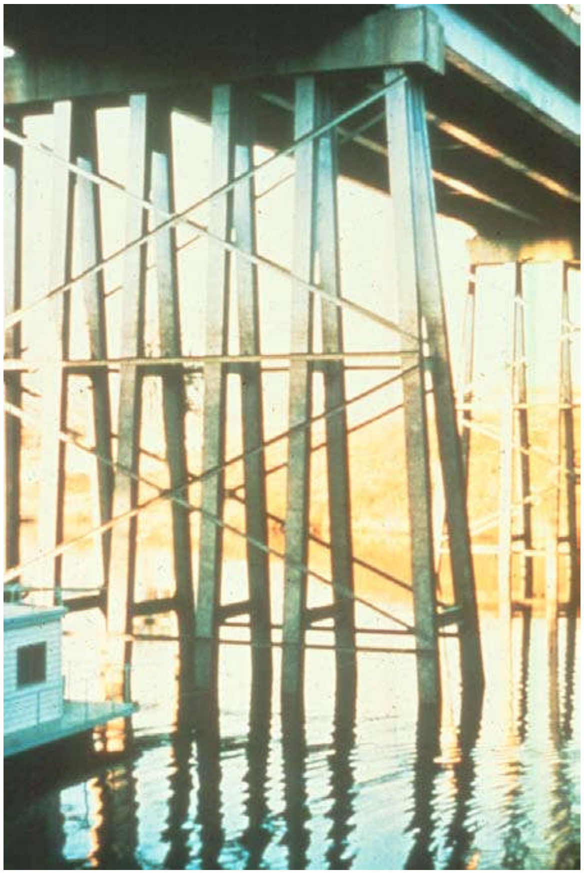

Figure 12.2.23 Pile Bent

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 12.1.16 of Topic 12.1, Abutments and Wingwalls.

Pier Protection

Piers are vulnerable to collision damage from trucks, trains, ships, ice flows and waterborne debris. Wall type piers are resistant to this type of collision damage and for this reason are often used in navigable waterways and waterways subject to freezing. Web walls also serve to protect columns (see Figures 12.2.24 and 12.2.25). 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 12.2.26 and 12.2.27). 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 12.2.28 and 12.2.29).

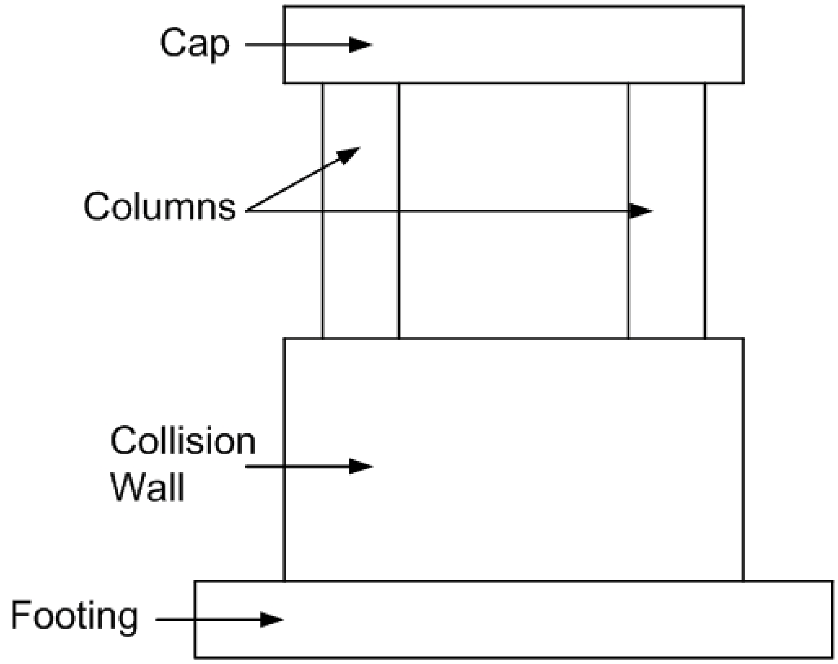

Figure 12.2.24 Collision Wall

Figure 12.2.25 Collision Wall

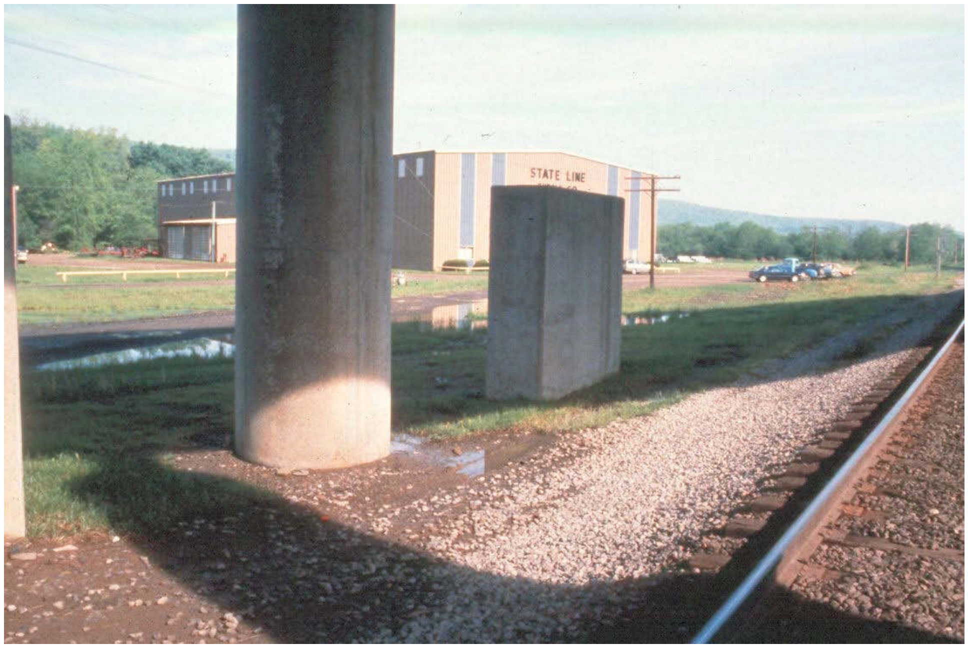

Figure 12.2.26 Concrete Block Dolphin

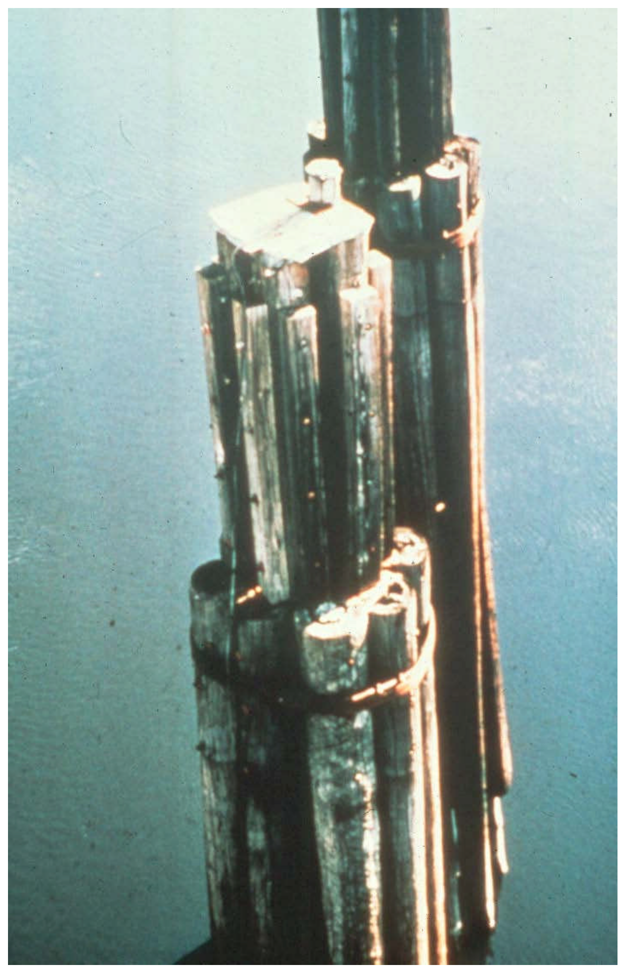

Figure 12.2.27 Timber Dolphin

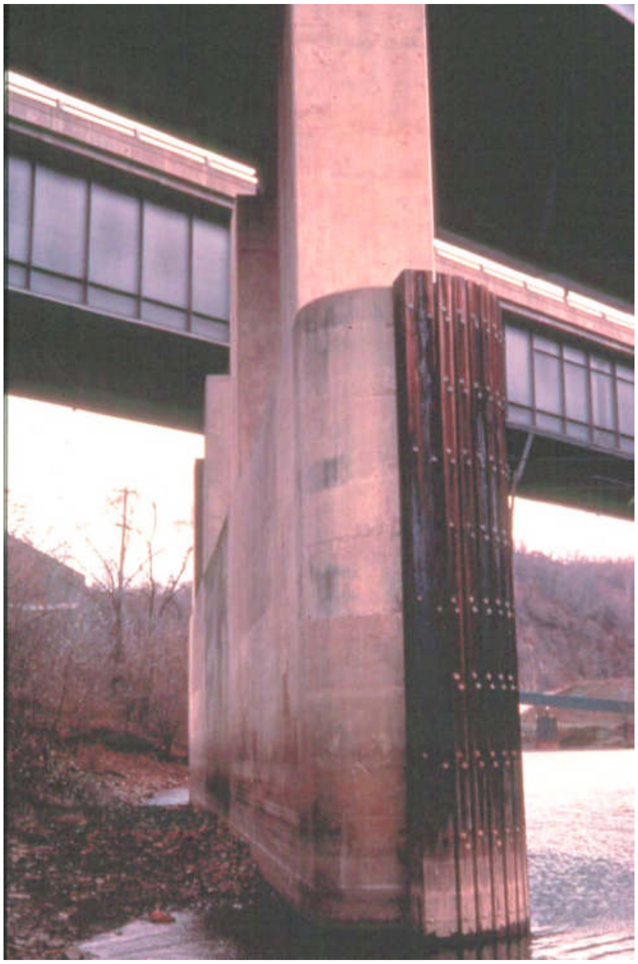

Figure 12.2.28 Pier Fender

Figure 12.2.29 Fender System

12.2.3 Inspection Methods and Locations

Inspection methods for piers and bents are similar to superstructures, particularly when it involves material deterioration.

Methods

There are three basic methods used to inspect a member. Depending on the type of inspection, the inspector may be required to use only one individual method or all methods. They include:

- Visual
- Physical
- Advanced inspection methods

The inspection method used is based on the type of material the pier or bent is made of and the methods are similar to the inspection of superstructures. See Topics 6.1 and 15.1 (Timber), Topics 6.2 and 15.2 (Concrete), 6.3 and 15.3 (Steel), or Topic 6.4 (Stone Masonry) for specific material defects and inspection methods.

Visual

There are two types of visual inspections that may be required of an inspector. The first, called a routine inspection, involves reviewing the previous inspection report and visually examining the members of the bridge. A routine inspection involves a visual assessment to identify obvious deficiencies.

The second type of visual inspection is called an in-depth inspection. An in-depth inspection is an inspection of one or more members above or below the water level to identify any deficiencies not readily detectable using routine methods. Hands-on inspection may be necessary at some locations. This type of visual inspection requires the inspector to visually assess all deficient surfaces at a distance no further than an arm's length. Surfaces are given close visual attention to quantify and qualify any deficiencies.

Concrete

As presented in Topic 6.2.6, visually inspect for the following concrete deficiencies:

- Cracking (structural, flexure, shear, crack size, nonstructural, crack orientation) (see Figure 12.2.31)
- Scaling
- Delamination
- Spalling (see Figures 12.2.30 and 12.2.32)
- Chloride contamination
- Freeze-thaw
- Efflorescence
- Alkali-Silica Reactivity (ASR)

- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage (see Figure 12.2.33)
- Abrasion
- Overload damage
- Internal steel corrosion
- Loss of prestress
- Carbonation
- Other causes (temperature changes, chemical attack, moisture absorption, differential foundation movement, design and construction deficiencies, unintended objects in concrete, fire damage)

Figure 12.2.30 Concrete Spalling due to Contaminated Drainage

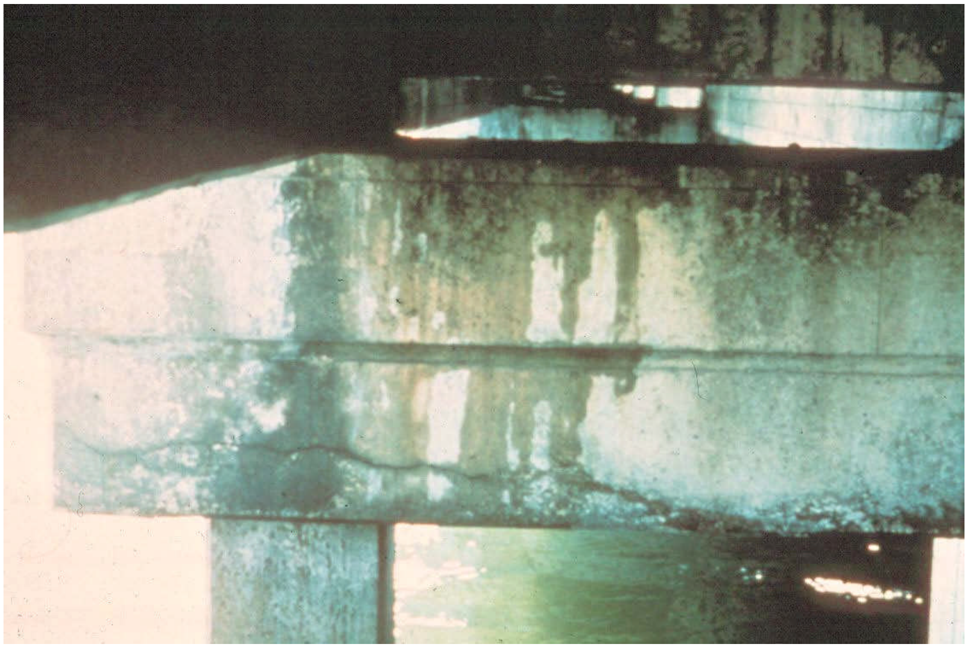

Figure 12.2.31 Crack in Concrete Bent Cap

Figure 12.2.32 Concrete Spalling on Bent Cap

Figure 12.2.33 Collision Damage to Concrete Pier Column

Masonry

As presented in Topic 6.5.4, visually inspect for the following masonry deficiencies:

- Weathering – hard surfaces degenerate into small granules, giving stones a smooth, rounded look; mortar disintegrates
- Spalling – small pieces of rock break out (see Figure 12.2.34)
- Splitting – seams or cracks open up in rocks, eventually breaking them into smaller pieces (see Figure 12.2.34)
- Fire – masonry is not flammable but can be damaged by high temperatures

Figure 12.2.34 Deteriorated and Missing Stone at Masonry Pier

Steel

As presented in Topic 6.3.5, visually inspect for the following steel deficiencies:

- Corrosion (see Figures 12.2.35 and 12.2.36)
- Fatigue cracking
- Overloads (see Figure 12.2.37)
- Collision damage
- Heat damage
- Coating failures

Figure 12.2.35 Deterioration of Steel Bent Leg

Figure 12.2.36 Corrosion of Steel Pile Bent at Water Surface

Figure 12.2.37 Steel Column Pile Bent with Cantilever - High Stress Areas for Moment, Shear and Bearing

Timber

As presented in Topic 6.1.5, visually inspect for the following timber deficiencies:

- Inherent defects: checks, splits, shakes, knots
- Fungi (see Figures 12.2.38 and 12.2.40)
- Insects
- Marine borers (see Figures 12.2.42 and 12.2.43)
- Chemical attack
- Delaminations
- Loose connection (see Figure 12.2.40)
- Surface depressions
- Fire
- Collision damage
- Wear
- Abrasion (see Figure 12.2.39)
- Overstress (see Figure 12.2.41)
- Protective coating failure

Several advanced methods are available for timber inspection. Non-destructive and other methods are described in Topics 13.1.2 and 13.1.3.

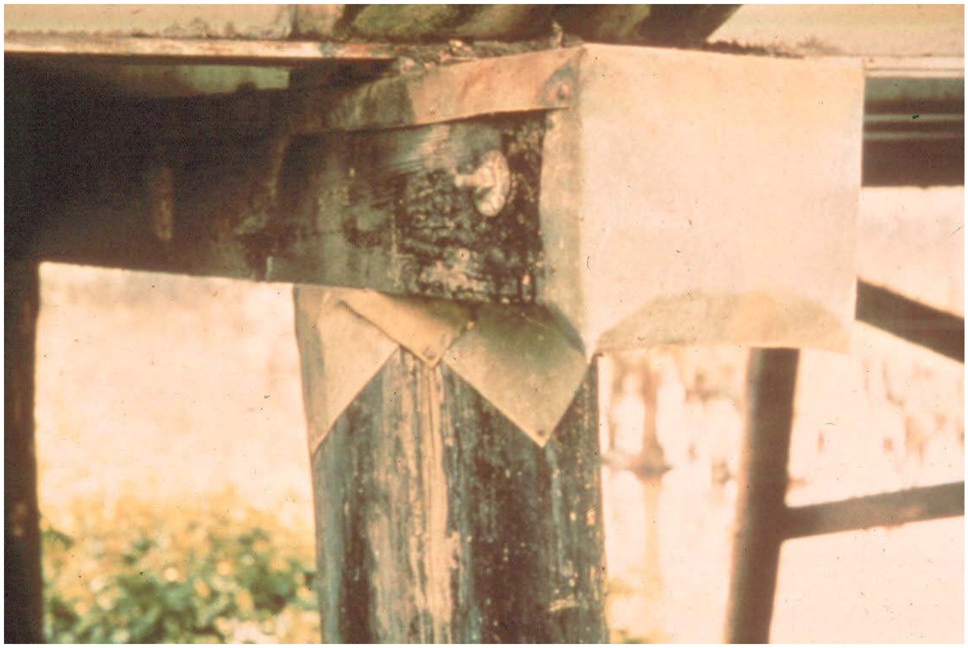

Figure 12.2.38 Decay in Timber Bent Cap (Note “Protective” Cover / Flashing)

Figure 12.2.39 Timber Bent Columns in Water

Figure 12.2.40 Decay of Timber Bent Column at Ground Line/Loose Connection

Figure 12.2.41 Timber Pile Bent with Overstress-Partial "Brooming" Failure at First Pile

Figure 12.2.42 Timber Pile Damage due to Limnoria Marine Borers

Figure 12.2.43 Timber Bent Damage due to Shipworm Marine Borers

Physical

Once the deficiencies are identified visually, physical methods are used to verify the extent of the deficiencies. Carefully measure and record deficiencies found during physical inspection methods.

Areas of concrete or rebar deterioration identified visually need to be examined physically using an inspection hammer. This hands-on effort verifies the extent of the deficiency and its severity. A delaminated area has a distinctive hollow “clacking” sound when tapped with a hammer. The location, length and width of cracks found during the visual inspection need to be measured and recorded.

For steel members, the main physical inspection methods involve the use of an inspection hammer or wire brush. Excessive hammering, brushing or grinding may close surface cracks and make the cracks difficult to find. Corrosion results in loss of member material. This partial loss of cross section due to corrosion is known as section loss. Section loss may be measured using a straight edge and a tape measure. However, a more exact method of measurement, such as calipers or an ultrasonic thickness gauge (D-meter), are used to measure the remaining section of steel. The inspector removes all corrosion products (rust scale) prior to taking measurements.

For timber members, an inspection hammer is used to tap on areas and determine the presence and extent of internal decay. This is done by listening to the sound the hammer makes. If it sounds hollow, internal decay may be present.

Advanced Inspection Methods

If the extent of the deficiency cannot be determined by the visual and physical inspection methods described above, advanced inspection methods are used.

For concrete inspections, non-destructive methods, described in Topic 15.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Electrical methods
- Delamination detection machinery
- Ground-penetrating radar
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods

- Pachometer
- Rebound and penetration methods
- Ultrasonic testing
- Smart concrete
- Carbonation

Other advanced methods for concrete members, described in Topic 15.2.3, include:

- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Petrographic examination
- Reinforcing steel strength
- Chloride test
- Matrix analysis
- ASR evaluation

For steel inspections, non-destructive methods, described in Topic 15.3.2, include:

- Acoustic emissions testing
- Corrosion sensors
- Smart coatings
- Dye penetrant
- Magnetic particle
- Radiography testing
- Computed tomography
- Robotic inspection
- Ultrasonic testing
- Eddy current
- Electrochemical fatigue sensor (EFS)
- Magnetic flux leakage (external PT tendons and stay cables)
- Laser vibrometer (for stay cable vibration measurement and cable force determination)

Other advanced methods for steel members, described in Topic 15.3.3, include:

- Brinell hardness test
- Charpy impact test
- Chemical analysis
- Tensile strength test

For timber inspections, non-destructive methods, described in Topic 15.1.1, include:

- Sonic testing
- Spectral analysis
- Ultrasonic testing
- Vibration

Other advanced methods for timber members, described in Topic 15.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Field Ohmmeter

Locations

Stability is a paramount concern; therefore checking for various forms of movement is required during the inspection of piers or bents.

The locations for inspection can be related to common pier and bent problems.

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

- Areas subjected to movement
- High stress areas
- Areas exposed to drainage
- Areas exposed to traffic
- Areas previously repaired
- Scour and undermining
- Problematic details and fracture critical members
- Dolphins and fenders

Areas Subjected to Movement

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

- Vertical movement
- Lateral movement
- Rotational movement

Vertical movement can occur in the form of differential settlement. Differential settlement at piers can cause severe problems in a bridge (see Figures 12.2.44 and 12.2.45). 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.

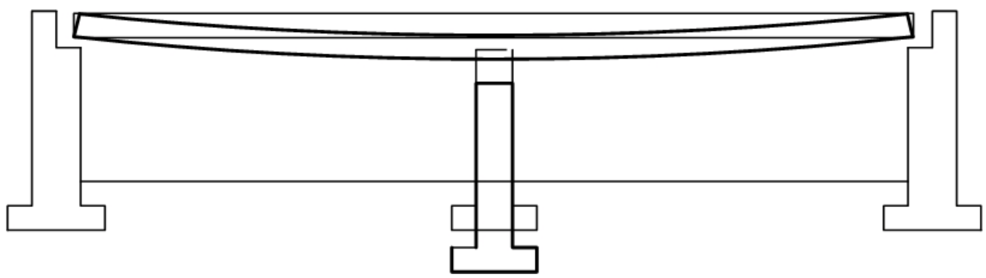

Figure 12.2.44 Differential Settlement Between Different Substructure Units

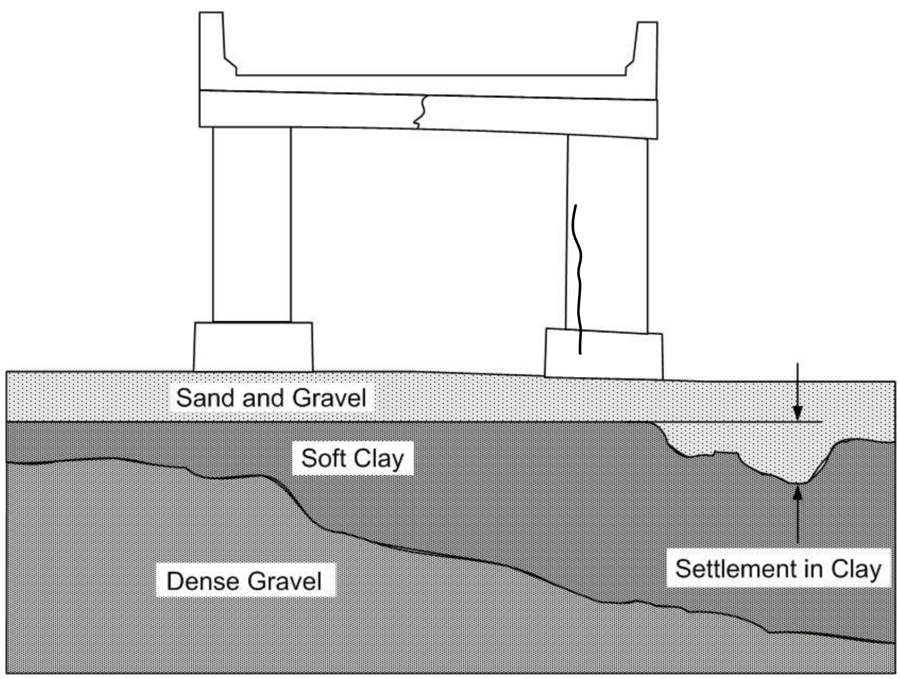

Figure 12.2.45 Differential Settlement Under a Pier

Inspection for vertical movement, or settlement, includes:

- 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 12.2.46).
- 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.

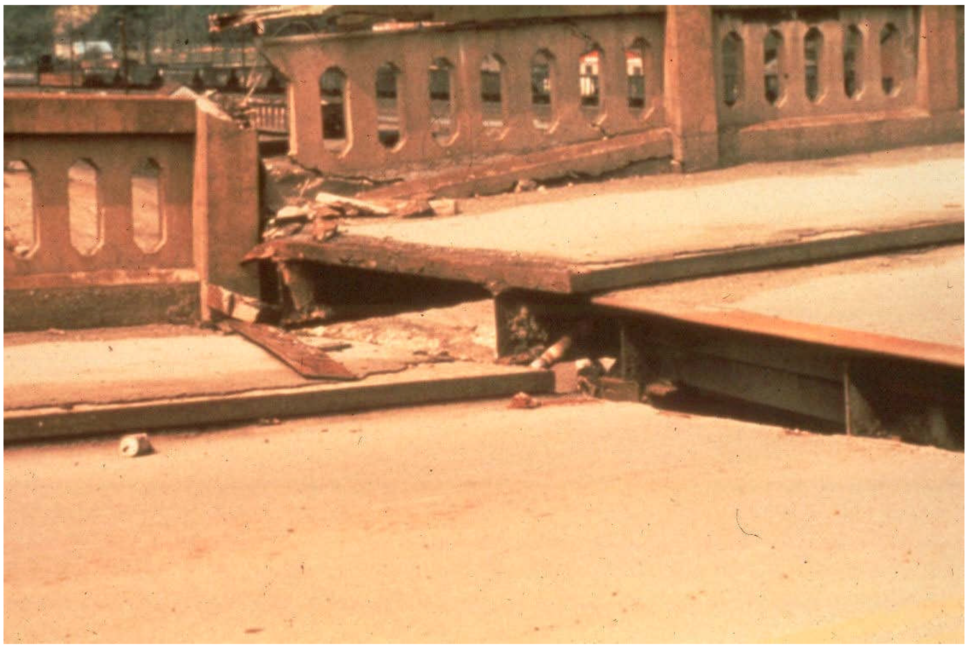

Figure 12.2.46 Superstructure Evidence of Pier Settlement

Inspection for lateral movement, or sliding, includes:

- Check 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 is readily apparent (see Figure 12.2.47).
- Check for scour or undermining around the pier or bent footing (see Figures 12.2.48 and 12.2.49). Refer to Topic 13.2 for a more detailed description of scour and undermining. Refer to Topic 13.3 for a more detailed description of underwater inspection.

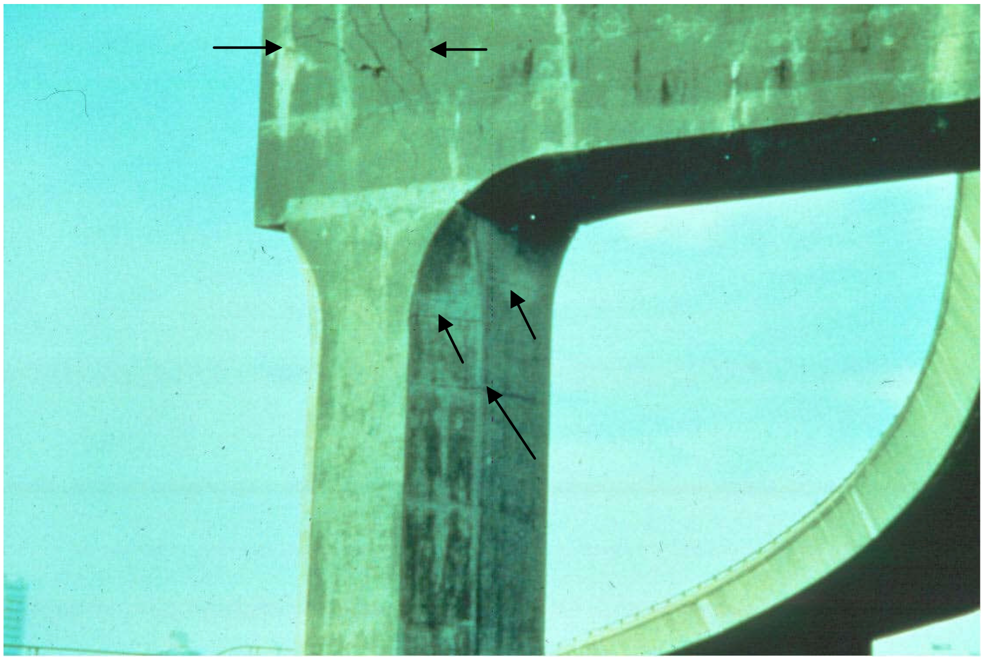

Figure 12.2.47 Cracks in Bent Cap due to Lateral Movement of Bent during Earthquake

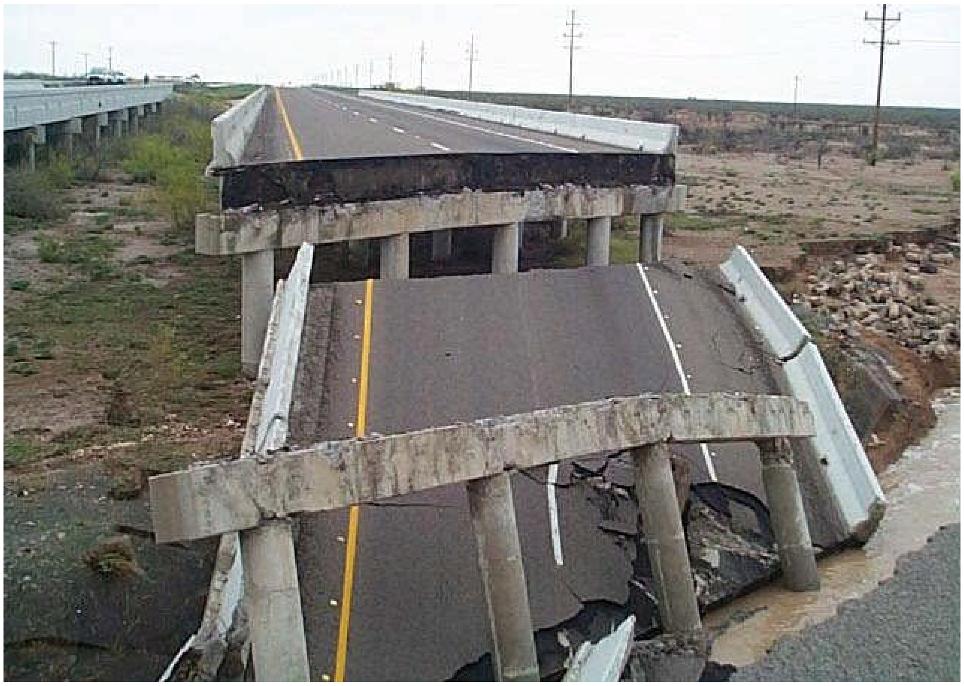

Figure 12.2.48 Pier Movement and Superstructure Damage due to Scour/Undermining

Figure 12.2.49 Tipping of Bent due to Scour/Undermining

Inspection for rotational movement, or tipping, includes:

- 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.

Bearing Areas

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.

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.

Shear Zones

Vertical forces cause high shear zones in pier caps close to points of support. 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.

Flexural Zones

Check the pier cap for signs of overstress in the positive and negative bending moment regions. 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 deficiencies 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 Drainage

Water can leak through the deck joints. Examine areas below deck joints for signs of water leakage, and dirt and debris build-up. Look for material deficiencies caused by exposure to moisture, such as corrosion and section loss on steel, spalls and delaminations on concrete and decay on timber. Examine the piers and bents at the ground level or water level for similar deteriorations.

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 reinforcement and possibly steel reinforcement section loss. Steel piers or bents may experience cracks, section loss, or distortion which needs to be documented. Timber piers and bents may experience cracks, section loss, distortion or loose connections which need to be documented.

Areas Previously Repaired

Examine thoroughly any repairs that have been previously made. Determine if repaired areas are sound and functioning properly.

For concrete members, effective repairs and patching are usually limited to protection of exposed reinforcement (see Figure 2.1.50). For steel members, document the location and condition of any repair plates and their connections. For timber members, document the location and condition of repaired areas and their connections.

Figure 12.2.50 Repaired Concrete Column Bent

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 13.2 for a more detailed description of scour and undermining.

Inspection for scour includes 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.

Problematic Details and Fracture Critical Members

Steel piers or bents may contain problematic or 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 12.2.51). See Topic 6.4 for a detailed description of details and fracture critical members.

Figure 12.2.51 Fracture Critical Steel Bent

Dolphins and Fenders

The condition of dolphins and fenders are 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 12.2.52). 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 (up to two feet above high tide or mean water level) carefully for corrosion. Where there are no tides, check the area from the mean water level to two feet above it. Examine steel members for corrosion, and check for structural damage (see Figure 12.2.53).

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 12.2.54). Check for hourglass shaping of piles at the waterline.

Figure 12.2.52 Concrete Dolphins

Figure 12.2.53 Steel Fender

Figure 12.2.54 Timber Fender System with Deteriorated Piles

12.2.4 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 condition rating method and the AASHTO *Guide Manual for Bridge Element Inspection* for element level condition state assessment method.

NBI Component Condition Rating Guidelines

Using NBI component condition rating guidelines, a one-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the entire substructure including abutments and piers. Component condition 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 component condition rating guidelines.

Consider previous inspection data along with current inspection findings to determine the correct component condition rating. Recognize that piers may be affected by scour or other conditions that may only be able to be accessed and evaluated by a separate underwater inspection. Therefore, the results of both the routine and underwater inspection, if applicable, are integrated and evaluated together to arrive at the correct component condition rating for the substructure. Note the findings of the underwater inspection in the narrative portion of the routine inspection report as documentation and justification for the determined substructure component condition rating code.

Element Level Condition State Assessment

In an element level condition state assessment of a pier or bent structure, possible AASHTO Bridge Elements (NBEs) and Bridge Management Elements (BMEs) are:

NBE No.	Description
Substructure	
202	Steel Column/Pile Extension
207	Steel Column Tower (Trestle)
225	Steel Submerged Pile
231	Steel Pier Cap
204	Prestressed Concrete Column/Pile Extension
226	Prestressed Concrete Submerged Pile
233	Prestressed Concrete Pier Cap
205	Reinforced Concrete Column/Pile Extension
210	Reinforced Concrete Pier Wall
220	Reinforced Concrete Pile Cap/Footing
227	Reinforced Concrete Submerged Pile
234	Reinforced Concrete Pier Cap
206	Timber Column/Pile Extension
208	Timber Column Tower (Trestle)
228	Timber Submerged Pile
212	Timber Pier Wall
235	Timber Pier Cap
213	Masonry Pier Wall
211	Other Pier Wall

BME No.	Description
Wearing Surfaces and Protection Systems	
515	Steel Protective Coating
521	Concrete Protective Coating

The unit quantity for the pier cap elements is feet, measured horizontally across the pier cap. The total length is distributed among the four available condition states depending on the extent and severity of the deficiency. The unit quantity for columns and piles is each, and the total quantity is placed in one of the available condition states depending on the extent and severity of the deficiency. The unit quantity for protective coatings is square feet, with the total area distributed among the four available conditions states depending on the extent and severity of the deficiency. Condition State 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

The following Defect Flags are applicable in the evaluation of the piers and bents..

Defect Flag No.	Description
356	Steel Cracking/Fatigue
357	Pack Rust
358	Concrete Cracking
359	Concrete Efflorescence
360	Settlement
361	Scour
363	Steel Section Loss
364	Steel Out-of-Plane (Compression Members)
367	Substructure Traffic Impact (load capacity)

See the AASHTO *Guide Manual for Bridge Element Inspection* for the application of Defect Flags.

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