Chapter 5
Gate Anchorage Systems

5-1. General Description

The trunnion girder is held in place by an anchorage system that extends into the concrete pier. Anchorage systems can be classified as prestressed or nonprestressed. The prestressed system includes high strength, preloaded components while the nonprestressed system incorporates structural steel components. A general arrangement of a gate anchorage system is shown in Figure 5-1.

a. Prestressed systems. Prestressed systems consist of groups of posttensioned members that anchor the trunnion girder to the pier. The posttensioning operation creates an initial compressive stress in the system that acts to maintain trunnion girder-to-pier contact and to reduce structural cracks in the pier concrete. Figure 5-2 describes a typical posttensioned anchorage system. The anchors are placed inside ducts embedded in the concrete and are tensioned after concrete has set and cured. Subsequent to tensioning, the annular space between the posttensioning steel and duct is grouted for corrosion protection. Generally, two groups of anchorage steel are installed, one near each pier face. A limited bearing area is provided directly under each anchorage group. A compressible material is placed between the anchorage bearing areas at the trunnion girder-to-pier interface to intentionally prevent the transfer of stress across this reach. This detail enhances structural performance by reducing negative bending moments in the trunnion girder, and a larger moment arm between anchorage groups is available to resist nonsymmetrical loads. Alternate anchorage systems are shown by Figure 5-3. These systems are comprised of additional plates or other structural members anchored into pier concrete and connected to the trunnion girder (e.g., embedded plates or separate structural members anchored to pier and connected to the trunnion girder). Loads are transmitted from the trunnion girder to the anchorage system through these additional members, creating a larger area of pier concrete to resist posttensioning forces and loads applied to the trunnion girder. Therefore, concrete stresses will be lower, and bursting and spalling reinforcement is reduced. Additional connections and components are required for these systems.

b. Nonprestressed systems. Nonprestressed systems may consist of embedded standard shapes, large-diameter rods or built-up sections. Nonprestressed systems are relatively easy to design and install. However, nonprestressed systems allow greater deflections of the trunnion girder, allow tension and possibly structural cracking in concrete (bonded anchors), and require a large cross-sectional area of steel. This type of anchorage system is not recommended except for projects with small tainter gates. This EM provides criteria only for prestressed systems.

5-2. Components

A complete posttensioned anchorage system includes tendons (bars or strands), anchorage devices or bearing plates, ducts, end caps, grout tubes, couplers, anchorage zones, and a corrosion protection system. Anchorage zones include a portion of pier in the vicinity of tendon anchorage at either end of the tendons. The anchorage zone is geometrically defined as the volume of concrete through which the concentrated tendon force applied at an anchorage device (or girder-to-pier bearing area) dissipates to an area of more linear stress distribution throughout a cross section some distance from the anchorage device.

a. Tendons and anchorage. Tendons can be high-strength, low-alloy steel bars or strands. The tendons are posttensioned at the trunnion girder (referred to as the live end) to hold the trunnion girder to the pier. They pass through the trunnion girder and terminate at embedded bearing plates or anchorage devices (referred to as the dead end) within the pier. The embedded length of the tendons is typically 9 to

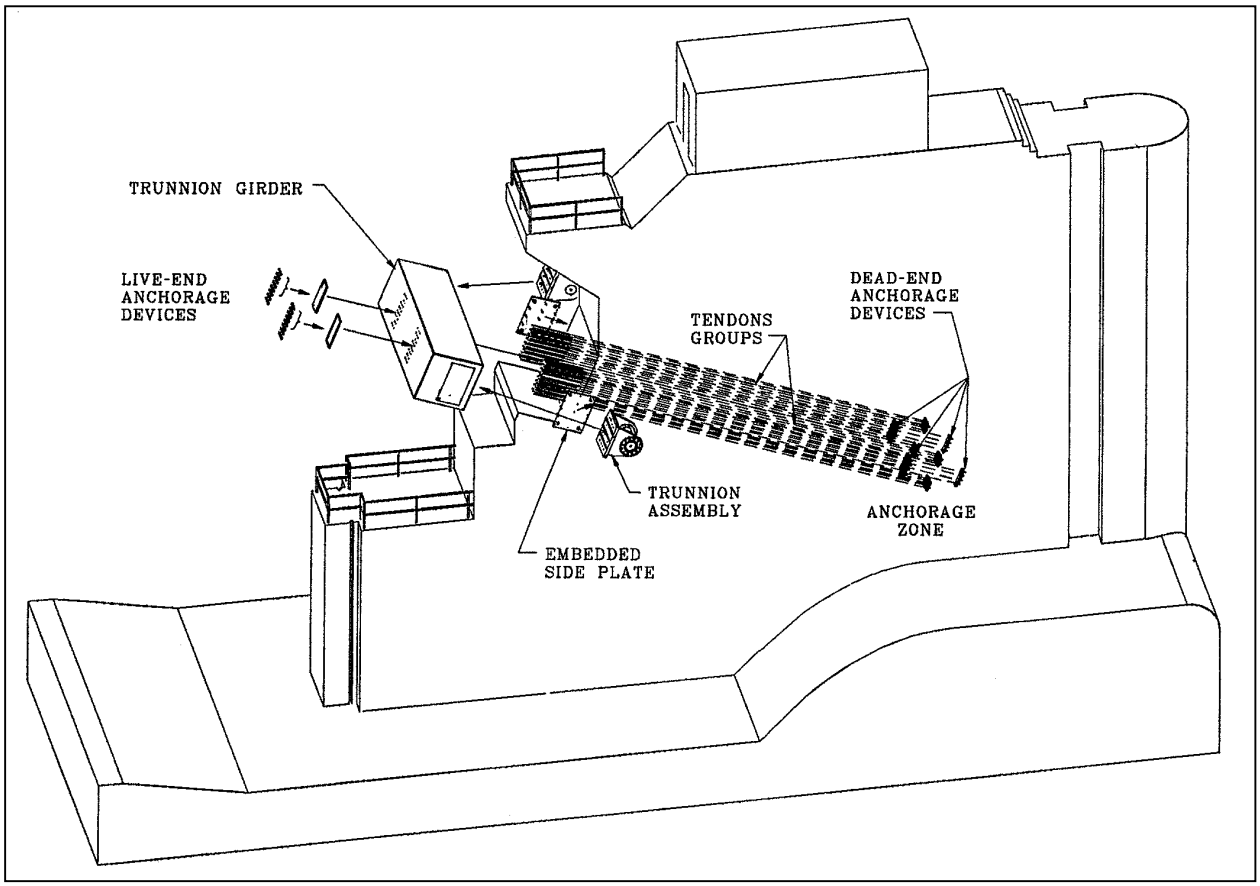

Figure 5-1. General arrangement of gate anchorage

15 m (30 to 50 ft). Longer lengths provide better control of posttensioned force and have higher pullout resistance since a larger area of concrete is effective in resisting the forces. Couplers are available to splice tendons; however, anchors are produced in sufficient lengths to make the use of couplers in typical trunnion girder installations unnecessary. The embedded ends of the prestressing steel are supported by a positive means rather than by gripping devices, which are vulnerable to slippage if grout penetrates into the anchorage device. Tendons are anchored at the dead end with embedded bearing plates that range in thickness from 25 to 63 mm (1 to 2-1/2 in.). The dead-end termination points of individual tendons are staggered from one another to distribute the transfer of load from the tendons to the concrete. Live-end anchorage devices may consist of a wedge, bell, or flat plate system and typically seat against the trunnion girder. Cable strands may also be continuous, extending from the live end to a fixed loop or 180-deg bend (that acts as the dead-end anchorage) back to the live end.

b. Tendon ducts or sheathing. Ducts encase the tendons to separate them from the surrounding pier and abutment concrete and allow tensioning after concrete has cured. The ducts also protect anchors during placement of concrete and act as part of the corrosion protection system. Ducts shall be rigid or semirigid, either galvanized ferrous metal or polyethylene, or shall be formed in the concrete with removable cores. Polyethylene ducts are usually corrugated to increase crushing resistance and to interlock with surrounding concrete.

c. Corrosion protection systems. The corrosion protection system for tendons consists of tendon ducts, duct fittings, connections between ducts and anchorages, grout tubes, end caps, and grout. A proper

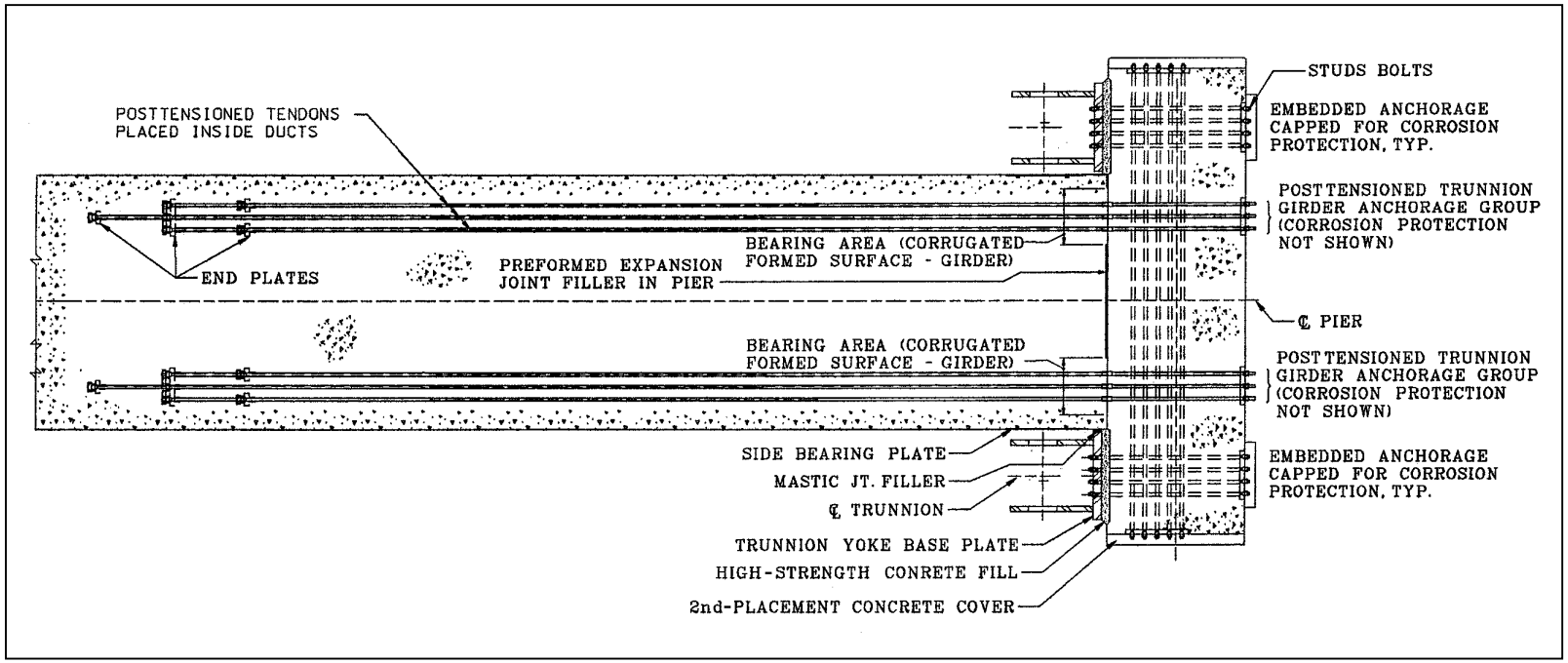

Figure 5-2. Typical posttensioned anchorage system

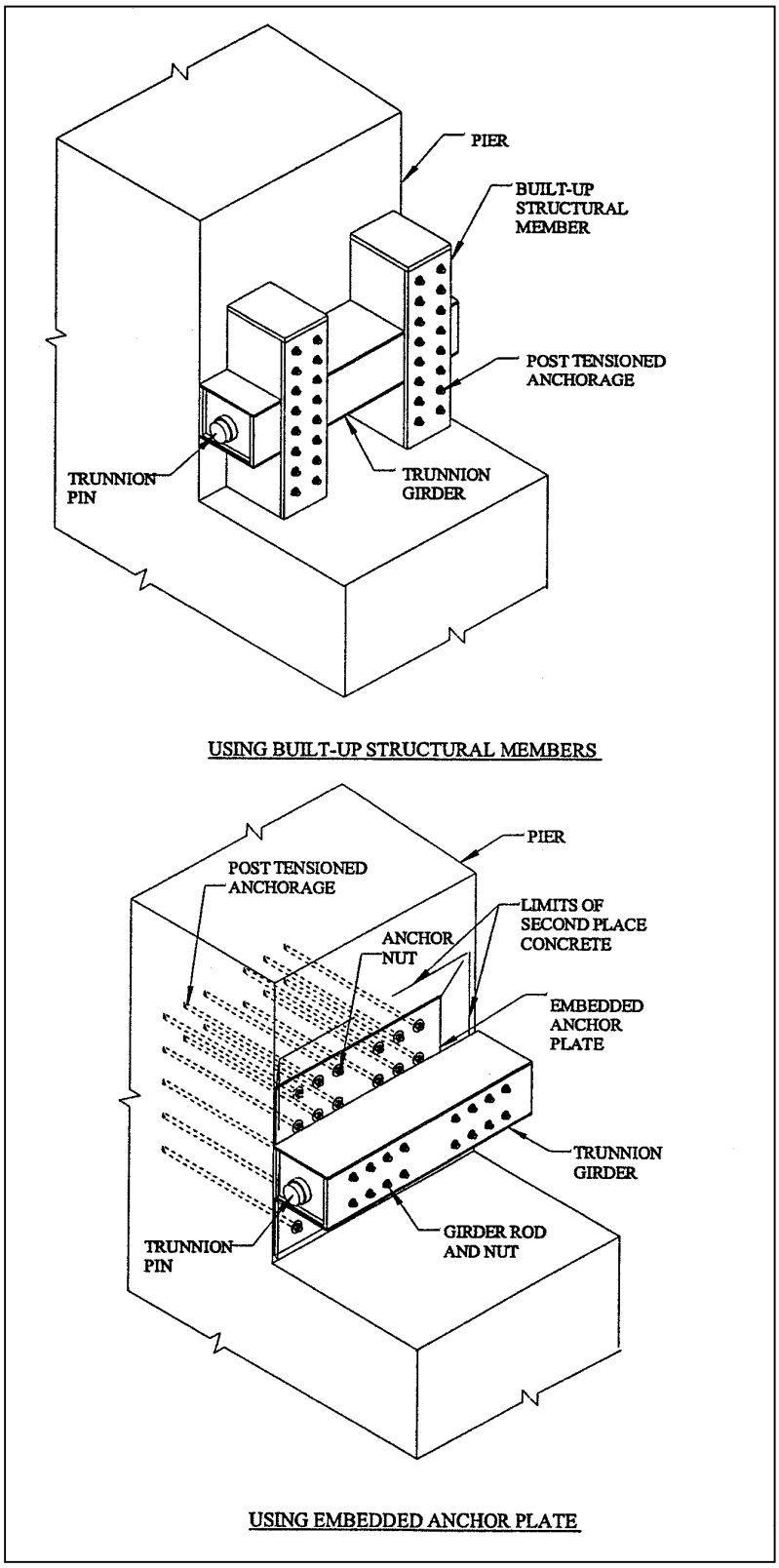

Figure 5-3. Alternate anchorage systems

duct system will prevent infiltration of moisture into the duct. Special fittings are provided for duct splices and connections between ducts and anchor plates using threaded or slip connectors and are provided with seals to prevent infiltration at these locations. Grout tubes extend from the sheathing to allow access for grouting. End caps are placed over the live end of the anchors and anchor nuts or wedges after stressing is complete and excess tendon removed. The grout encapsulates the tendon to prevent corrosion. Additional information on ducts can be found in Article 10.8.2, AASHTO LRFD Bridge Construction Specifications (AASHTO 1994).

5-3. Material Selection

a. Pier concrete. The minimum compressive strength of concrete in anchorage zones shall be 30 MPa (4500 psi). The minimum compressive strength of concrete between the anchorage zones shall be 28 MPa (4000 psi). Higher concrete strengths may be considered if required; however, specifications should include requirements on material controls and fabrication procedures to ensure the required strength. The maximum concrete aggregate size should be selected to pass between reinforcing bars.

b. Tendons. Posttensioning bars shall be of high-tensile alloy steel, conforming to the requirements of ASTM Designation A722. Cable strands shall conform to ASTM A416 with a minimum strength of 1860 MPa (270 ksi).

c. Steel for pier reinforcement. Reinforcing steel shall be deformed bars conforming to ASTM A615, ASTM A616 including Supplementary Requirement S1, ASTM A617, or ASTM A706. The specified yield strength shall be 400 Mpa (60 ksi). ASTM A706 shall be specified when bars are welded to form a cage.

d. Ducts. Galvanized steel pipe ducts shall conform to ASTM A53. Additional information on ducts can be found in Article 10.8.2, AASHTO LRFD Bridge Construction Specifications (AASHTO 1994).

5-4. Design Requirements

A properly designed anchor system will prevent structural cracking of concrete, limit deflections, account for all time-dependent stress losses, and safely accommodate specified loads for the life of the structure. Objectionable deflections and structural cracking may occur if the trunnion girder looses contact with the pier (lift-off). Lift-off can be controlled by an effective anchorage force that maintains residual compressive stresses between the trunnion girder and pier. The design of the gate anchorage system is based on strength and service limit states. The strength limit states ensure that the anchorage system will resist all factored loading combinations without failing. Service limit states are provided to restrict stresses, deformations, and cracks that adversely affect performance under typical or normal loading conditions at specified stages of use.

a. Design basis. Except as modified herein, the posttensioned anchorage system shall be designed in accordance with AASHTO (1994). The system shall be proportioned such that the limit states as specified in paragraph 5-4.c are not exceeded when the system is subject to loads as specified in paragraph 5-4.b. In general, the amount of anchorage steel required will be controlled by service limit states. Anchorage groups shall be sized such that the long-term effective anchorage force provides a minimum specified compressive stress between the girder and pier while the system is subject to the maximum trunnion reaction due to service loads. Additionally, the anchorage group shall have an ultimate strength greater than that required for factored loads. The anchorage zones, including spalling, bursting, and edge tension reinforcement shall be designed following procedures described by AASHTO (1994), Section 5.10.9, using factored jacking forces as specified in paragraph 5-4.b(1). The initial jacking force is based on the

required long-term effective stress and includes all prestress losses (paragraph 5-5.h). A recommended analytical model to determine anchorage forces is described in paragraph 5-5.b.

b. Load requirements. The anchor system shall be designed to resist loads as follows. In general, the maximum load will occur when one gate is raised just off the sill and the adjacent gate (if applicable) is unloaded.

(1) Strength limit state. Load cases shall be as specified in paragraph 3-4, except that a uniform load factor of 1.9 shall be applied to each of the applied loads for the design of tendons. The anchorage zone shall be designed for the jacking load only using a load factor of 1.2.

(2) Service limit state. Load combinations shall be as specified in paragraph 3-4, except that a uniform load factor of 1.0 shall be applied to each of the applied loads.

c. Limit states. Limit states are identified for tendons, anchorage zone reinforcement, girder-to-pier bearing, and pier concrete.

(1) Strength limit state. The strength limit of the tendons shall be as specified AASHTO (1994), Section 5.9.3, and the resistance factor ϕ shall be 1.0. The strength limit of the pier concrete shall based on the criteria for an eccentrically loaded tension member as specified in AASHTO (1994), Section 5.7.6.2, and the resistance factor ϕ shall be 0.9. Resistance factors for the design of anchorage zones shall be as specified in AASHTO (1994), Section 5.5.4.

(2) Service limit state. The service limit states are intended to limit tendon and pier concrete stresses at three stages including jacking (tendons only), after transfer of jacking loads and before losses, and after losses with trunnion service loads. Tendon stresses shall be limited to those values provided in Section 5.9.3, AASHTO (1994). The tendons shall be sized to maintain a minimum compressive bearing stress between the girder and the pier of 1.4 MPa (200 psi). For pier concrete, stresses shall be limited in accordance with Section 5.9.4, AASHTO (1994), except that tension stresses are not allowed.

5-5. Analysis and Design Considerations

a. Primary axis orientation. The orientation of the tendons (or primary axis) of the gate anchorage system is usually set to coincide with line of action of the maximum trunnion reaction based on service loads. The maximum gate reaction usually occurs with unsymmetrical hoist support conditions.

b. Analytical model for anchorage forces. The trunnion girder is assumed to behave as a simply supported beam with cantilevered end spans as shown in Figure 5-4. The gate anchorage represents the simple supports. The position of support is assumed to lie at the center of gravity of the anchorage steel group. Reaction forces are determined by summing moments about the supports. The anchorage force is equal to the calculated reaction R_{max}.

c. Analytical model for anchorage zones. Analysis for the design of anchorage zones may include strut and tie models, elastic stress analysis or other approximate methods. These methods are described in Section 5.10.9 of AASHTO (1994).

d. Girder-to-pier bearing stresses. Compressive bearing stresses exist along the contact area between the girder and the pier due the posttensioning operation. Time-dependent losses and external

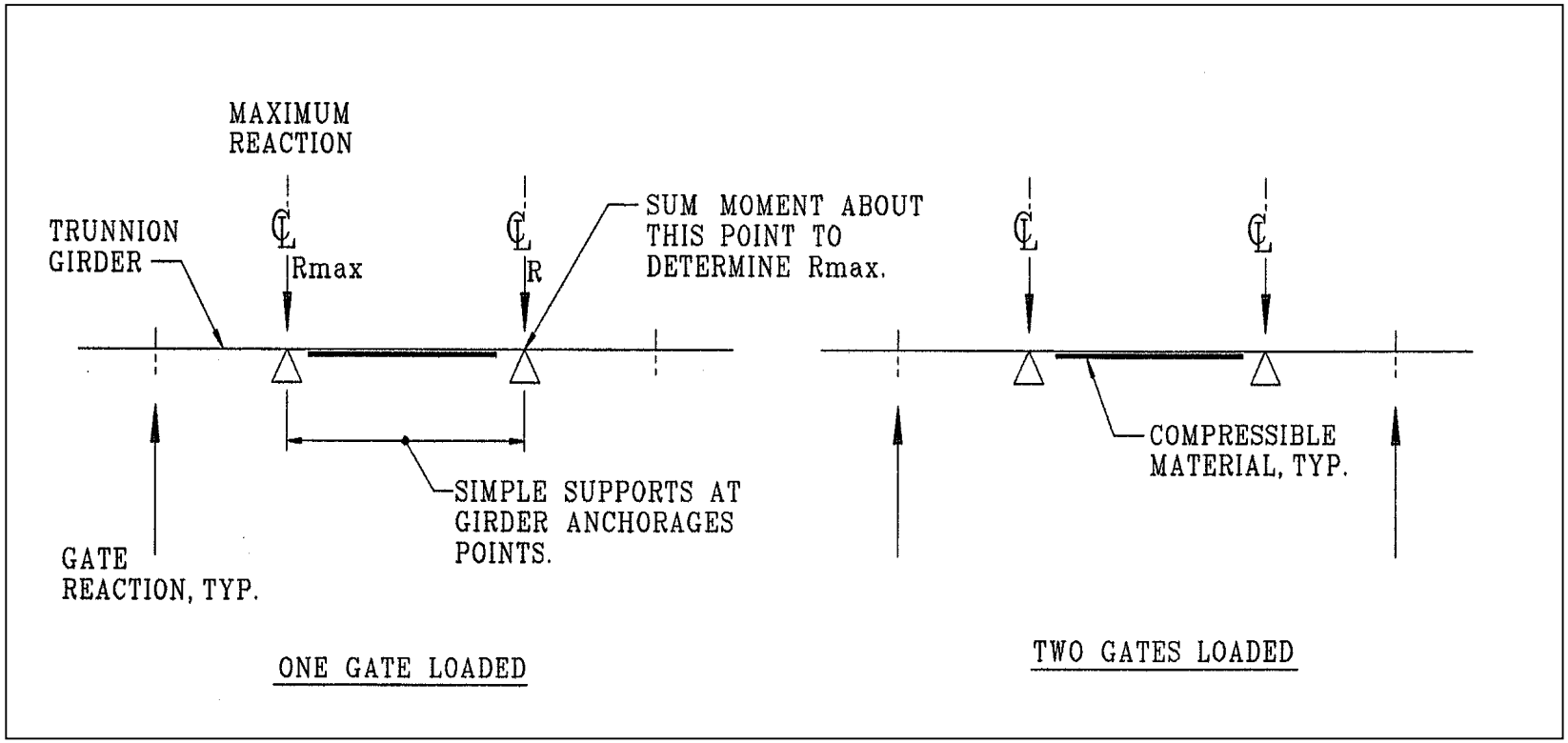

Figure 5-4. Analytical model to establish minimum anchorage force

gate loads act to reduce the bearing stresses. The net effect can be evaluated by superposition of stresses. Maximum stresses, located at the corners of the girder-pier bearing area are determined by superimposing the initial stress from the posttensioning operation, time-dependent losses, and the change in stresses due to trunnion reaction (gate) loads. The effect of gate loads can be represented as an equivalent set of normal force (P) and couples (M_x and M_y) due to eccentricity of the normal force about orthogonal axes of the contact area. The resulting bearing stresses are determined assuming that the girder acts as a rigid body. Figure 5-5 shows a typical design layout and assumed section properties of the bearing area. The bearing stress distribution for an unloaded gate and a loaded gate is shown in Figure 5-6. The change in bearing stresses due to gate loads $\Delta\sigma$ is determined as

$$\Delta\sigma = \frac{P}{A} \pm \frac{M_x c}{I_x} \pm \frac{M_y c}{I_y} \tag{5-1}$$

where

A = total bearing area

M_x = couple about the x axis

M_y = couple about the y axis

c = distance from the respective axis to the point in question

I_x and I_y = section moments of inertia as defined by Figure 5-5.

e. Finite element models. Elastic analysis of anchorage zone problems is discussed in Section 5.10.9.5, AASHTO (1994). Elastic analysis can be accomplished using 2-D or 3-D finite element models. Practical analyses are limited to linear behavior; however, models can be used to validate more simplified analyses and to determine required reinforcement in areas of complicated local conditions.

f. Anchorage depth. The depth of anchorage into the pier or abutment should be maximized to the extent possible to maximize the area of concrete effective in resisting the anchorage forces. Anchorage tendons of approximately 80 to 90 percent of the gate radius have been used with satisfactory performance. Interference with embedded metals (side-seal plates) usually limits the anchorage depth.

g. Girder movement. Girder movement across the girder-to-pier interface shall be investigated using the shear friction concept. As shown in Figure 5-7, a sufficient residual contact pressure must be available to resist shear and minimize movement. Unless other means such as dowels or mechanical confinement by adjacent concrete are provided to prevent relative movement between the trunnion girder and pier, the condition described by Equation 5-2 shall be satisfied. The right hand side of Equation 5-2 represents the available shear strength due to frictional resistance.

$$V_u \leq 0.85\mu R \tag{5-2}$$

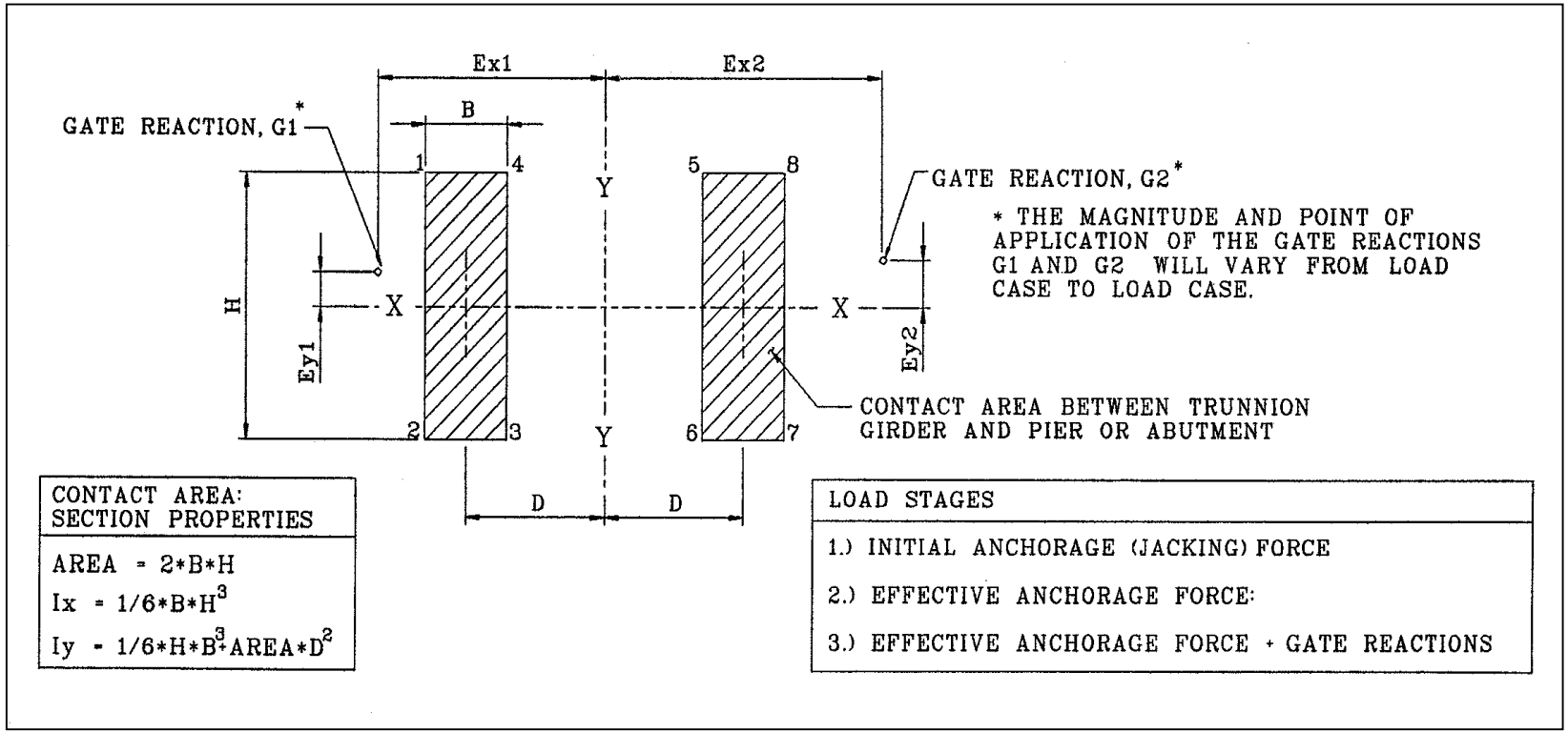

Figure 5-5. Analytical model to evaluate anchorage bearing stresses

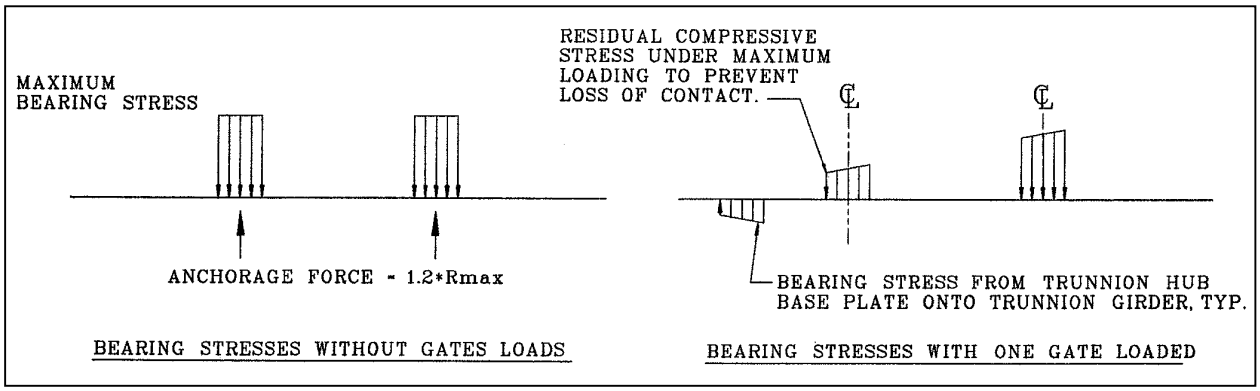

Figure 5-6. Stress distributions between pier/trunnion girder interface

where

V_u = factored shear force

μ = coefficient of friction for the interface

R = residual compressive force between the girder and pier

h. Effective stresses. Estimated lump-sum losses (assumed values not supported by computation) may be used for the initial design of prestressed concrete. However, the final design should account for individual losses due to elastic shortening, shrinkage, concrete creep, steel relaxation, anchorage set, and friction. For straight tendons, losses due to friction may be neglected. The value of anchor set loss can be assumed or obtained from the manufacturer and should be verified prior to construction. A more refined incremental time-step analysis of losses is typically not required. AASHTO (1994), Section 5.9.5, provides guidance for estimating prestress losses.

i. Anchorage zone reinforcement. A portion of pier concrete adjacent to the trunnion girder and anchor plates will be subject to tensile stresses. Tension exists in a portion of concrete located at the center of the anchorage tendons (bars) ahead of the anchorage device or girder. This area is termed the bursting zone. At the end of the pier adjacent to the girder, edge tension forces may exist along the sides and end surface. The edge tension forces along the end surface are referred to as spalling forces. Reinforcement shall be provided where required in the tendon anchorage zones to resist bursting and edge tension forces induced by tendon anchorages. Design guidance regarding bursting, spalling and edge tension is specified by AASHTO (1994), Section 5.10.9.3.

5-6. Serviceability

Corrosion of the tendons and anchorage components is the primary serviceability concern regarding design of the anchorage system. Corrosion of tendons must be avoided because it can lead to potential failure of the tendons and because the tendons are difficult to replace. The anchorage system shall be doubly protected against corrosion. With a properly constructed system, the tendons are doubly protected against corrosion since ducts and grout both prevent moisture penetration.

a. Duct and grout requirements. To eliminate the penetration of moisture or other corrosive substances, the duct system (including sheathing and all connections) shall be water or gas tight. Ducts shall be nonreactive with concrete, tendons, and grout. Ducts shall have an inside diameter at least 6 mm

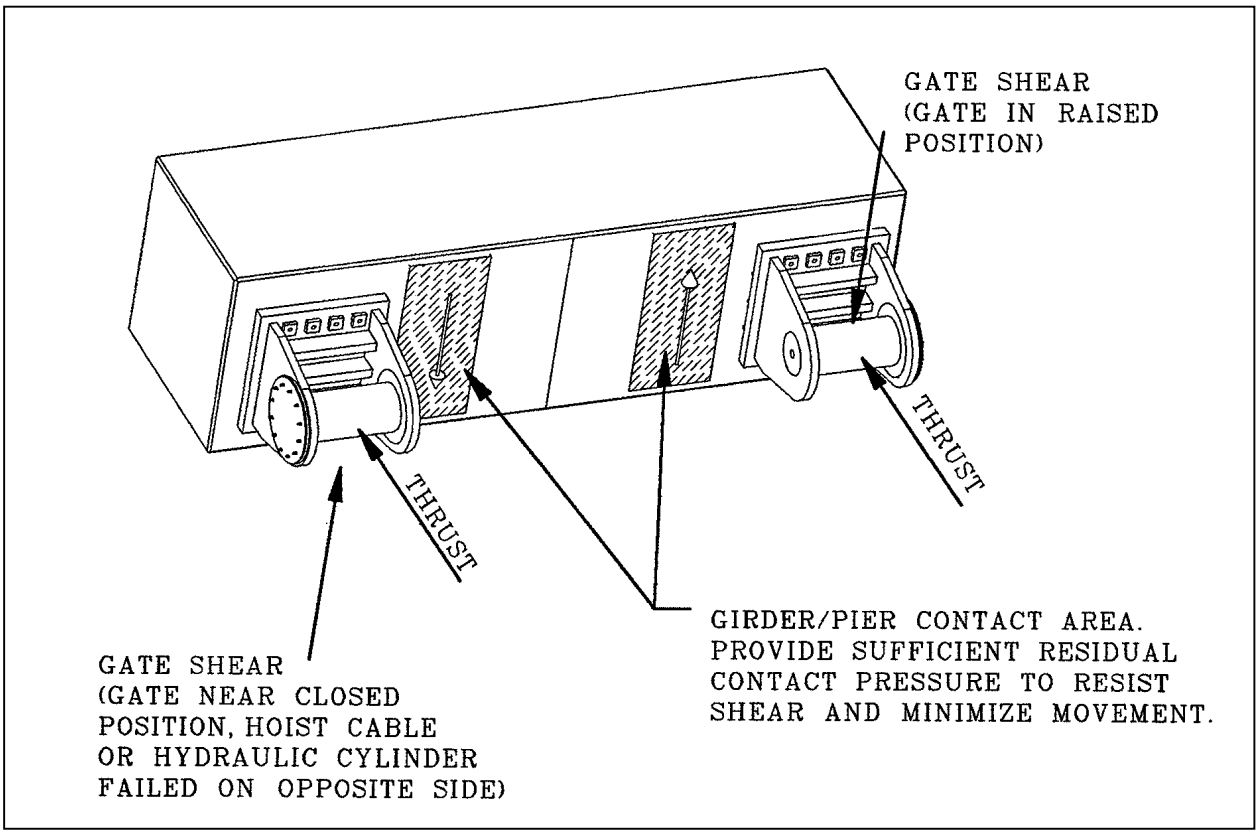

Figure 5-7. Trunnion girder movement

(1/4 in.) larger than the tendon diameter. Grout shall be placed such that tendons are completely encapsulated in grout with no air voids present. Where corrosion is of great concern, metalic sheathing should be avoided. A practice recommended in the previous version of this EM was to use a soft nonhardening, water-displacing, corrosion-inhibiting compound in lieu of grout. This was done to facilitate possible future removal and replacement of the trunnion girder; however, this practice is no longer recommended due to a poor performance record.

b. Anchorage devices and end caps. Anchorage devices shall be encapsulated by second placement concrete. Where aggressive chemical environments are encountered or where corrosion is of great concern, anchor plates and anchorage ends can be encapsulated in plastic. End caps shall be filled with grout or anticorrosion compound and should be fitted with a sealing device.

5-7. Design Details

a. Anchorage layout.

(1) The posttensioning anchorage steel should be installed in two groups with each group being located as close to the adjacent pier face as practicable. To place conventional pier steel reinforcement, clearance outside the prestressing bars of approximately 250 mm (10 in.) should be provided.

(2) Anchorage plates for alternate tendons should be installed in a staggered pattern so all anchorage loads are not transferred to one plane. This will significantly reduce the quantity of reinforcing steel that

would otherwise be required to control vertical tension cracks in the concrete. A staggered spacing of 0.6 to 1.2 m (2 to 4 ft) has been used successfully in the past to distribute anchorage forces.

b. Reinforcement considerations.

(1) Anchorage zones. Spalling zone reinforcement that consists of conventional grid reinforcement designed to resist approximately 4 percent of the total prestressing force will be adequate for most cases. The reinforcement should be placed as near to the surface as practicable. For typical arrangements, tensile stresses in the bursting zone have been shown to be a maximum of about 18 percent of the unit compression stress due to the longitudinal prestressing. Reinforcement for these stresses should be provided from the downstream pier face into the pier for a distance of approximately one-half the width of the pier.

(2) Pier corners. To prevent spalling of the concrete at the corners of the pier, it is suggested that the outer layer of reinforcement be welded to angles that are embedded along the vertical edges of the pier.

c. Construction considerations.

(1) To minimize integral action between the girder and the pier during posttensioning, all contact surfaces between the girder and the pier (except structural bearing zones) should be troweled smooth or separated by a premolded expansion joint material.

(2) Tendons can be placed horizontally if the gate trunnion is oriented so that the vertical component of thrust is negligible. With horizontal tendons, fewer lifts of anchorage zone concrete are required and construction is simplified.

(3) Pier prestressing tendons should be installed prior to installation of conventional reinforcement and forms. This will permit close inspection of the embedded ends to ensure proper construction.