Chapter 12

STRUCTURAL SYSTEMS AND DIMENSIONS

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 12

STRUCTURAL SYSTEMS AND DIMENSIONS

This Chapter provides guidance to bridge designers in determining the most efficient and economical overall structure type and size to meet the structural, geometric, hydraulic, environmental, and right-of-way characteristics of the site. This decision will significantly impact the detailed structure design phase, construction costs, and operational costs over the life of the structure.

12.1 IN-HOUSE OPERATIONS

Part I of the *SCDOT Bridge Design Manual* documents the Department's in-house operations for project development (e.g., organization of the Bridge Design Section, coordination with other SCDOT Units, administrative policies and procedures).

12.2 GENERAL STRUCTURAL DESIGN CRITERIA

The bridge designer must evaluate certain general structural design criteria in the selection of the structure type and size. This Section discusses these general structural considerations.

12.2.1 Definition of Terms

12.2.1.1 Substructure vs Foundation

The dividing line between substructure and foundation is not always clear, especially in the case of extended pile bents and drilled shafts. Traditionally, foundations include the supporting rock or soil and parts of the substructure that are in direct contact with, and transmit loads to, the supporting rock or soil. In the *SCDOT Bridge Design Manual*, this definition will be used.

12.2.1.2 Substructure vs Superstructure

A similar difficulty exists in separating substructure and superstructure where these parts are integrated. For integral bents, the *SCDOT Bridge Design Manual* will refer to the substructure as any component or element located below the bearings. The superstructure then consists of the bearings and all of the components and elements resting upon them.

12.2.2 Live-Load Deflection Criteria

Reference: LRFD Articles 2.5.2.6.2 and 2.5.2.6.3

12.2.2.1 General

The *LRFD Specifications* states that the traditional live-load deflection criteria is optional for bridges both with and without sidewalks because static live-load deflection is not a good measure of dynamic excitation. Nonetheless, in the absence of a better criterion and because of concerns on durability, SCDOT has determined that it is appropriate to limit live-load deflections.

12.2.2.2 Criteria

Live-load deflections shall be limited based upon the span-length-based criteria of LRFD Article 2.5.2.6.2 with consideration to either the presence or the absence of pedestrian traffic. The minimum superstructure depth limits of LRFD Article 2.5.2.6.3 shall also be met.

12.2.3 Continuous vs Simple Spans

In general, continuous structures (and jointless bridges) provide superior structural performance when compared to bridges with simple spans and joints. However, in rare cases, it may be appropriate to use simple spans, including widenings of existing simple-span bridges and longer spans or other geometric constraints.

Back-to-back multiple simple spans should be avoided, if possible.

12.2.4 Jointless Bridges

12.2.4.1 General

When practical, a jointless bridge should be considered in design. Problems with expansion joints include:

- corrosion caused by de-icing chemicals leaking through the joints,

- accumulation of debris and other foreign material restricting the free joint movement often resulting in joint damage,

- differential elevation at the joints causing additional impact forces,

- unexpected bridge movements and settlements that affect the joint, and

- high initial and maintenance costs.

Joints can be eliminated with special consideration to:

- load path,
- gravity and longitudinal loads,
- effects of concrete creep and shrinkage,
- effects of temperature variations,
- stability of superstructure and substructure during construction and service,
- skew and curvature effects,
- the superstructure-end bent-foundation connection design and details,
- effects of superstructure and substructure stiffness,
- effects of settlement and earth pressure,
- effects of varying soil properties and type of foundation, and
- effect of approach slab and its connection to the bridge.

Jointless bridges, already in service, have demonstrated the ability to perform successfully under the previous considerations. Therefore, in the absence of in-depth analyses, it is reasonable to design a jointless bridge under the following parameters:

- 240-ft total maximum length for steel girder bridges or 300-ft total maximum length for prestressed concrete beam bridges,
- 30° skew or less,
- settlement is not anticipated, and
- end bent types that are flexible.

If one or more of these parameters are not met, the use of a jointless bridge will require a more detailed analysis.

12.2.4.2 Geotechnical Considerations for Jointless Bridges

Section 12.5 discusses the selection of a foundation type; Chapter 19 discusses the design of foundation types, and also discusses the engineering coordination between the bridge designer and Geotechnical Design Section for geotechnical issues. For more information on geotechnical engineering, see the *SCDOT Geotechnical Design Manual*.

12.2.4.2.1 Site Conditions

Geotechnical considerations for jointless bridges are generally the same as for jointed bridges, with additional consideration given to soil-structure interactions and longitudinal stiffness. Subsurface soil conditions at the bridge site must be determined to an acceptable degree prior to determining if a jointless bridge is a practical option. Consult with the Geotechnical Design Engineer regarding subsurface conditions at the bridge site.

Generally, geotechnical investigations for jointed bridges are acceptable for jointless bridges, with special consideration given to the upper strata where longitudinal foundation movements are expected. Jointless bridges require superstructure movements to be accommodated by the foundation through soil-structure interaction. These movements require "flexible" foundations that are capable of deflecting longitudinally without damage to the foundation or significant disturbance to the roadway surface. Soil conditions that allow the use of flexible foundations range from soft clay to loose sand. Generally, "poor" soil conditions result in foundations that have less lateral stiffness and accommodate larger lateral movements than "good" soil conditions. Dense sand and gravel or hard clays will often result in foundations that are too stiff and cannot deflect horizontally the amount required by long superstructures.

Softer soil conditions have a greater potential for settlement problems. Thus, soil conditions that favor longitudinal movements of the foundation also have an increased risk of significant foundation settlement. Although longitudinal deflections of the foundation are encouraged, foundation settlement is discouraged. Foundations at jointless bridges will generally require a more in-depth geotechnical analysis than jointed bridges, especially in areas exhibiting high seismic demands.

12.2.4.2.2 Foundation Type

Foundations are the structural elements that transfer vertical, lateral, and rotational loads into the soil by soil-structure interaction. Soil-structure interaction is influenced by the type and geometry of the foundation and the characteristics of the surrounding soil. In typical designs, the foundation is considered to be infinitely stiff. However, the foundation stiffness should be compared to the substructure stiffness to verify this assumption. In many cases, the longitudinal bridge stiffness will significantly decrease if the foundation stiffness is combined with the substructure stiffness. Foundation types should be matched with the intent of the design. If the foundation is considered rigid, then it should be very stiff. If the foundation is intended to accommodate translation, as is typical in jointless bridges, then it should be flexible.

Deep foundations such as piles are typically very stiff axially, but flexible laterally. Thus, they are good choices for jointless bridges, under certain soil conditions. Drilled shafts are similar to piles, except they are typically stiffer laterally and are generally used in more competent soil stratifications. Shallow foundations such as spread footings are generally very stiff both axially and laterally, especially at the embedment depths typically used for bridge foundations. Often, different foundation types are used for the interior and end bents based upon soil conditions.

The type of foundation used at an end bent of a jointless bridge will largely be determined by the type of soil at the site and the seismic performance requirements. It will also be a function of the length of the span or lateral movement expected. Thus, the soil conditions can control the foundation type, which can control the length of span used for a jointless bridge. Under certain soil conditions, jointless bridges are not practical.

Very loose to loose cohesionless soil or very soft to soft clay will require deep foundations such as piles or, possibly, drilled shafts; see Section 12.5. Deep foundations in these soil deposits will be flexible enough to accommodate large longitudinal movements at end bents associated with long jointless bridges. However, high to moderate foundation settlement can be expected in these soils. Extra conservatism may be warranted when designing the foundations to resist axial loads to limit settlement.

Dense cohesionless soils such as sandy gravel, gravelly sand, or cobbles and boulders are often not well suited for deep foundations due to the difficulty in installing the piles or drilled shafts to the required elevations to resist the axial loads. When deep foundations are used in these cases, the lateral stiffness is usually very high and typically will not permit the longitudinal movements necessary at the end bent for a long jointless bridge. Short jointless bridges, however, may use these types of foundations at end bents in these soil deposits, when significant longitudinal movement is not expected. Spread footings can be used in these soil conditions; see Section 12.5. Spread footings are typically very stiff foundations and can often be considered rigid in soil deposits of this nature. Foundation settlements in these soil deposits are likely to be negligible.

Medium dense cohesionless soil or stiff to hard clays are intermediate materials. Deep foundations or shallow foundations can both be used in these materials. However, the stiffness of shallow foundations such as spread footings is likely to be too high to be used at end bents on a long jointless bridge. Even deep foundations such as piles, which are usually flexible, are likely to be too stiff to allow enough longitudinal movement for a moderate to long jointless bridge. In these soil conditions, the length of the bridge and the foundation type will be critical. Foundation settlements may range from negligible to moderate in these soil deposits.

12.2.5 Girder Bridges

12.2.5.1 Deck and Girder Composite Action

Reference: LRFD Articles 4.5.2.2 and 9.4.1

Deck and girder composite action enhances the stiffness and economy of bridges. Bridge decks and their supporting members shall be made fully composite throughout the entire span of the bridge, in both positive and negative moment regions. Thus, the shear connectors and other connections between decks and their supporting members shall be designed to develop full composite action. In other words, the shear connections must be able to resist the horizontal interface shear at the nominal resistance of the section.

The stiffness characteristics of composite girders shall be based upon full participation of the effective width of the concrete deck. In other words, composite concrete bridge decks shall be considered uncracked throughout the span for the determination of moments and shears for Service and Strength limit states in structural analysis.

12.2.5.2 Number of Girders

Because of concerns for redundancy, new bridges shall have a minimum of four girders per span.

12.2.5.3 Girder Spacing

The typical girder spacing for SCDOT bridges is 7½ ft to 10 ft. The maximum spacing shall not exceed 10½ ft.

12.2.5.4 Interior vs Exterior Girders

Reference: LRFD Article 4.6.2.2.1

To simplify future bridge widenings and for economy of fabrication, all girders within a span should be designed identically to the governing condition, either interior or exterior girder.

12.2.5.5 Deck Overhang

The bridge deck overhang is measured perpendicular from the centerline of the exterior girder to the outside edge of the slab. SCDOT limitations on maximum deck overhang are based on the following:

1. Girder Spacing. Deck overhang shall not exceed 50% of the average girder spacing for parallel girders (i.e., either straight or curved). For chorded girders, the overhang at any point shall not exceed 50% of the average girder spacing.
2. Girder Depth/Type. Figure 12.2-1 presents SCDOT limitations on maximum deck overhang based on the depth and type of girder.

The lesser of the two values from the above will govern the maximum bridge deck overhang.

SCDOT criteria for minimum bridge deck overhang is that the slab shall extend 12 in beyond the edge of the top flange of the exterior girder or 2′-3″ beyond the centerline of the exterior girder, whichever is greater.

The deck overhang shall be designed in accordance with Section 13 of the *LRFD Specifications*.

Type of Beam	Depth of Beam[1]	Maximum Deck Overhang
Prestressed Concrete	< 54″	42″
	54″ - 63″	48″
	> 63″	54″
Structural Steel	< 36″	Depth of Beam
	36″ - 48″	42″
	> 48″	45″

[1] *For structural steel plate girders, the web depth shall be used as the depth of beam.*

MAXIMUM DECK OVERHANG

Figure 12.2-1

12.2.6 Seismic Requirements

The bridge designer shall incorporate the seismic requirements of the *SCDOT Seismic Design Specifications for Highway Bridges* with the selection of a superstructure, substructure, or foundation type. The seismic demand of the bridge and the flexibility/stiffness of the bridge are coexistent. Therefore, any selection must satisfy the seismic performance, ductility requirements, plastic hinge location, and all other design criteria as specified in the *SCDOT*

Seismic Design Specifications for Highway Bridges, which should be referenced for additional information.

12.2.7 Approach Slabs

Approach slabs are required on projects that meet one of the following conditions:

- any bridge that is located on an Interstate, US, or SC route;
- any bridge that is located on a Secondary Road that has a current ADT greater than 400 vpd or that has a new approach fill height that exceeds 10 ft; or
- any bridge having parallel wing walls (wing walls parallel to the centerline of the bridge).

12.2.8 Sleeper Slabs

A sleeper slab is a foundation slab, inverted tee-beam or L-beam placed transversely supporting the end of the approach slab away from the bridge. Sleeper slabs should be used to provide an off-bridge joint at the end of the approach slab, where:

- a jointless bridge exceeds 240 ft total length for steel girder bridges or 300 ft total length for prestressed concrete beam bridges, or
- the distance from an integral or semi-integral end bent to the nearest expansion joint exceeded 240 ft for steel girder bridges or 300 ft for prestressed concrete beam bridges.

The embankment beneath the sleeper slab shall be designed to prevent differential settlement along the length of the sleeper slab.

12.3 SUPERSTRUCTURES

This Section discusses those factors that should be considered in the initial selection of the superstructure type.

12.3.1 Superstructure Types/Characteristics

12.3.1.1 General

Throughout the nation, many types of superstructures have been developed for the myriad applications and constraints that prevail at bridge sites. However, South Carolina, like most other States, has narrowed its typical selection of superstructure types to a relatively small number based on the Department's experience, geography, terrain, environmental factors, local costs, local fabricators, the experience of the contracting industry, availability of materials, and Department preference. This promotes uniformity throughout the State and simplifies the bridge design process.

This Section presents summary information on the available superstructure types used by SCDOT and identifies their typical application. This information will assist the bridge designer in the initial selection of a superstructure type that will ultimately provide a practical, cost-effective selection for the site under consideration.

12.3.1.2 Span Length Guidelines

Figure 12.3-1 indicates the span lengths for which the typical SCDOT superstructure types will generally apply.

Structure Type	**Span Length Ranges (ft)**		
	≤ 40	**> 40 to 100**	**> 100**
Prestressed Concrete Girders		X	X
Flat Slabs (Reinforced, Cast-in-Place Concrete Slabs)	X		
Steel Welded Plate Girders		X	X
Steel Rolled Beams		X	
Cored Slabs (Prestressed Concrete Cored Slabs)	X	X	

Note: See Section 12.3.2 for more discussion on span ranges for each type.

SPAN LENGTH RANGES FOR TYPICAL SUPERSTRUCTURE TYPES

Figure 12.3-1

12.3.2 Typical SCDOT Superstructure Types

This Section discusses the basic characteristics of those superstructure types most frequently used in South Carolina. Collectively, these five types represent approximately 90% of all new bridges and bridge replacements constructed by the Department. The information in this Section is intended to assist the bridge designer in the selection of a superstructure type for a given site.

12.3.2.1 Prestressed Concrete Girders

Because of their economy and applicability, prestressed, precast concrete girders are the most commonly used type of superstructure used in South Carolina. This system is used wherever possible within cost and clearance constraints. Span lengths typically range from 50 ft to 120 ft. Where designs for span lengths greater than 120 ft are necessary and transportation of the beams will occur in States other than South Carolina, the Contractor must obtain approval from the DOTs for the States through which the beams must be transported. The designer must consider how this structure type will be erected and how the girders will be delivered to the site.

When compared to other bridge types, the advantages of prestressed, precast concrete girder bridges include moderate construction cost on smaller bridges to fairly low construction cost on larger bridges, low maintenance cost, no falsework requirements, relatively quick fabrication time, and reasonably fast on-site construction. Disadvantages include difficulty of lifting and transporting, difficulty of adapting to complex geometrics, and slightly higher depth-to-span ratios.

Multiple spans of prestressed girders should be made continuous in the longitudinal direction for live loads and composite dead loads. In this arrangement, their ends, which are made continuous, are connected by a common diaphragm that is cast monolithically with the slab.

See the *SCDOT Bridge Drawings and Details*, available at the SCDOT website, for the Department’s typical details for prestressed concrete beams. See Chapter 15 for SCDOT design details.

12.3.2.2 Flat Slabs (Reinforced Cast-in-Place Concrete Slabs)

The flat slab is frequently used in South Carolina because of its suitability for short spans and low clearances and its adaptability to skewed and curved alignments. The most common applications of the flat slab in South Carolina are over small creeks and swamps and as approaches to large interior spans. The limit of its application is the cost effectiveness of the required substructure and hydraulic or aesthetic issues.

Standard span lengths are 22 ft, 30 ft, and 40 ft, with 30 ft being preferred. For a 40-ft span, the bridge designer must consider the long-term deflections with respect to camber.

Typical SCDOT practice is to use constant-depth slabs with no haunches in the negative-moment regions. Equal length spans are preferred for continuous slab bridges. For ease of construction and crack avoidance, non-integral bent caps shall be used.

See the *SCDOT Bridge Drawings and Details*, available at the SCDOT website, for typical flat slab details. See Chapter 15 for SCDOT design details.

12.3.2.3 Steel Welded Plate Girders

SCDOT typically limits the use of structural steel plate girder superstructures to longer spans (75 ft to 300 ft) or to where a concrete superstructure is not the best choice because:

- Superstructure dead load is a critical issue.
- Vertical clearances are a critical issue (Note: High-performance steel (HPS) offers good span/depth ratios).
- Geometrics are difficult (e.g., sharp horizontal curvature).

When compared to other bridge types, the advantages of structural steel girder bridges include fast on-site construction, no falsework requirements, adaptability to complex geometrics, and longer span capability. Its disadvantages include high construction and maintenance costs, longer lead time for girder fabrication, and necessary attention to detailing practices. Poor detailing will greatly increase the cost of the bridge and can decrease durability.

Steel plate girders should be designed to optimize fabrication and erection costs. Girder field sections can be transported in lengths up to approximately 120 ft. Where designs for field sections greater than 120 ft are necessary and transportation of the girders will occur in States other than South Carolina, the Contractor must obtain approval from the DOTs for the States through which the girders must be transported. The designer must consider how this structure type will be erected and how the girders will be delivered to the site.

See Chapter 16 for SCDOT design details.

12.3.2.4 Steel Rolled Beams

Because of availability concerns, the use of steel rolled beams is usually limited to bridge widening projects.

Rolled steel beams are characterized by doubly symmetrical, as-rolled cross sections with equal-dimensioned top and bottom flanges and relatively thick webs. Thus, the cross sections are not optimized for weight savings, as are the cross sections for a plate girder, but are cost effective due to lower fabrication and erection costs. The relatively thick webs eliminate the need for web stiffeners. Unless difficult geometrics or limited vertical clearances control, rolled steel beam superstructures are more cost effective in relatively shorter spans (50 ft to 90 ft).

Rolled steel beams are available in depths up to 3 ft, with beams more than 3 ft rolled less frequently. Before beginning final design, verify with one or more potential fabricators that the section size and length are available.

12.3.2.5 Cored Slabs (Prestressed Concrete Cored Slabs)

Prestressed concrete cored slabs ("cored slabs") are an alternative to flat slabs when the bridge designer anticipates the necessity of an accelerated construction schedule. Cored slab bridges consist of longitudinal, precast voided concrete slab members placed against each other to form a self-supported bridge deck. Cored slab details are available in span lengths of 30 ft, 40 ft, 50 ft, and 60 ft. See the *SCDOT Bridge Drawings and Details*, available at the SCDOT website.

The use of cored slabs is limited because of durability concerns due to the longitudinal and transverse joints. Voided concrete slabs are not allowed on any National Highway System (NHS) route nor on any facility with an ADT that equals or exceeds 3000 vpd.

In addition to permanent installations, cored slabs may be used for temporary bridges (i.e., a design life less than 5 years).

For Contractor-designed projects, such as design/build, cored slabs will only be allowed if the bid documents specifically allow their use. The substitution of a cored slab is not a valid Value Engineering proposal.

The maximum allowable skew is 15°, and the bridge designer must ensure a proper fit on the bent caps where the bridge is on a longitudinal grade or on a skew. In addition, other geometric elements may merit special consideration in the design of a cored slab.

12.3.3 <u>Other Structure Types</u>

Structures types other than those specified herein may be used. Their acceptability may be based upon other owner's successful experiences. The State Bridge Design Engineer must provide written approval for the selection of other structure types.

12.4 SUBSTRUCTURES

12.4.1 Objective

This Section discusses those types of substructure systems used by the Department, and it presents their general characteristics and usage. The designer should use this information and the information presented in Section 12.5 to select the combination of substructure and foundation types that is suitable at the site to satisfy economically the geometric requirements of the bridge and to safely use the strength of the soil or rock to carry the anticipated loads. The designer should also consider the seismic performance criteria requirements of the bridge when determining the substructure and foundation types that will be used. See the *SCDOT Seismic Design Specifications for Highway Bridges.* Chapter 20 discusses the detailed design of substructure elements, and Chapter 19 discusses the design of foundations.

12.4.2 End Bents

Reference: LRFD Article 11.6

12.4.2.1 General

The term "end bent" is used interchangeably with the LRFD term "abutment."

An end bent includes either a backwall or an end wall, a cap, and wing walls. A backwall or end wall is the upper portion of the end bent that functions as a wall that provides lateral support for fill material that the roadway or approach slab rests on. The term "backwall" refers specifically to the upper portion of a free-standing end bent, while the term "end wall" refers to the upper portion of an integral or semi-integral end bent in which the beams or girders are encased.

End bents are typically supported on piles but may also be supported on drilled shafts or footings. Piles and drilled shafts shall extend below any compacted fill, including MSE wall backfill. Footings supporting an end bent are rare, and shall not be permitted to be placed on compacted fill materials. Where pile-supported, vertical piles are preferred over battered piles.

12.4.2.2 End Bent Types

End bents can be generally classified as rigid or flexible. This classification refers to the end bent's fixity to the foundation and should not be confused with the fixity of the beams or girders to the substructure.

Rigid end bents incorporate expansion joints at the end of the bridge between the deck and the backwall to accommodate thermal movements.

Flexible end bents eliminate expansion joints at the end of the superstructure by integrating the bridge deck and encased beam ends with the "backwall" to form an end wall. Flexible end bents must be able to accommodate the movements through elastic behavior of the bridge and the surrounding soil because the deck and beams are integral with the end bent.

An end bent may be designed as one of the following three types in descending order of preference:

1. Integral End Bent. Flexible end bent without an expansion joint between the end bent and the bridge deck (in cross section, the end wall and bent cap may appear as a monolithic rectangle with no apparent division between them). See Figure 12.4-1.

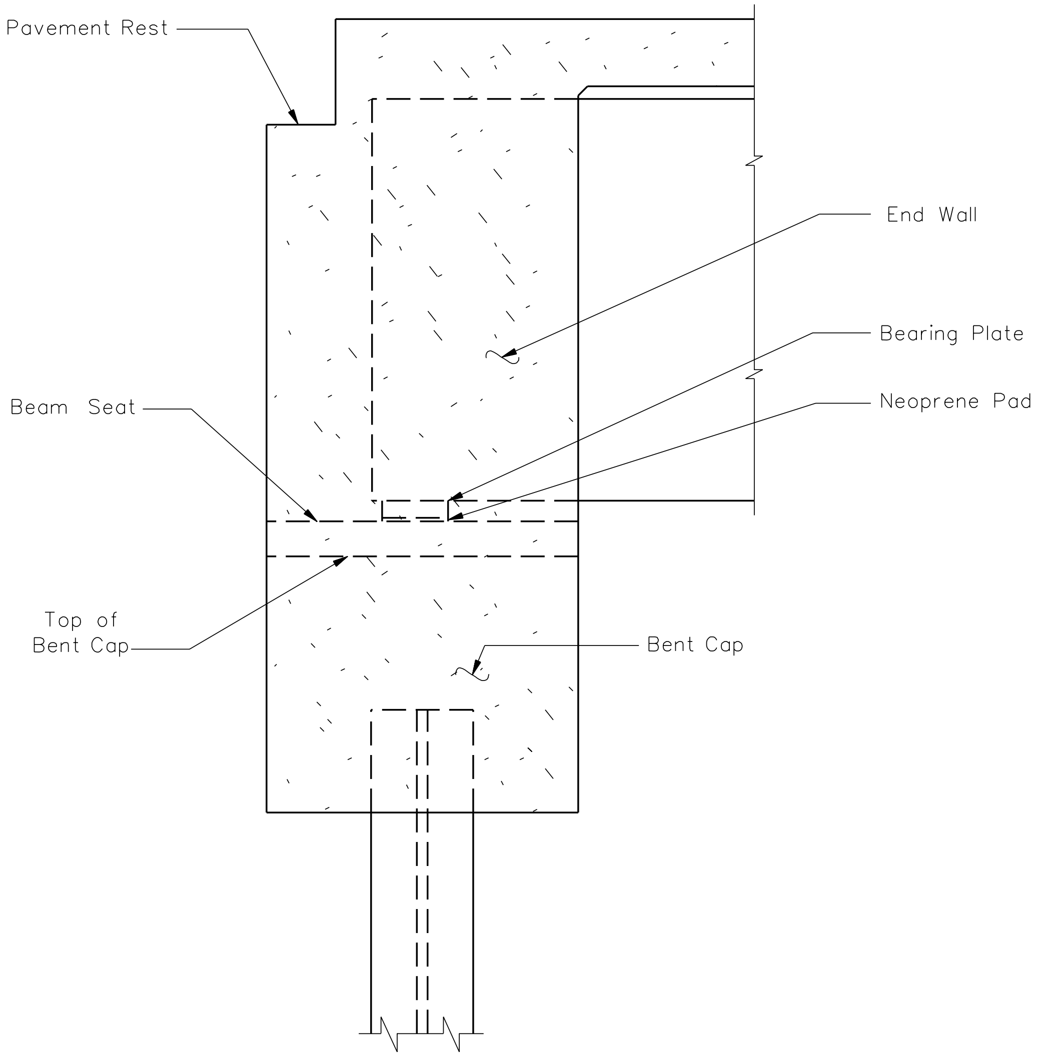
2. Semi-Integral End Bent. Flexible end bent with the bridge deck cast monolithically with the end wall but with a bearing under the beam and a bond-breaker between the end wall and bent cap to facilitate construction and subsequent maintenance. See Figure 12.4-2.

3. Free-Standing End Bent. Rigid end bent with a joint between the bridge deck and the backwall. See Figure 12.4-3.

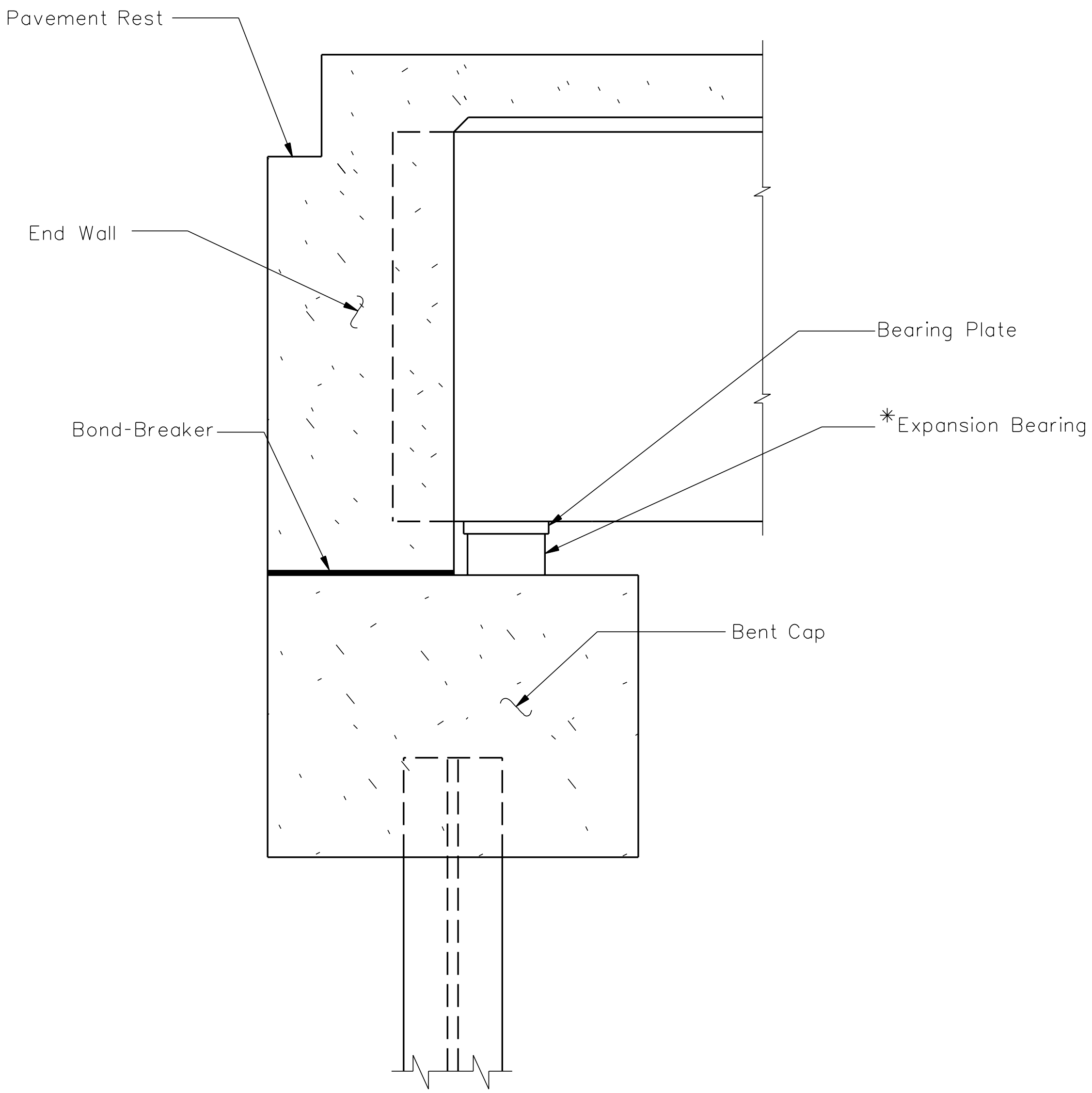
End bents shall consist of a cast-in-place, reinforced concrete cap founded on drilled shafts, piles or, on rare occasions, spread footings. End bents on piles or shafts may use MSE walls to retain the approach fill.

A jointless flexible end bent, either integral or semi-integral, is preferred. Free-standing rigid end bents shall be used where the anticipated translational movements of the piles are too great, or excessive settlement of the bent is anticipated. The force effects of these displacements shall be included in the design.

End bents are strongly impacted by the bridge geometry and site conditions; therefore, they may be designed in an infinite variety of shapes and sizes. If the wing walls are excessively large, the wing walls may be directly supported by piles or footings.

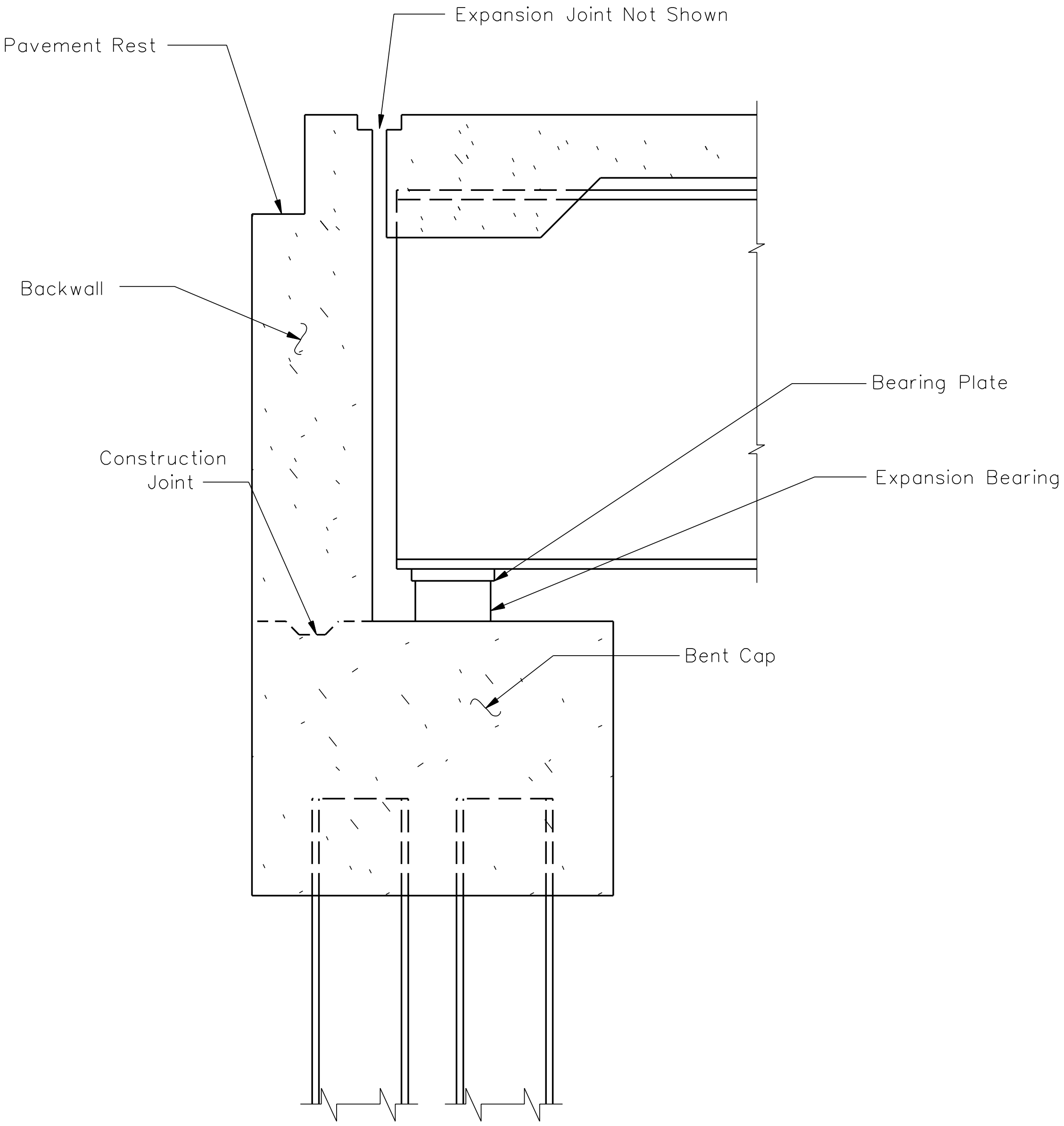


TYPICAL INTEGRAL END BENT
Figure 12.4-1



∗ Note: If elastomeric bearings are used, the bond breaker shall be designed to ensure that the load path will be through the bearing and not through the end wall.

TYPICAL SEMI-INTEGRAL END BENT
Figure 12.4-2



TYPICAL FREE-STANDING END BENT
(Shown for Steel Girder)

Figure 12.4-3

12.4.2.3 Integral End Bents

Formerly, bridges were designed with expansion joints and other structural releases that allowed the superstructure to expand and contract relatively freely with changing temperatures, time-dependent effects of creep and shrinkage, and other geometric effects. Integral end bents eliminate expansion joints in the bridge decks, which reduces both the initial construction costs and subsequent maintenance costs. Therefore, an integral end bent is the first choice of the Department in selecting an end bent type.

Integral end bents are those where the superstructure is extended directly into the end bent end wall. There is no expansion joint in the bridge deck, and the end wall is rigidly connected to the pile cap. Integral end bents require flexible foundation elements to allow superstructure rotation and thermal motion. Typically, a single row of piles will provide the required flexibility, but drilled shafts or spread footings will not.

There can be no settlement in the piles because the superstructure cannot be raised for maintenance. If there is a possibility of settlement, consider a semi-integral end bent.

Integral end bents are effective in accommodating horizontal seismic forces. Minimum beam seat width requirements are not investigated for integral end bent bridges.

12.4.2.4 Semi-Integral End Bents

The semi-integral end bent is SCDOT's second choice for end bents, and it is typically used where settlement is possible. Semi-integral end bents are similar to integral end bents except that there is a bond-breaker between the end wall and the bent cap and the beams rest on a bearing. Expansion bearings can be used to reduce translation in the substructure. The bond-breaker between the end wall and the cap allows the superstructure to be raised if needed.

With the semi-integral end bent, transverse and longitudinal superstructure forces are transmitted to the substructure through anchor bolts or other means that allow rotation. Typically, the end wall and wing walls are cast around the girder ends, attached to the slab, and isolated from the bent cap. When parallel wing walls are used, the wings can either be monolithic with the end wall and isolated from the bent cap or attached to the bent cap with the end wall left free to rotate.

12.4.2.5 Free-Standing End Bents

Free-standing end bents usually consist of a bent cap, which supports the superstructure by bearings, and a backwall that retains the embankment fill in the longitudinal direction of the bridge and may support the end of the approach slab. Wing walls are usually needed to retain the fill in the transverse direction. Continuity of the riding surface between the end bent and the superstructure is provided by a deck joint.

Use free-standing end bents where integral and semi-integral end bents cannot accommodate the magnitude of the longitudinal movements. Free-standing end bents can be supported on piles, drilled shafts, or spread footings.

For restricted geometry, deep superstructures, or large relative longitudinal movements between the superstructure and the substructure, the free-standing end bent may be the only feasible alternative. Free-standing end bents are, however, generally expensive to construct. For small bridges, construction costs could be out-of-proportion with respect to other components of the bridge. With large end bents, located close to the edge of roadway or waterway below, superstructure spans can be reduced. Large end bents, however, may result in poor aesthetics of the bridge and may impair visibility at overpasses.

12.4.2.6 End Bents Using MSE Walls

Mechanically stabilized earth (MSE) walls may be used to retain approach embankment fills for end bents supported on piles or drilled shafts. This use of MSE walls must be decided during the preparation of the Conceptual Bridge Plans. End bents using MSE walls are an acceptable strategy to reduce right-of-way, utility, and environmental impacts. End bents using MSE walls may be used to reduce bridge lengths when a detailed geotechnical study indicates that the use of MSE walls is the most effective and economical solution.

Do not use spread footings to support end bents at MSE walls. An absolute minimum distance of 3 ft shall be maintained on the fill side between the inside face of the MSE wall and the face of the piling. The wall shall be detailed to provide sufficient compressible material between the end bent cap and the wall to accommodate movements.

12.4.3 Interior Bents

Reference: LRFD Article 11.7

12.4.3.1 General Usage

The following summarizes SCDOT typical practice for the type selection of interior bents (termed “piers” in the *LRFD Specifications*) for bridges based on the type of crossing:

1. Water Crossings. If lateral forces, considering scour, do not exceed the lateral design capacity of the bent, a pile bent is the preferred selection for the interior bents for spans less than 50 ft in length. Otherwise, use multi-column bents with caps or single-column bents with hammerhead caps.

2. Highway Crossings. Use multi-column bents with caps or single-column bents with hammerhead caps.

3. Railroad Crossings. Use multi-column bents with caps or single-column bents with hammerhead caps and crash walls, if crash walls are required by railroad clearance policies. See Chapter 22.

The following sections briefly describe the interior bents used by SCDOT. Figure 12.4-4 provides schematics in the plan and elevation views of the interior bents in combination with typical foundation types. For superstructures consisting of girders, interior bent caps may be made integral with the superstructure when necessary to provide the proper clearances.

12.4.3.2 Multi-Column Bents

Concrete multi-column bents are the Department's first choice for interior bents to support steel and prestressed concrete girder superstructures, and are strongly preferred in areas having high seismic demands. Columns shall have circular cross sections, unless a circular column cannot be designed for the required loading. In this case, an oblong cross section shall be used with specific requirements with respect to column reinforcement to sustain seismic loadings; see the *SCDOT Seismic Design Specifications for Highway Bridges***.** Multi-column bents are generally applicable to bridge span lengths that exceed 50 ft, but their selection is sometimes the best even for shorter span lengths.

Figures 12.4-4(a), 12.4-4(b), and 12.4-4(c) illustrate the most common types of multi-column bents, founded on either piles, drilled shafts, or spread footings. The bents consist of vertical columns and a cap beam.

12.4.3.3 Single-Column Bents

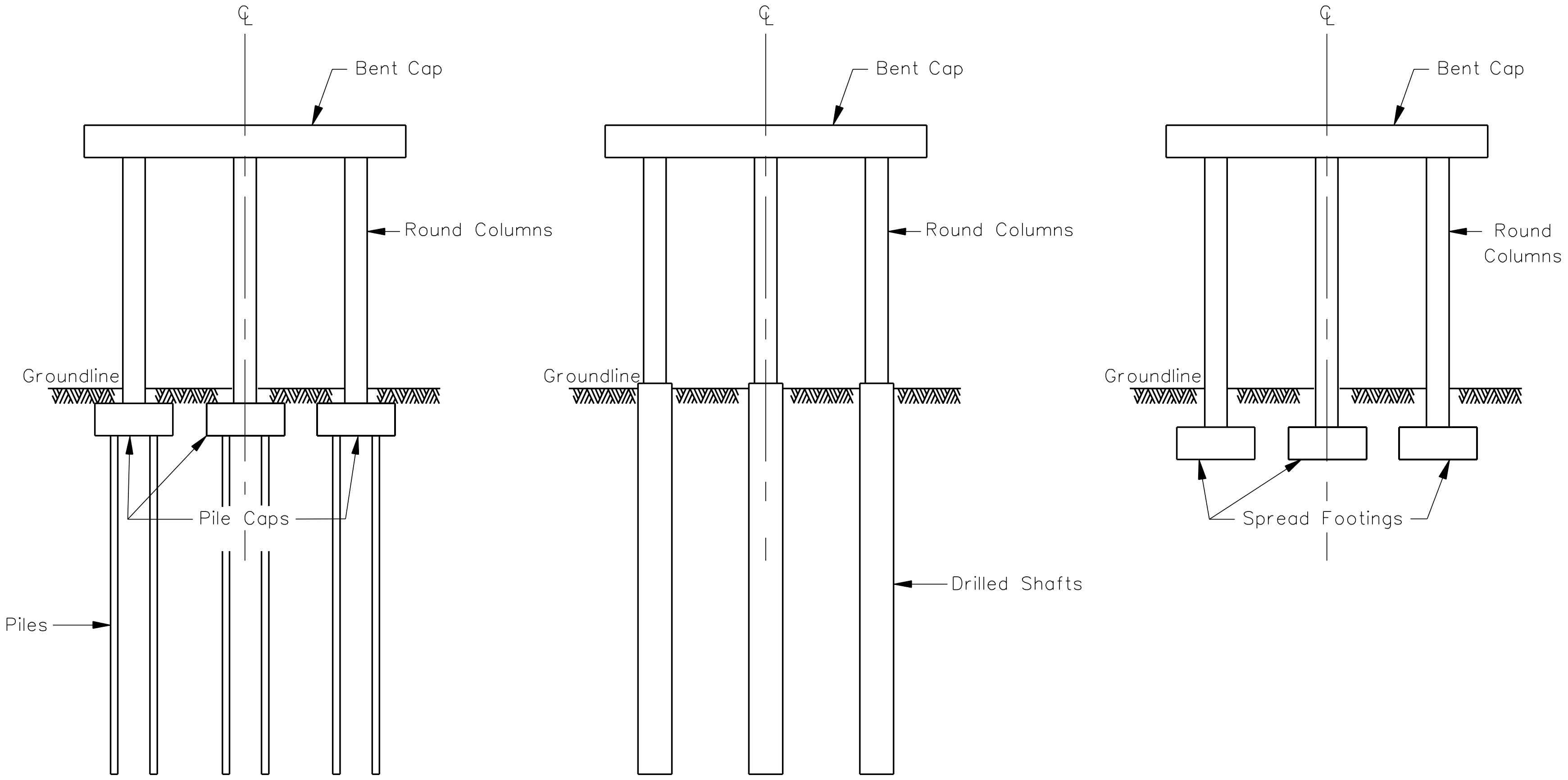
A single-column bent with a hammerhead cap may be preferred for the following applications:

- Aesthetics are important.
- The bridge is narrow.
- A stream is prone to debris.

The use of a single-column bent should be carefully evaluated in areas having high seismic demands.

Columns shall have circular cross sections, unless a circular column cannot be designed for the required loading. In this case, an oblong cross section shall be used.

Figures 12.4-4(d) and 12.4-4(e) illustrate a typical single-column bent supported on either piles or a drilled shaft.

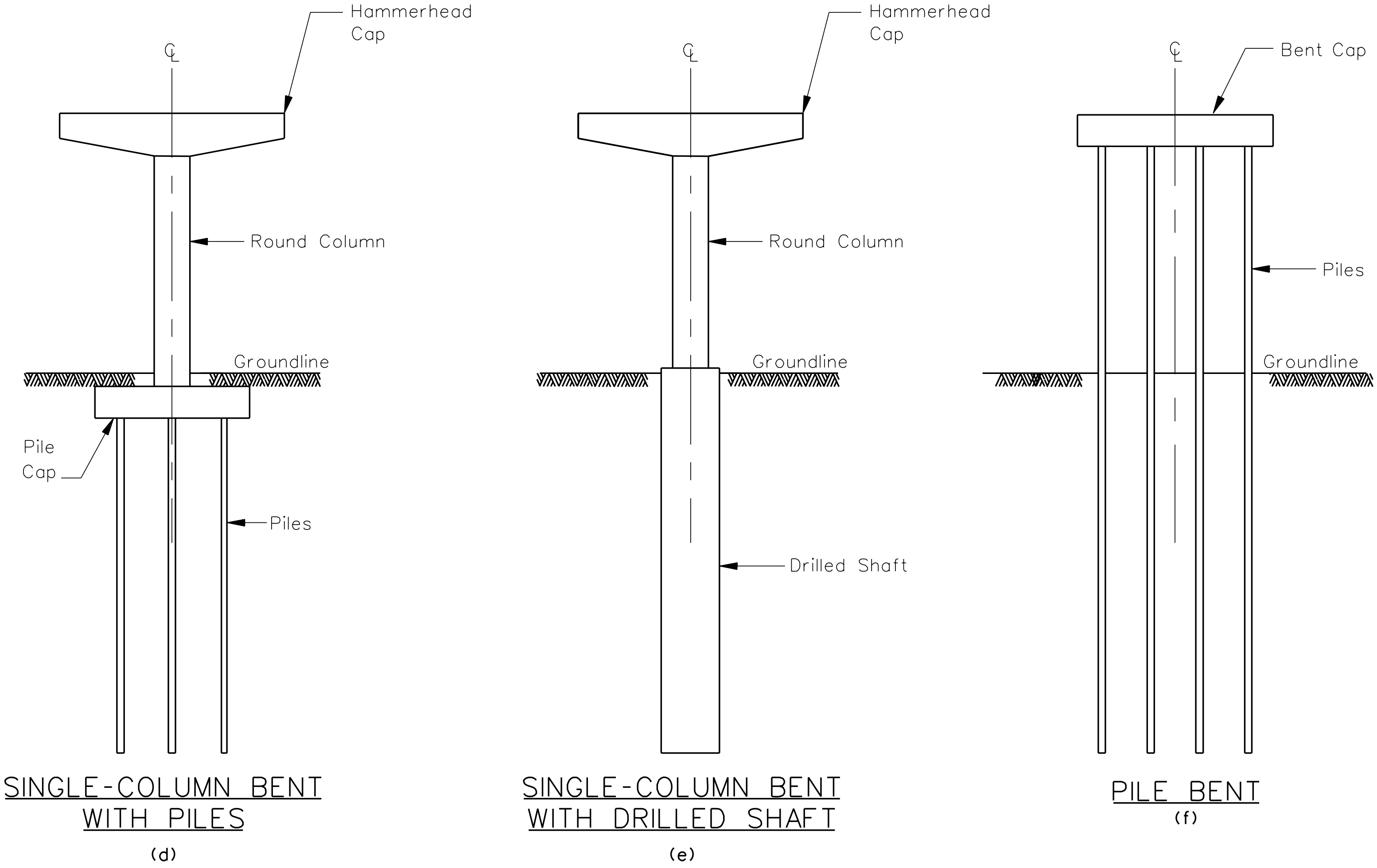


MULTI-COLUMN BENT WITH PILES
(a)

MULTI-COLUMN BENT WITH DRILLED SHAFTS
(b)

MULTI-COLUMN BENT WITH SPREAD FOOTINGS
(c)

TYPICAL INTERIOR BENTS
(In Combination with Typical Foundation Types)
Figure 12.4-4



SINGLE-COLUMN BENT WITH PILES
(d)

SINGLE-COLUMN BENT WITH DRILLED SHAFT
(e)

PILE BENT
(f)

TYPICAL INTERIOR BENTS
(In Combination with Typical Foundation Types)
Figure 12.4-4
(Continued)

12.4.3.4 Pile Bents

Under certain conditions, the economy of substructures can be enhanced by extending the deep foundation above ground level to the superstructure. Pile bents shall not be used where large horizontal forces may develop due to collision by vehicles, or stream flow intensified by accumulated debris, or where large displacements are anticipated during a seismic event. A typical application of a pile bent is over shallow water where pile driving is allowed and where span lengths are less than 50 ft. Pile bents also result in minimal environmental impacts.

The extended piles always need a cap-beam for structural soundness. Figure 12.4-4(f) illustrates a typical pile bent.

12.5 FOUNDATIONS

12.5.1 Selection of Foundation Type

The selection of the foundation type is a collaborative effort between the bridge designer, the geotechnical design engineer, and (for bridges over waterways) the hydraulics engineer based on the Preliminary Geotechnical Report and/or the Hydraulic Report/Scour Report.

Typically, the selection of a foundation type is based on the foundation investigation, loads on the structure, and the engineering judgment of the Geotechnical Design Section. The bridge designer provides the geotechnical engineer with the applicable loads (axial and lateral) with a proposed foundation type. The evaluation includes examining the test boring data, the existing ground lines, whether or not the proposed foundation is below, at, or above the existing ground line, and hydraulic considerations such as scour depth. The geotechnical design engineer reviews the load data and recommends the type of foundation in coordination with the seismic engineer. The information for selection of a foundation type should include the following:

- logs of subsurface investigation; and
- plan and elevation showing proposed foundations, existing and proposed finished grade lines, and future ultimate sections.

See Section 19.1 for more discussion on the necessary coordination with the Geotechnical Design Section to determine the type of foundation. See Section 4.2 for a discussion on coordination with the Hydraulic Engineering Section.

12.5.2 Impact on Superstructure Type

The detailed foundation study is typically performed after the superstructure selection. Therefore, the designer must anticipate the nature of the foundation characteristics in the analysis. The following should be considered:

1. Number of Supports. The expected foundation conditions will partially determine the number of and spacing of the necessary substructure supports. This will have a significant impact on the acceptable span lengths.
2. Dead Load. When foundation conditions are generally poor, the economics of using structural steel and lightweight concrete over normal concrete should be considered.
3. Scour. The geologic or historic scour may have a significant impact on the foundation design which may, in turn, have a significant impact on the superstructure type selection.

12.5.3 Usage

The following summarizes SCDOT typical practices for the selection of the foundation type. Figure 12.4-4 illustrates the basic types of foundations used by SCDOT. See Chapter 19 for SCDOT design practices for foundations.

12.5.3.1 Piles

Reference: LRFD Article 10.7

A pile is a long, slender deep foundation element driven into the ground with power hammers. The bridge designer should consider the following in the selection of piles:

- Pile bents are generally applicable to span lengths up to 50 ft.
- For longer spans and at-grade separations, a footing supported on piles is used.
- Exposed steel piles shall not be used in standing water or marsh.

If underlying soils cannot provide adequate bearing capacity or tolerable settlements for spread footings, piles may be used to transfer loads to deeper suitable strata through friction and/or end bearing. The selected type of pile is determined by the required bearing capacity, length, soil conditions, and economic considerations. SCDOT typically uses steel pipe piles, steel H-piles, prestressed concrete piles, or a combination pile-prestressed concrete pile with a steel pile extension. Figure 19.2-1 provides a guide to the selection of pile type**.**

12.5.3.2 Drilled Shafts

Reference: LRFD Article 10.8

A drilled shaft is a deep-foundation element constructed by excavating a hole with auger equipment and placing concrete, with reinforcing steel, into the excavation. Casing and/or drilling slurry may be necessary to keep the excavation stable. Drilled shafts should be considered where conditions do not exist that permit the use of spread footings or piles. Drilled shafts should be considered to resist large lateral or uplift loads where deformation tolerances are relatively small. Also, use drilled shafts where significant scour is expected, where there are limitations on water crossing work, or where piles are not economically viable due to high loads or obstructions to driving. Limitations on pile-driving vibration and/or noise may also dictate the use of drilled shafts.

The following also applies to the use of drilled shafts:

- Drilled shafts are typically good for seismic applications.
- Drilled shafts are generally applicable to span lengths greater than 50 ft.

12.5.3.3 Spread Footings

Reference: LRFD Article 10.6

SCDOT rarely uses spread footings. Spread footings are not allowed at stream crossings where they may be susceptible to scour; they are not allowed as a foundation for end bents at MSE walls; and they are not allowed on fills. The use of spread footings requires firm bearing conditions; competent material must be near the ground surface.

A spread footing is a shallow foundation consisting of a reinforced concrete member that bears directly on the founding stratum. A spread footing's geometry is determined by structural requirements and the characteristics of supporting components, such as soil or rock. The primary role of spread footings is to distribute the loads transmitted by interior bents or end bents to suitable soil strata or rock at relatively shallow depths (less than 10 ft).

Settlement criteria need to be consistent with the function and type of structure, anticipated service life, and consequences of unanticipated movements on service performance. Angular distortions between adjacent spread footings greater than 0.008 radians in simple spans and 0.004 radians in continuous spans should not be ordinarily permitted.

12.6 ROADWAY DESIGN ELEMENTS

The *SCDOT Highway Design Manual* documents SCDOT's roadway design criteria. In general, the road design criteria will determine the proper geometric design of the roadway. The bridge design will accommodate the roadway design across any structures within the project limits. This will provide full continuity of the roadway section for the entire project. This process will, of course, require proper communication between the bridge designer and road designer to identify and resolve any inconsistencies. This Section provides roadway design information that is directly relevant to determining the structural dimensions for bridge design and to provide the bridge designer with some background in road design elements.

12.6.1 Roadway Cross Section (Bridges)

This Section presents criteria for the roadway cross section across bridges based on the type of highway. Section 12.6.4 presents several typical bridge sections.

12.6.1.1 *SCDOT Highway Design Manual*

Chapter 13 "Cross Section Elements" and Part III "Design of Functional Classes" of the *SCDOT Highway Design Manual* provide Department criteria for the various cross section elements for the roadway. This includes lane and shoulder widths, cross slopes, auxiliary lanes, parking lanes, medians, side slopes, and sidewalks. This Section of the *SCDOT Bridge Design Manual* provides Department criteria for roadway cross section elements specifically across bridges.

12.6.1.2 Point of Grade/Profile Grade Line

The location of the point of grade (which is in the cross section view) and the profile grade line (which is in the elevation view) on the bridge must match those on the approaching roadway. The point of grade location varies according to the type of highway and type of median. See Section 12.2 of the *SCDOT Highway Design Manual* for SCDOT criteria.

12.6.1.3 Cross Slope

Bridges on tangent sections typically provide a uniform cross slope of 48H:1V (2.08%) from the crown line to the edge of the deck. Typically, the cross slope of the shoulder (and sometimes one or more of the travel lanes) on the approaching roadway is steeper than 2.08%; therefore, the roadway must be transitioned to a uniform 2.08% slope before it reaches the bridge; this is the responsibility of the road designer when designing the roadway approaches.

On a case-by-case basis, the bridge designer may consider exceptions to the use of a uniform 2.08% cross slope on the tangent sections, including:

1. If the bridge cross section includes a third travel lane away from the crown, the cross slope of this lane may be steepened to 36H:1V (2.78%). This enhances drainage of the bridge deck.

2. A general concern for bridge deck drainage may indicate the desirability of using a cross slope steeper than 2.08%. See Chapter 18.

12.6.1.4 Bridge Roadway Widths

In general, bridge widths should match the approach roadway widths (traveled way plus shoulders). Figure 12.6-1 provides guidelines for bridge widths. However, in determining the width for major water crossings, consider the cost of the structure, traffic volumes, and potential for future width requirements.

Approach Roadway	Conditions	Bridge Width (Gutter to Gutter)
Urban Streets (Curb and Gutter)	With or without concrete sidewalk.	Provide a sidewalk on bridge matching roadway gutter hinge points with bridge gutter hinge points.
Freeways and Arterials	12-ft shoulder (10 ft paved + 2 ft unpaved).	Use 12-ft shoulder hinge point for bridge gutter line.
	10-ft shoulder (paved and unpaved).	Use 10-ft shoulder hinge point for bridge gutter line.
	10-ft shoulder (6 ft paved + 4 ft unpaved).	Use 10-ft shoulder hinge point for bridge gutter line on inside of divided highways.
	10-ft shoulder (4 ft paved + 6 ft unpaved).	
Rural Collectors and Local Roads	6- to 8- ft shoulders (2 ft paved + 4 to 6 ft unpaved) with paved roadway.	Use shoulder hinge point for bridge gutter line. Bridge width is equal to width of roadway section (outside shoulder to outside shoulder).
Ramps	In direction of traffic (left) 10-ft shoulder (4 ft paved + 6 ft unpaved).	Use 10-ft shoulder hinge point for bridge gutter line.
	In direction of traffic (right) 10-ft shoulder (6 ft paved + 4 ft unpaved).	Use 10-ft shoulder hinge point for bridge gutter line.

GUIDELINES FOR BRIDGE ROADWAY WIDTHS

Figure 12.6-1

12.6.1.5 Sidewalks

12.6.1.5.1 Warrants

In general, include sidewalks on all bridges if there is curb and gutter on the roadway approach. Sidewalk requirements for each side of the bridge will be evaluated individually; i.e., placing a sidewalk on each side will be based on the specific characteristics of that side. However, typical Department practice is to place a sidewalk on both sides of the bridge.

12.6.1.5.2 Cross Section

The typical sidewalk width is 5′-6″ as measured from the gutter line to the back of the sidewalk; i.e., this width includes the width of curb. The maximum cross slope on the sidewalk is 2% sloped towards the roadway.

12.6.1.6 Bicycle Accommodations

The bicycle is classified as a vehicle according to South Carolina law, and bicyclists are granted all of the rights and are subject to all of the duties applicable to the driver of any other vehicle. Engineering Directive Memorandum 22 discusses considerations for bicycle accommodation on SCDOT projects.

A bridge may need to be configured to accommodate bicycle traffic. This must be coordinated with the Road Design Section, which will refer to EDM 22 for bicycle accommodation. In general, the bicycle accommodation on the approaching roadway will be carried across the bridge. The preferred accommodation is to provide a shoulder wide enough to accommodate bicycles. Although a 4-ft wide shoulder is considered adequate for bicycle traffic on the roadway, this needs to be increased by 1 ft to provide a shy distance where barriers are present. Therefore, a 5-ft wide shoulder is considered the minimum shoulder width for bridges that are designed to carry bicycle traffic. In addition, on bridges, a minimum of 4 ft from the edge of travel lane should be clear of drainage inlets.

On the approaching roadway, bike lanes will have a cross slope of 24H:1V (4.16%). On bridges, this cross slope will be transitioned to 48H:1V (2.08%).

If the approaching roadway includes a separate bicycle lane, then the width of the lane will be carried across the bridge. Requests for and accommodation for anticipated future bicycle lanes are only warranted when they are part of SCDOT long-range plans.

12.6.1.7 Medians

For multi-lane facilities, the bridge designer must decide if one structure will be used for the entire roadway section (including the median) or if dual structures will be used. In general, a single structure will be used for roadways with a flush or raised median, and dual structures will be used for roadways with a depressed median. Where dual structures are used, the minimum distance between the backs of the two bridge rails is 8 in to allow for slip forming the two barriers. See Section 13.4 of the *SCDOT Highway Design Manual* for more information on medians.

12.6.2 Alignment at Bridges

12.6.2.1 Horizontal Alignment

The road designer will determine the horizontal alignment at the bridge based on Chapter 11 of the *SCDOT Highway Design Manual* (e.g., curve radius, superelevation transition). From the perspective of the roadway user, a bridge is an integral part of the roadway system and, ideally, horizontal curves and their transitions will be located irrespective of their impact on bridges. However, practical factors in bridge design and bridge construction warrant consideration in the location of horizontal curves at bridges. The following presents, in order from the most desirable to the least desirable, the application of horizontal curves to bridges:

1. Considering both the complexity of design and construction difficulty, the most desirable treatment is to locate the bridge and its approach slabs on a tangent section; i.e., no portion of the curve or its superelevation development will be on the bridge or bridge approach slabs.

2. If a horizontal curve is located on a bridge, the superelevation transition should not be located on the bridge or its approach slabs. This will result in a uniform cross slope (i.e., the design superelevation rate) throughout the length of the bridge and bridge approach slabs.

3. If the superelevation transition is located on the bridge or its approach slabs, the designer should place on the roadway approach that portion of the superelevation development that transitions the roadway cross section from its normal crown to a point where the roadway slopes uniformly; i.e., to a point where the crown has been removed. This will avoid the need to warp the crown on the bridge or the bridge approach slabs.

4. As a worst case, place the superelevation transition angle points at the centerline of the bents.

Specifically for maximum superelevation rates, Section 11.3 of the *SCDOT Highway Design Manual* discusses the Department’s e_{max} criteria. As illustrated in Figure 11.3A, e_{max} will vary between 4% and 8% depending on the type of facility, the urban/rural location, and the design speed.

12.6.2.2 Vertical Alignment

The bridge designer and road designer will coordinate on the vertical alignment of the roadway across a bridge. Chapter 12 of the *SCDOT Highway Design Manual* provides the Department's criteria. The following applies specifically to the vertical alignment at bridges:

1. Minimum Gradient. The minimum longitudinal gradient should be limited to 0.3%. Flatter gradients will require approval from the State Bridge Design Engineer.

2. Maximum Grades. See Chapters 19 through 22 of the *SCDOT Highway Design Manual* for the Department's maximum grade criteria based on the highway type, design speed, and rural/urban location.

3. Vertical Curves. Crest and sag vertical curves will be designed according to Section 12.5 of the *SCDOT Highway Design Manual*. If practical, no portion of a bridge should be located in a sag vertical curve. If the bridge is located in a sag vertical curve, the low point of the sag should not be located on the bridge or the approach slab. See Section 18.2 for additional requirements on bridges in sag vertical curves with respect to bridge deck drainage.

12.6.2.3 Skew

Skew is defined by the angle between the end line of the deck and the normal drawn to the longitudinal centerline of the bridge at that point. Typically, the bridge skew is determined by the roadway alignment and the bridge is designed to accommodate the skew. The impacts of skew on structural design are discussed at their respective locations throughout the *SCDOT Bridge Design Manual*. In general, skew angles of more than 30° will affect the design of structural elements.

12.6.3 Underpasses

For bridges over highways, the design of the underpassing roadway will determine the length of the overpassing bridge. Section 12.6.4 presents typical sections for bridge underpasses. See Chapter 22 for railroads underpassing a highway bridge.

12.6.3.1 Roadway Cross Section

The approaching roadway cross section, including any auxiliary lanes, should be carried through the underpass. Desirably, include the clear zone width for each side through the underpass. It is important to consider the potential for further development or traffic increases in the vicinity of the underpass that may significantly increase traffic or pedestrian volumes. If appropriate, an allowance for future widening may be provided to allow for sufficient lateral clearance for one additional lane in each direction. The need for accommodating future travel lanes will be made on a case-by-case basis. See the *SCDOT Standard Drawings for Road Construction* for more information on roadway underpasses.

12.6.3.2 Vertical Clearances

The vertical clearance for underpassing roadways will significantly impact the vertical location of the overpassing structure and may dictate the selection of the superstructure type. Chapters 19 through 22 of the *SCDOT Highway Design Manual* present the Department's vertical clearance criteria for underpassing roadways based on type of highway and rural/urban location. These criteria are summarized in Figure 12.6-2.

12.6.4 Typical Sections

This Section presents the following typical section figures for bridges and underpasses:

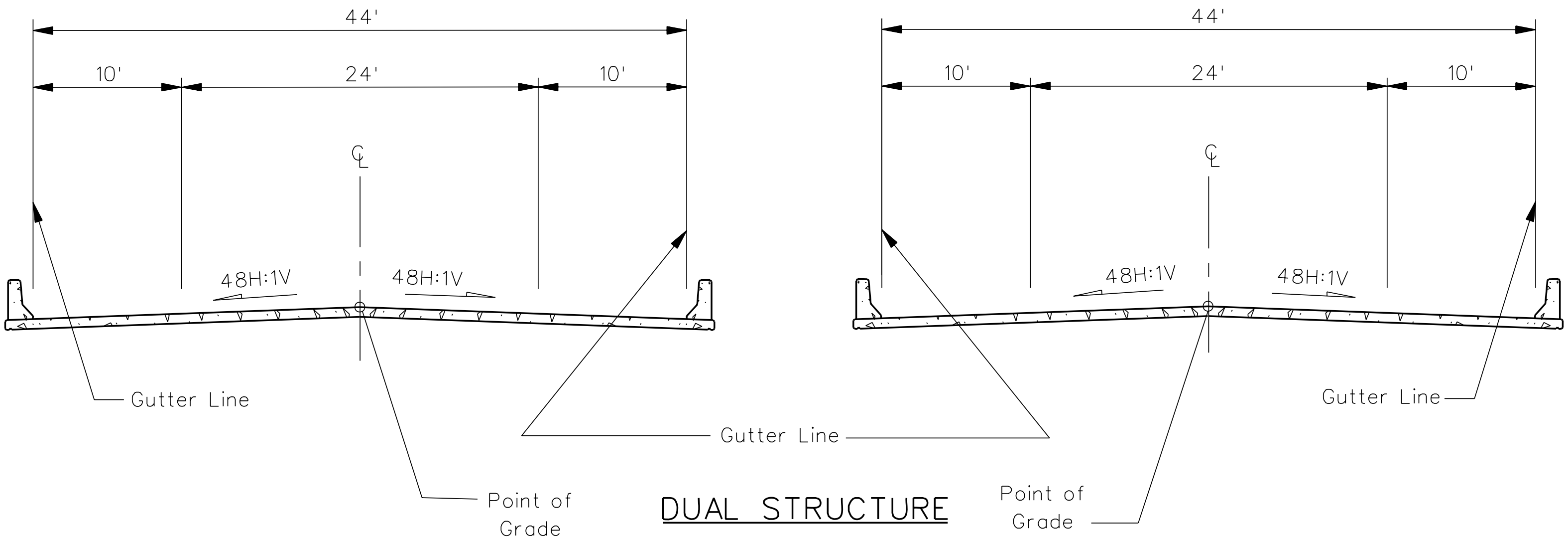
- Figure 12.6-3 "Bridge Cross Section (Four-Lane Divided Facility)."
- Figure 12.6-4 "Bridge Cross Section (Six-Lane Divided Facility)."
- Figure 12.6-5 "Bridge Cross Section (Rural Two-Lane Highway)."
- Figure 12.6-6 "Bridge Cross Section (Multi-Lane Facility with Flush Median)."
- Figure 12.6-7 "Bridge Cross Section (Urban Facility with Sidewalks)."
- Figure 12.6-8 "Multi-Lane Divided Highway Underpass."
- Figure 12.6-9 "Two-Lane Highway Underpass."

Facility	**Structure**	**Clearance**
Freeway Under	New/Replaced Overpassing Bridges	17′-0″
	Existing Overpassing Bridges	16′-0″
	Pedestrian Bridges	18′-0″
Arterial Under	New/Replaced Overpassing Bridges	17′-0″
	Existing Overpassing Bridges	16′-0″
	Pedestrian Bridges	18′-0″
Collector Under	New/Replaced Overpassing Bridges	16′-0″
	Existing Overpassing Bridges	16′-0″
	Pedestrian Bridges	18′-0″
Secondary and State “C” Roads	New/Replaced Overpassing Bridges	16′-0″
	Existing Overpassing Bridges	14′-0″
	Pedestrian Bridges	17′-0″
All Facilities Over	Railroads	* 23′-0″
	Lakes and Reservoirs	8′-0″
	Navigable Water	Contact Coast Guard

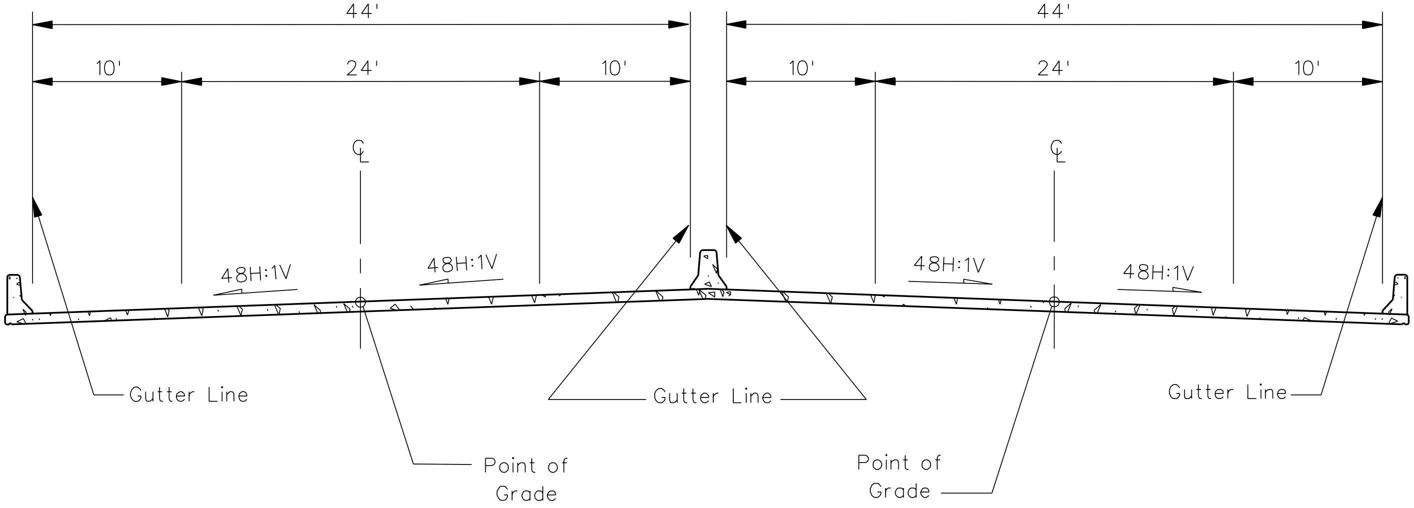
***For widenings, maintain existing clearance.**

MINIMUM VERTICAL CLEARANCES

Figure 12.6-2



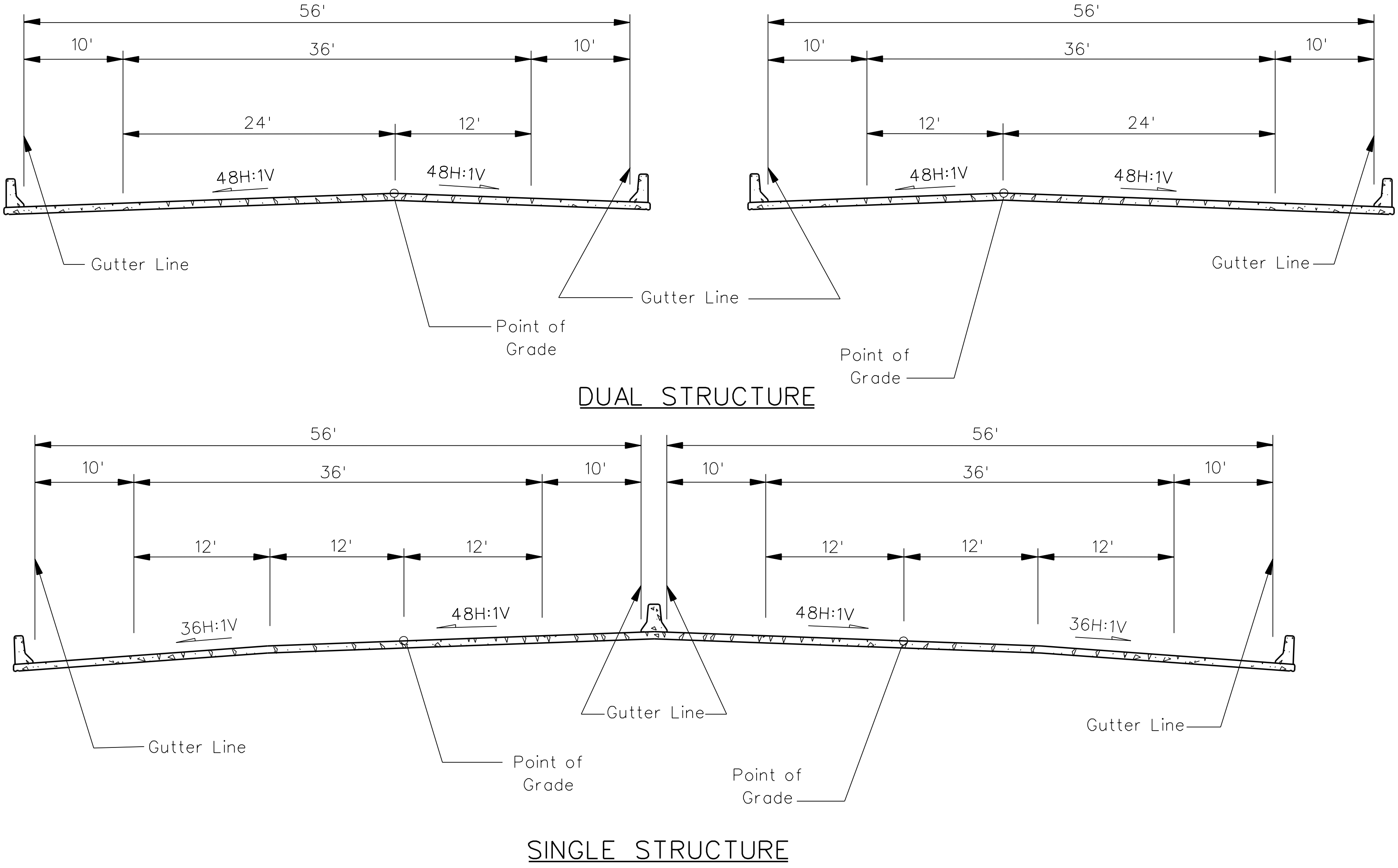
<u>DUAL STRUCTURE</u>



<u>SINGLE STRUCTURE</u>

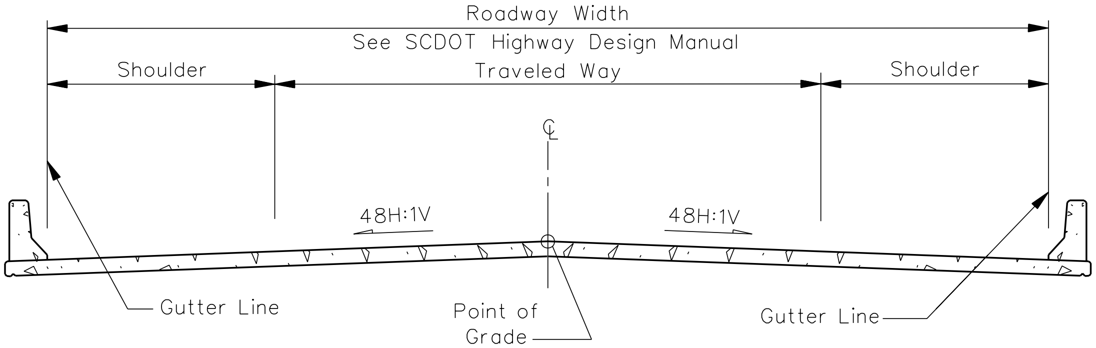
BRIDGE CROSS SECTION
(Four-Lane Divided Facility)

Figure 12.6-3



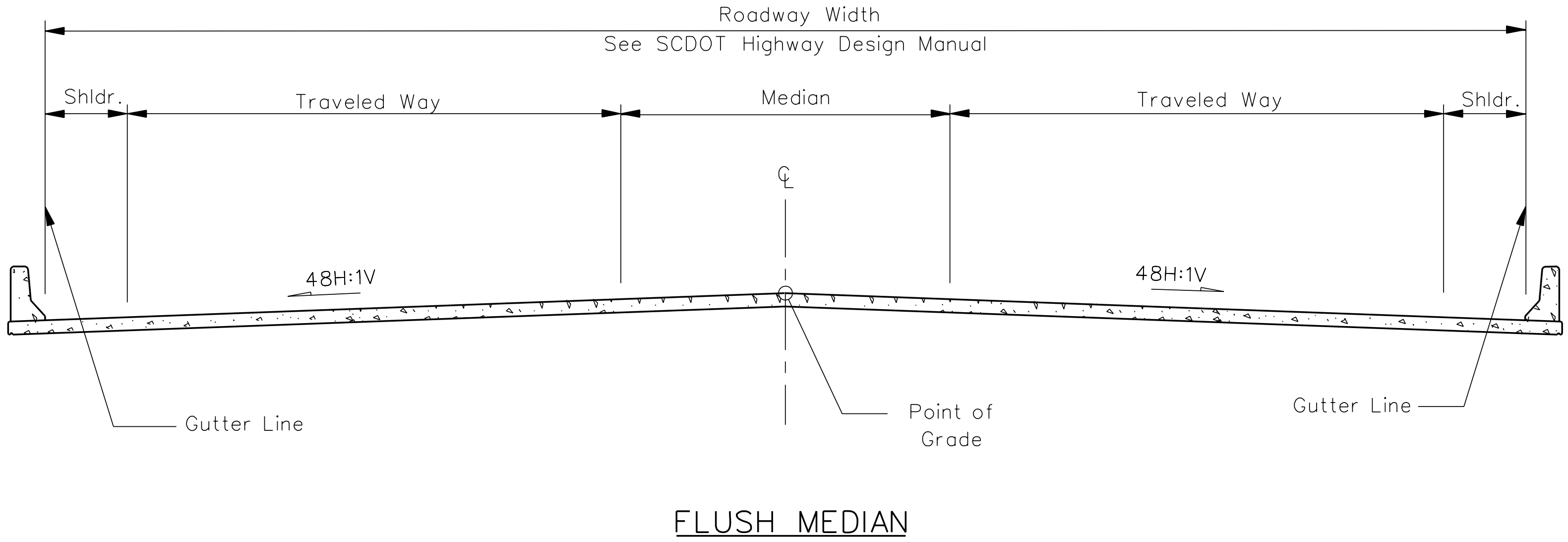
BRIDGE CROSS SECTION
(Six-Lane Divided Facility)

Figure 12.6-4



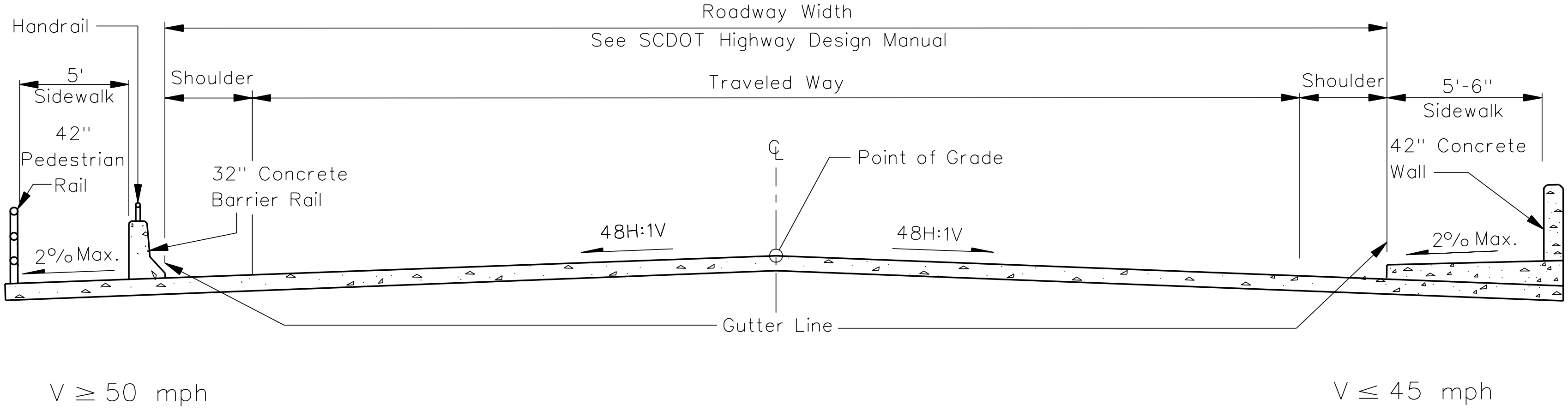
BRIDGE CROSS SECTION
(Rural Two-Lane Highway)

Figure 12.6-5



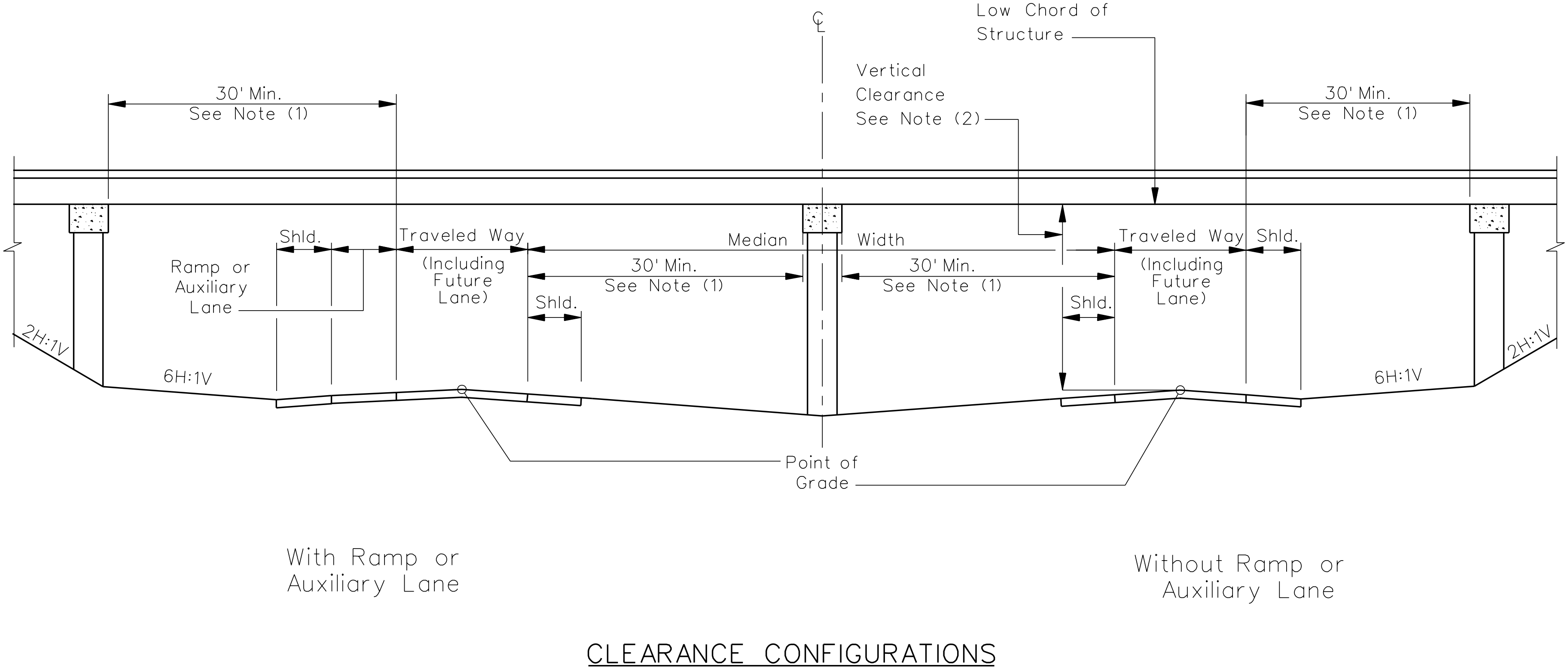
BRIDGE CROSS SECTION
(Multi-Lane Facility with Flush Median)

Figure 12.6-6



BRIDGE CROSS SECTION
(Urban Facility with Sidewalks)

Figure 12.6-7

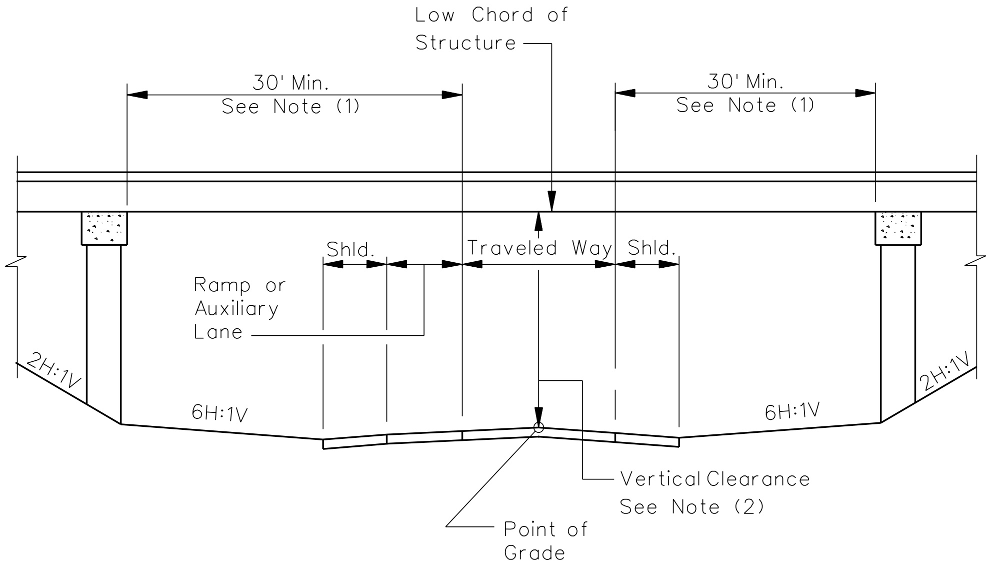


Notes:

1. *See Section 14.3 of the SCDOT Highway Design Manual. Where the 30-ft minimum cannot be provided, a roadside barrier must be provided.*
2. *Locate the minimum clearance point over the entire roadway section.*
3. *Locate the interior bent in the median, if required, at the median centerline.*

MULTI-LANE DIVIDED HIGHWAY UNDERPASS

Figure 12.6-8



CLEARANCE CONFIGURATIONS

Notes:

1. *See Section 14.3 of the SCDOT Highway Design Manual. Where the 30-ft minimum cannot be provided, a roadside barrier must be provided.*
2. *Locate the minimum clearance point over the entire roadway section.*

TWO-LANE HIGHWAY UNDERPASS

Figure 12.6-9

12.7 GENERAL EVALUATION FACTORS

This Section provides a brief summary of several evaluation factors not related to structural design that will impact the selected structural system and its dimensions.

12.7.1 Aesthetics

Reference: LRFD Article 2.5.5

Structures should be aesthetically pleasing to the traveling public. The *LRFD Specifications* emphasizes and SCDOT encourages the objective of improving the appearance of highway bridges in the State. The Department promotes uninterrupted lines, contours that follow the load paths, and the avoidance of cluttered appearances. The provisions on aesthetics have been prompted because many bridges have been exclusively selected and designed on the basis of construction cost and/or engineering simplicity without regard for their appearance and for their compatibility with the environment.

Any bridge design must integrate three basic elements: efficiency, economy, and appearance. Regardless of size and location, the quality of the structure, its aesthetic attributes, and the resulting impact on its surroundings must be carefully considered. Achieving the desired results involves:

- full integration of the three basic elements listed above, and
- the designer accepting the challenge and opportunity presented.

A successful bridge design will then be aesthetically pleasing in and of itself and will be compatible with the site by proper attention to form, shapes, and proportions. Attention to detail is of primary importance in achieving a continuity of line and form. In general, the rule "form following function" shall be used. In other words, the shape of the structure is not chosen merely for aesthetic reasons but also considering the load paths from the points of application to the points of support. The designer must consider the totality of the structure and its individual components and the environment of its surroundings. A disregard for continuity or lack of attention to detail can negate the best intent. The following references provide excellent guidance:

1. Billington, D.P., *The Tower and the Bridge*, 306 pp., Basic Books, New York, New York, 1983.

2. Leonahardt, F., *Bridges: Aesthetics and Design*, 308 pp., Deutsche Verlags-Anstalt (MIT Press, Cambridge, Massachusetts), 1982.

3. Stewart C. Watson and M. K. Hurd, *Esthetics in Concrete Bridge Design*, 331 pp., Library of Congress Catalog Card Number 89-85388.

4. *Aesthetic Bridges User's Guide*, Maryland Department of Transportation, State Highway Administration, Office of Bridge Development, 1993.

5. Adele Fleet Bacow and Kenneth E. Kruckemeyer, *Bridge Design, Aesthetics and Developing Technologies*, 157 pp., Library of Congress Catalog Card Number 86-061840.

6. *Bridge Aesthetics Around the World*, Committee on General Structures, Subcommittee on Bridge Aesthetics, Transportation Research Board, National Research Council, Washington, D.C., 1991.

7. *Aesthetic Guidelines for Bridge Design*, Minnesota Department of Transportation, Manual Sales Office, G-19-M.S. 260, 395 John Ireland Boulevard, St. Paul, Minnesota 55155.

The designer is expected to be familiar with the subject of bridge aesthetics and committed to fulfilling both the structural and aesthetic needs of the site. The challenge differs for major and minor structures. In fact, the challenge may be greater for the smaller project. Major structures, because of their longer spans, taller interior bents, or curving geometry, often offer inherent opportunities not available for their minor counterparts.

Guidelines for aesthetic considerations are especially significant for:

- bridges highly visible to a large number of users (e.g., Interstate overpasses);
- bridges located in or adjacent to parks, recreational areas, or other major public gathering points;
- pedestrian bridges;
- bridges in urban areas in or adjacent to commercial and/or residential areas; and
- multi-bridge projects (e.g., interchanges, corridors) should have conformity of theme and appearance by avoiding abrupt changes in structural features.

Normally, there are three general levels of aesthetic consideration at each structure's site:

1. <u>Cosmetic Improvements</u>. These improvements consist of the use of masonry coatings or color pigments in the concrete, brick pavers, texturing the surfaces (e.g., fluted columns, shadow boxes), form liners, rustication grooves, and modification to barrier walls and beams. Providing more pleasing shapes of columns and/or bent caps for the substructure should also be studied (e.g., rounded bent caps ends).

2. <u>Overall Structure Aesthetics</u>. The bridge designer should strive for full integration of efficiency, economy, and appearance into all bridge components and the structure as a whole. Consider structural systems that are inherently more pleasing such as

hammerhead or "T" shaped interior bents, oblong-shaped columns, integral caps and bents, smooth transitions at superstructure depth change locations, etc.

3. Overall Project Aesthetics. The project as a whole must be considered when passing through or under an interchange or at other sites such as historic or highly urbanized areas where landscaping or unique neighborhood features must be considered. This level may require input from an architect.

The aesthetic levels described above are not exclusive. For the second and third levels, public input may be appropriate.

12.7.2 Context Sensitive Solutions

12.7.2.1 Background

During the 1990s, highway design changed rapidly throughout the United States. Transportation agencies have learned that they must be more sensitive to the impact of highways on the environment and communities. New and better ways of designing highways and bridges are evolving following the completion of the Interstate system, based on a growing interest in the improvement of highways and their integration into the communities they serve.

Working with community stakeholders to preserve and enhance the human and natural environment has become a significant component of transportation projects. "Stakeholders" are defined as all individuals, businesses, organizations, etc., that have a direct interest in the consequences of a transportation project. To best address the challenges of transportation projects, SCDOT has implemented a Context Sensitive Solutions (CSS) approach to project development.

12.7.2.2 Principles

The following are the basic principles behind Context Sensitive Solutions:

1. Qualities of Excellence in Transportation Design. The following apply:

    - The project satisfies the purpose and needs as agreed to by a full range of stakeholders. This agreement is forged in the earliest phase of the project and amended as warranted as the project develops.

    - The project is a safe facility for both the user and the community.

    - The project is in harmony with the community, and it preserves the environmental, scenic, aesthetic, historic, and natural resource values of the area (i.e., exhibits context sensitive design).

    - The project exceeds the expectations of both designers and stakeholders and achieves a level of excellence in the public's minds.

- The project involves the efficient and effective use of the resources (e.g., time, budget, community) of all involved parties.
- The project is designed and built with minimal disruption to the community.
- The project is seen as having added lasting value to the community.

2. Characteristics of the Process Contributing to Excellence. The following apply:

   - Communication with all stakeholders is open, honest, early, and continuous.
   - A multidisciplinary team is established early, with disciplines based on the needs of the specific project, and with the inclusion of the public.
   - A full range of stakeholders are involved with transportation officials in the scoping phase. The purposes of the project are clearly defined, and consensus on the scope is forged before proceeding.
   - The highway development process is tailored to meet the circumstances. This process should examine multiple alternatives that will result in a consensus of approach methods.
   - A commitment to the process from top agency officials and local leaders is secured.
   - The public involvement process, which includes informal meetings, is tailored to the project.
   - The landscape, the community, and valued resources are understood before engineering design is started.
   - A full range of tools for communication on project alternatives is used (e.g., visualization).

12.7.3 <u>Environmental Considerations</u>

The evaluation of potential environmental impacts can have a significant impact on structure-type selection and configuration, especially for highway bridges over streams. In general, any bridge project should, within reason, attempt to minimize the environmental impacts, especially in sensitive areas (e.g., wetlands). The Environmental Management Office is responsible for identifying all environmental resources within the proposed project limits and for evaluating the potential project impacts on these resources. In particular, the following water-related environmental permits/approvals may be necessary for a bridge design project:

- US Army Corps of Engineers Section 404 Permit,
- Section 401 Water Quality Certification,

- Section 402 NPDES Permit,
- US Coast Guard Section 10 Permit, and
- Floodplains Encroachment Approval.

In some cases, a proposed bridge project may precipitate other environmental impacts. These include Section 106, Section 4(f), Section 6(f) and Threatened and Endangered Species. See Chapter 27 of the *SCDOT Highway Design Manual* for a detailed discussion on environmental considerations and permits.

12.7.4 Navigable Waters

Before engaging in any work activities on or near any bridges over the navigable waters of the United States, the bridge designer must notify the US Coast Guard Homeland Security Command Center in Miami. This notification includes field inspections by SCDOT employees and work performed under contract.

12.7.5 Hydraulics

The Hydraulic Engineering Section will prepare a Hydraulic Report/Scour Report in advance of the Bridge Design Section's structure type and size selection. See Section 5.5 for more information. The following sections briefly discuss hydraulic considerations that affect the various structural elements.

12.7.5.1 End Bents

The principal hydraulic concerns for end bents are orientation and protection from scour-related failure. Concerns for scour are usually resolved by protective and preventive measures that are determined by the Hydraulic Engineering Section. Orientation is usually the same as for adjacent interior bents.

12.7.5.2 Interior Bents

Economy of construction usually plays a large role in the determination of spans, interior bent locations and orientation, and substructure and superstructure design. There are hydraulic considerations, maintenance costs and risks of future costs to repair flood damages that should also be factors in making decisions on the number of interior bents and their location, orientation, and type.

The number of interior bents in any channel should be limited to a practical minimum, and interior bents in the channel of small streams should be avoided, if practical. Interior bents properly oriented with the flow do not contribute significantly to bridge backwater, but they do contribute to general scour. In some cases, severe scour develops immediately downstream of bridges because of eddy currents and because interior bents occupy a significant area in the channel. Lateral and vertical scour also occurs at some locations.

Interior bents should be aligned with flow direction at flood stage to minimize the opportunity for drift to be caught in piling or columns, to reduce the contraction effect of interior bents in the waterway, to minimize debris forces and the possibility of debris dams forming at the bridge, and to minimize backwater and local scour. Bent orientation is difficult where flow direction changes with stage or time. Single-column bents, if practical, are typically the best alternative if orientation at other than flood stage is critical.

Interior bents should not be located on a bank or in the stream channel near the bank because these bent locations are likely to cause lateral scouring of the bank. The design of interior bents located near the stream bank in the floodplain should take into consideration the potential for bank scour and meander migration of the stream.

Interior bent shape is also a factor in local scour. A solid bent will not collect as much debris as a multiple-column bent. Rounding or streamlining the leading edges of interior bents helps to decrease the accumulation of debris and reduces local scour at the bent.

12.7.5.3 Foundations

The foundation is usually the element of a bridge that is most vulnerable during floods. Examination of individual boring logs and plots of the profiles of various subsurface materials are important to the prediction of potential scour depths and to the estimation of the bearing capacity of the soils.

Piles or drilled shafts usually depend upon the surrounding material for skin friction and lateral stability. In some cases, these deep foundations can be extended to rock or other dense material for load-carrying capacity. Tip elevations for piling or drilled shafts should be based on estimates of potential scour depths and bearing to avoid losing lateral support and load-carrying capacity during floods. Pile-bearing capacity derived from driving records have little validity during floods if the material through which the piles were driven is scoured away.

The bridge designer must consider the potential scour and the possibility of channel shifts in designing foundations for bridges on floodplains and spans approaching the stream channel. The thalweg in the channel, which is the line in a stream channel connecting the lowest flow point along the bed, should not be considered to be in a fixed location when establishing founding elevations. The history of a stream and a study of how active the stream has been is important when making decisions on pile and drilled shaft tip elevations.

12.7.6 Construction

12.7.6.1 General

Reference: LRFD Article 2.5.3

The *LRFD Specifications* requires that, unless there is a single obvious method, at least one sequence of construction should be indicated in the contract documents. If an alternative sequence is allowed, the Contractor should prove that stresses, which accumulate in the structure during construction, will remain within acceptable limits.

12.7.6.2 Access and Time Restrictions

Bridges over water may have restrictions associated with their construction. These restrictions must be considered during structure-type evaluation.

Access to a water way beneath a bridge may be restricted for a variety of reasons. These include access restrictions required by permits (e.g., Section 404) and restrictions that limit the type of equipment that can be used during construction.

The time period that the Contractor will be allowed to work within the waterway may be restricted by regulations administered by various agencies. Depending on the time limitations, a bridge with fewer interior bents or faster interior bent construction may be more advantageous for a particular project.

12.7.6.3 Staged Construction

At times, due to the proximity of existing structures or a congested work area, it may be necessary to build a structure in multiple phases. The arrangement and sequencing of each stage of construction are unique to each project, and due consideration must be given to requirements for adequate construction clearances and the requirements of the traveling public. If stages of construction are required, then the staging sequence and controlling lane/construction dimensions must be shown on the plans.

12.7.6.4 Construction Costs

Initial construction costs should be one factor in the selection of the structure type, but not the only factor. Future expenditures during the service life of the bridge should also be considered. The initial costs depend on a variety of factors including:

- type of structure,
- economy of design,
- general state of the economy,
- experience of local Contractors,

- vicinity of fabricating shops, and
- local availability of structural materials and labor.

These factors may change rapidly, and the designer may have no control over them. A review of the cost of structural components within a bridge, and that of Contractor's claims, may direct the designer towards optimum combinations for future bridge projects.

12.7.7 Right-of-Way and Utilities

The Right of Way Office is responsible for securing project right-of-way. The designer should consider the following right-of-way factors when selecting the structure type:

1. Expensive Right-of-Way. If right-of-way will be expensive, this may lead to the use of MSE walls.

2. Structure Depth. The available right-of-way at the bridge site may affect the vertical alignment of the structure which may, in turn, affect the acceptable structure depth to meet the vertical clearance requirements.

3. Detour Bridges. For bridge widening projects, if right-of-way is not available for detour bridges, it may be necessary to maintain traffic across the existing bridge.

Any bridge design must be consistent with SCDOT utility accommodation policies. Chapter 17 discusses utility attachments to bridges.

12.7.8 Maintenance

The structure type selection will, over the life of the structure, have a major impact on maintenance costs. Based on type of material, the following is the approximate order of desirability from a maintenance perspective:

- reinforced concrete slab bridges,
- prestressed concrete,
- unpainted weathering steel, and
- painted structural steel.

The following maintenance considerations apply:

1. Deck Joints. Open, or inadequately sealed, deck joints have been identified as the foremost reason for structural corrosion of structural elements by permitting the seepage of water from the deck. To address this, SCDOT promotes the use of jointless bridges with continuous decks, integral end bents, and improvements in drainage. See Section 12.2 for a discussion on jointless bridges.

2. Paint. The environmental concern for removing paint from steel structures makes the use of weathering steel preferable to painted steel from a maintenance perspective. However, see the discussion in Chapter 16 for the aesthetic considerations and acceptable locations of using weathering steel.

3. Drainage. Closed drainage systems and elaborate piping systems should only be used where required. See Chapter 18.

4. Bridge Inspection. In addition to the maintenance needs of the structure, the designer should consider the bridge inspection logistics.

5. Structural Details. As another maintenance/inspection consideration, the designer should, as practical, limit the number of different structural details (e.g., bearings, expansion joints).