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Chapter Thirteen
STRUCTURAL SYSTEMS AND DIMENSIONS

Chapter Thirteen provides guidance to MDT bridge designers in determining the most appropriate overall structure type and size to meet the structural, geometric, hydraulic, environmental and right-of-way characteristics of the site. This selection is a critical event in project development. The decision will significantly impact the detailed structure design phase, construction costs and maintenance costs over the life of the structure.

13.1 PROCEDURES

13.1.1 Scope of Work

To determine the proper application of Chapter Thirteen to a proposed project, it is necessary to identify the scope (or extent) of the proposed structural work. This will determine, for example, the MDT criteria for bridge width. Chapter 13 applies to a new bridge (i.e., construction of a new bridge at a new location) and to a bridge replacement (i.e., replacement of the entire existing bridge). See Chapter Twenty-two (Section 22.1) for definitions of project scopes of work on existing bridges.

13.1.2 Coordination

The structure type analysis will produce as an output the preliminary general layout and grade of the bridge for evaluation and further investigation by various units within the Department. These include the Road Design Section, Geotechnical Section, Environmental Services (e.g., for the Stream Preservation Act review), Right-of-Way Bureau and Utilities Section (for utilities and railroads). Ultimately, after finalization of the General Layout Sheet, the bridge designer will perform the detailed structural design of the bridge and prepare the final plans for project advertisement.

Chapters Two and Three describe the necessary coordination between the Bridge Bureau and other MDT units in selecting structure type and size.

13.1.3 Documentation

Chapter Four "Administrative Policies and Procedures" presents MDT's format and procedures for project documentation. The Preliminary Field Review (PFR) Report documents the characteristics of the project site. This, among other items, will be used to prepare the preliminary bridge layout and grade. Once the structure type and size has been approved, this will be documented in the Scope of Work Report. Section 4.1.2 presents the format and content of the Scope of Work Report.

13.1.4 Plan Preparation

Chapter Five presents MDT criteria and procedures for preparing bridge plans. This includes the sequence of construction plan sheets, CADD conventions and the content of individual sheets. One of these is the General Layout of Structure Sheet, including its plan view, elevation view and profile grade. The structure type analysis will yield the preliminary General Layout and Grade of the proposed structure. As practical, this preliminary sheet should be prepared according to the conventions in Chapter Five for final construction plans.

13.1.5 Preliminary Cost Estimate

Chapter Seven presents MDT criteria for producing construction cost estimates; Section 7.1 discusses preliminary cost estimates. At the structure type and size selection stage of project development, the cost estimate will typically be based on the area of the proposed bridge deck (m^2), the type of structure, recent projects in the geographic area and engineering judgment. The bridge designer will include the preliminary cost estimate in the Scope of Work Report as discussed in Section 4.1.2.2.

13.2 GENERAL EVALUATION FACTORS

Section 13.2 provides a summary of the many evaluation factors which will impact the selected structural system and its dimensions with references, where applicable, to more detailed information.

13.2.1 Hydraulics

The Hydraulics Section will prepare a Hydraulics Report in advance of the Bridge Bureau's structure type and size selection. The critical hydraulic factors include:

1. channel bottom elevation and width;
2. water surface elevation for the design-year flood;
3. skew angle and side slopes of channel;
4. required low beam elevation if determined to be critical;
5. hydraulic scour potential;
6. passage of ice and debris; and
7. stream flow conditions.

See Section 13.7 for more discussion on bridge hydraulics.

13.2.2 Roadway Design

Often the considerations for bridge design are different than those for road design because the design life of the bridge is 3 to 4 times the design life of the roadway. Roadway design factors which impact structural type and size selection include:

1. horizontal alignment (e.g., tangent, curve, superelevation, skew);
2. vertical clearances and alignment (e.g., longitudinal gradient, vertical curves);
3. traffic volumes;
4. roadway width;
5. presence of sidewalks and bike lanes; and
6. clear zones through underpasses.

See Sections 13.5 and 13.6 and the **Montana Road Design Manual** for a detailed discussion on roadway design elements at bridges.

13.2.3 Structural

Section 13.3 provides information on the selection of a superstructure type, and Section 13.4 provides information on selecting a substructure/foundation type.

13.2.3.1 Constraints

The structural constraints which impact structure type selection include:

1. limitations on structure depth,
2. foundations and groundwater conditions,
3. anticipated settlement,
4. acceptable span lengths,
5. dead load restrictions,
6. seismic factors,
7. phased construction requirements,
8. scour,
9. anticipated lateral loads,
10. requirements for phase construction because of traffic, and
11. geometric limitations on configuration.

13.2.3.2 Number/Length of Spans

In general, the fewest number of spans as practical should be used. This will minimize the interference with the elements underneath the structure (e.g., railroads, highways, marine traffic, water passage). The minimum number of and length of spans will be determined by several factors including:

1. foundation conditions,
2. vertical clearance requirements,
3. waterway opening requirements,
4. safety of underpassing traffic,
5. navigation requirements,
6. ice and flood debris considerations, and
7. construction costs.

13.2.3.3 Structural Details

The use of bearings, drainage appurtenances, expansion joints, excessive skew, etc., is costly and creates construction and maintenance problems. The designer should attempt to select a structure type which will minimize the use of these structural details.

13.2.3.4 Seismic

It is important to address the seismic response of a structure during the preliminary structure type selection. The structural system should be selected in recognition of the importance of seismic response. Ideally, bridges should have a regular configuration so that seismic behavior is predictable and so that plastic hinging is promoted in multiple, readily identifiable and repairable yielding components. Selecting a structural form based solely on gravity-type loading considerations and then adding seismic-resistive elements and details is unlikely to provide the best solution.

All structures will be designed in accordance with the seismic provisions of the **LRFD Bridge Design Specifications**. Other analysis and design techniques may be warranted for retrofit or unique design projects. All bridges are required to meet at least a minimum level of seismic performance. Although the LRFD Specifications seismic provisions do not discuss preliminary structure type selection, certain guidelines should be followed. In general, structure type should be selected with the following considerations:

1. <u>Alignment</u>. Straight bridges are preferred because curved bridges can lead to unpredictable seismic response.

2. <u>Substructure Skew</u>. Substructure units should have little or no skew. Skewed supports cause rotational response with increased displacements.

3. <u>Superstructure Weight</u>. Superstructure weight should be minimized.

4. <u>Joints</u>. The deck should have as few expansion joints as practical, with a jointless deck being ideal.

5. <u>Foundations</u>. Shallow foundations should be avoided if the foundation material is susceptible to liquefaction.

6. <u>Substructure Stiffness</u>. Large differences in the stiffness of the substructure units should be avoided; i.e., the use of piers of uniform cross section with varying heights should be avoided if practical.

7. <u>Plastic Hinges</u>. Plastic hinges should be forced to develop only in the columns rather than the cap beams or superstructure and should be accessible for inspection and repair after an earthquake.

The Seismic Unit supports the Bridge Design Section in the seismic design and analysis of new and rehabilitated bridges. In this capacity, the Seismic Unit performs a significant amount of design work for bridges within the context of addressing seismic vulnerability. Bridge work which involves seismic concerns should be reviewed by the Seismic Unit.

13.2.3.5 Foundation Considerations

The following applies, in general, to foundation considerations:

1. Grade Adjustment. When considering structural-system selection, the ability to adjust the structure through jacking is an important issue. Jacking stiffeners or diaphragms may be required. The subgrade may settle differently from the calculated estimates. It is understood that, where superstructures and substructures are integral with each other, this facility for adjustment cannot exist.

   The nature of the subgrade should be considered prior to the final selection and design of the superstructure, substructure and foundation to ensure adjustability if needed.

2. Settlement Limits. Experience demonstrates that bridges can accommodate more settlement than traditionally allowed in design due to creep, relaxation and redistribution of force effects. Article 10.6.2.2.1 of the LRFD Specifications mandates that settlement criteria be developed consistent with the function and type of structure, anticipated service life and consequences of unanticipated movements on service performance. Further, in the commentary it suggests that angular distortions between adjacent spread footings greater than 0.008 in simple spans and 0.004 in continuous spans should not be ordinarily permitted.

13.2.4 Falsework

Temporary falsework is an expensive construction item. If the bridge is over a waterway and/or will have a high finished elevation, the cost of the falsework may become prohibitive, and the designer should consider another structural system.

The following will apply to the use of falsework:

1. Water. The use of falsework over water is generally discouraged. However, each specific site should be investigated on a cost versus risk basis. If a falsework opening for at least the five-year event can be provided, the use of falsework over water may be considered.

2. Railroads. Each railroad company has its own requirements for falsework over its facilities. Depending on the railroad company and the type and amount of railroad traffic, the railroad company may prohibit the use of falsework. The railroad company should be contacted early in project development to determine if falsework may be used and its minimum clearance requirements.

3. Traffic. Falsework may unduly interfere with traffic passing beneath the structure or may create an unacceptable safety hazard. For example, falsework may reduce the vertical clearance below acceptable levels and may require a barrier installation to shield traffic from the falsework. The designer should contact the District prior to using falsework over traffic. The minimum clearance for falsework will be determined on a case-by-case basis.

4. Environmental. Some sites may be very sensitive environmentally, and the use of falsework may be prohibited. Falsework for typical flat slab construction is usually not an issue.

Basically, if the use of falsework is unacceptable or impractical, this eliminates the use of any cast-in-place concrete or shored construction type structure.

13.2.5 Aesthetics

Structures should be aesthetically pleasing to the traveling public. The LRFD Specifications emphasize improving the appearance of highway bridges in the United States. It promotes uninterrupted lines, contours that follow the flow of stresses and the avoidance of cluttered appearances. Structures should incorporate attractive shapes and surface treatments and should be similar in appearance to adjacent structures.

In addition to overall structure type, other factors will impact the aesthetic appeal of the structure (e.g., fine surface finish on concrete, color of steel). Aesthetic considerations may also become a factor in structure-type selection because, for example, of historic or local community considerations.

13.2.6 <u>Environment</u>

The evaluation of potential environmental impacts can have a significant impact on structure-type selection and configuration, especially for highway bridges over streams. See Section 13.8 for a detailed discussion on environmental considerations. The bridge designer must seriously evaluate these issues in project development.

13.2.7 <u>Construction</u>

13.2.7.1 General

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.

13.2.7.2 Access and Time Restrictions

Water-crossing bridges will typically have construction restrictions associated with their construction. These must be considered during structure type evaluation.

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 piers or faster pier construction may be more advantageous even if more expensive.

Contractor access to the water may also be restricted. To work in or gain access areas, a work bridge may be necessary. Work bridges may also be necessary for bridge removal as well as new bridge construction.

13.2.7.3 Phase Construction

At times, due to the proximity of existing structures or a congested work area, it may be necessary to build a structure in several phases. The arrangement and sequencing of each phase 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 phase construction is required, then the phasing sequence and controlling lane/ construction dimensions must be shown on the plans.

The phase sequencing must be developed with the District. In general, it is usually allowable to restrict traffic to a 3.35-m lane width, although this depends on traffic speeds and District concurrence.

13.2.8 <u>Construction Costs</u>

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:

1. type of structure,

2. economy of design,

3. general state of the economy,

4. degree of occupancy and experience of local contractors,

5. vicinity of fabricating shops, and

6. local availability of structural materials and labor.

These factors may change rapidly, and the designer may have no control over them. It may be advisable to prepare competitive plans (i.e., for both concrete and steel superstructures) occasionally even for small-span structures. A review of the cost of structural components within a bridge, and that of contractor's claims, may direct the designer towards optimum combinations and the avoidance of future errors.

13.2.9 Highway Bridges Over Railroads

Railroad geometric requirements must be considered in structure-type selection. Chapter Twenty-one presents specific details which will apply to highway bridges over railroads.

13.2.10 Right-of-Way/Utilities

The Right-of-Way Bureau 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 reinforced earth abutments.

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. Detours. For bridge rehabilitation projects, if right-of-way is not available for detours, it may be necessary to maintain traffic across the existing bridge.

Any bridge design must be consistent with MDT utility accommodation policies. Utility attachments to bridges are discussed in Chapter Fifteen.

13.2.11 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:

1. prestressed concrete,
2. reinforced concrete slab bridges,
3. unpainted weathering steel, and
4. painted structural steel.

With proper detailing and periodic simple flushing with water to remove corrosion-encouraging debris buildup, unpainted weathering steel can be relatively maintenance-free. Additional experience may move unpainted weathering steel up in the order of desirability from a maintenance perspective.

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 percolation of salt-laden water through the deck. To address this, the LRFD Specifications promotes jointless bridges with continuous decks, integral abutments and improvements in drainage. See Section 13.4.4 for a discussion on jointless bridges.

2. Re-bars. The overwhelming problem for reinforced concrete slabs is the corrosion of the re-bars, the volumetric expansion of corrosion products, and the resulting spalling and delamination of the concrete. Epoxy-coated reinforcement is judged to be the best solution currently available for use with steel re-bars.

3. Paint. The environmental concern for removing paint from steel structures makes the future use of painted steel structures questionable. Where practical, the application of self-protecting weathering steels should be used.

4. Drainage. Drainage facilities should be few and large, and elaborate plumbing systems should be avoided.

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

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

13.2.12 Future Widening

In general, the designer should consider the possibility of future structure widening. For example, structures supported by single columns or cantilevered piers cannot practically be widened; a separate adjacent structure will be required.

Almost every superstructure type can be widened, but not with the same level of ease. Slabs, slab on girders, and systems consisting of prefabricated concrete elements lend themselves best to widening.

13.2.13 ADA

Many highway elements can affect the accessibility and mobility of disabled individuals. These include sidewalks, parking lots, buildings at transportation facilities, overpasses and underpasses. The Department's accessibility criteria must comply with the 1990 **Americans with Disabilities Act** (ADA) and with the **ADA Accessibility Guidelines for Buildings and Facilities** (ADA Guidelines). Where other agencies' or local codes require standards which exceed the **ADA Guidelines**, then the stricter criteria may be required. This will be determined on a case-by-case basis.

Chapter Eighteen of the **Montana Road Design Manual** presents the MDT criteria to comply with **ADA** for highway-related elements (e.g., sidewalks, parking lots, bus stops, curb ramps). Further, the **ADA** accessibility criteria depends on whether the sidewalk is on an accessible route or on a non-accessible route, as defined below. Where the Department is upgrading a facility and installing a sidewalk, the bridge must be configured to meet accessible route criteria:

1. Accessible Route. An accessible route is a continuous, unobstructed path connecting all accessible elements and spaces in a building, facility or site. A "site" is defined as a parcel of land bounded by a property line or a designated portion of a public right-of-way. A "facility" is defined as all or any portion of buildings, structures, site improvements, complexes, equipment, roads, walks, passageways, parking lots, or other real or personal property on a site. Interior accessible routes may include corridors, floors, ramps, elevators, lifts and clear floor space at fixtures. Exterior accessible routes may include parking access aisles, curb ramps, crosswalks at vehicular ways, walks, ramps and lifts.

   For highway projects, the application of the accessible route criteria applies to sites which are related to highway purposes. These include rest areas, recreational areas, park-and-ride lots, sidewalks adjacent to public roadways, etc. Most sidewalks adjacent to public highways are considered accessible routes.

2. Non-Accessible Route. A non-accessible route is any pedestrian facility which contains features that make it impractical to meet the criteria for accessible routes. These features include terrain that results in steep grades on the facility, narrow

sidewalks or stairs where adjacent development precludes widening or replacement with ramps. These features are typically associated with existing facilities; however, they may also affect the accessibility of routes on new construction projects.

The **ADA** criteria for sidewalks on a bridge are:

1. <u>Longitudinal Slope</u>. Provide the flattest longitudinal slope practical which, desirably, will not exceed 5%. Where slopes are greater than 5% on non-accessible routes, it will not be necessary to provide handrails, which are required on accessible routes.

2. <u>Cross Slopes</u>. Cross slopes greater than 2% may be used provided that transitions at cross slope changes are smoothly blended. The designer should attempt to provide the flattest cross slope practical.

3. <u>Width</u>. The minimum clear width at any isolated point along an accessible or non-accessible route shall be 915 mm. If the clear width is less than 1525 mm, then passing spaces at least 1525 mm by 1525 mm shall be located at reasonable intervals not to exceed 61 m. Note that, where the Department's typical 1.6-m sidewalk width is used (see Section 13.5), MDT meets all **ADA** requirements without the need for passing spaces.

Where necessary, the Bridge Bureau coordinates with the Human Resources Division, Civil Rights Bureau, to ensure compliance with the **Americans with Disabilities Act**. The Division will, for example, provide interpretations on the intent and application of the **Act**.

13.3 SUPERSTRUCTURES

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

13.3.1 Superstructure Types/Characteristics

The following figures provide summary guidance in selecting the bridge superstructure type that is most appropriate for the given site conditions:

1. Past Usage of Bridge Types. Figure 13.3A presents the bridge types which have been constructed by MDT from 1985 to 1995.

2. Superstructure Types. Figure 13.3B presents a schematic cross section of those bridge types which are used in Montana. Each of these is further discussed in Section 13.3.2.

3. Span Lengths. Figure 13.3C indicates the typical ranges of span lengths for which the various superstructure types will generally apply.

4. Minimum Depths. Figure 13.3D presents the minimum depths for constant depth superstructures.

5. Girder Spacing Ranges. Figure 13.3E presents the range of girder spacings which typically apply to the superstructure types.

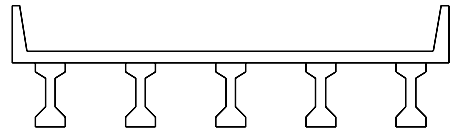
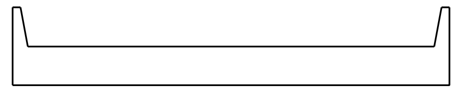
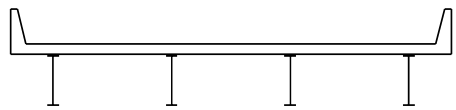
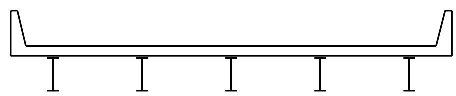
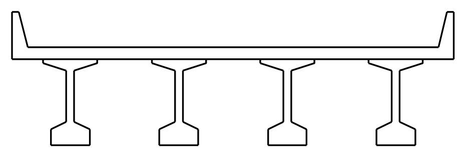
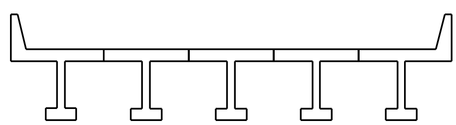
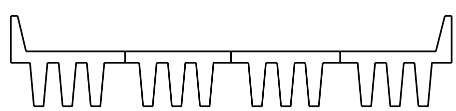
6. Superstructure Characteristics. Figure 13.3F tabulates several basic characteristics of the superstructure types in Figure 13.3B.

TYPE	NUMBER	PERCENTAGE
Prestressed, Precast Concrete I-Girders	108	47%
Reinforced Concrete Slabs	35	15%
Composite Rolled Steel Girders	26	11%
Jointed, Prestressed, Precast Longitudinal Concrete Elements	22	10%
Composite Steel Welded Plate Girders	21	9%
Other Types	19	8%
Total	231	100%

Dates: 1985 to 1995

NEW BRIDGE TYPES CONSTRUCTED IN MONTANA
(State-Owned Structures Only)

Figure 13.3A

Type	Structure Description	Cross Section Schematic
A	Prestressed, Precast Concrete I-Girders	
B	Reinforced, Cast-in-Place Concrete Slabs	
C	Composite Steel Welded Plate Girders	
D	Composite Rolled Steel Girders	
E	Post-Tensioned, Concrete I-Girders	
F1	Jointed, Prestressed, Precast Longitudinal Concrete Bulb Tees	
F2	Jointed, Prestressed, Precast Longitudinal Concrete Tri-Deck	

SUPERSTRUCTURE TYPES USED BY MDT

Figure 13.3B

Type	Structure Description	Subgroup	Span Length Ranges (in meters)				
			Up to 10	10-30	30-50	50-100	>100
A	Prestressed, Precast Concrete I-Girders	N.A.		x	x		
B	Reinforced, Cast-in-Place Concrete Slabs	Haunched	x				
C	Composite Steel Welded Plate Girders	N.A.		x	x	x	x
D	Composite Rolled Steel Girders	Straight		x			
E	Post-Tensioned, Concrete I-Girders	Straight		x	x		
F	Jointed, Prestressed, Precast Longitudinal Concrete Elements	1. Bulb Tees		x	x		
		2. Tri-Deck	x	x			

Note: See Section 13.3.2 for more precise span ranges.

SPAN LENGTH RANGES

Figure 13.3C

Type	Structure Description	Subgroup	Minimum Depth (Including Deck)	
			Simply Supported	Continuous
A	Prestressed, Precast Concrete I-Girders	N.A.	0.045 L	0.040 L
B	Reinforced, Cast-in-Place Concrete Slabs	Haunched	$\frac{1.2\,(S+3000)}{30}$	$\frac{S+3000}{30} \geq 165$ mm
C	Composite Steel Welded Plate Girders	N.A.	0.040 L	0.032 L
D	Composite Rolled Steel Girders	Straight	0.040 L	0.032 L
E	Post-Tensioned, Concrete I-Girders	Straight	0.045 L	0.040 L
F	Jointed, Prestressed, Precast Longitudinal Concrete Elements	1. Bulb Tees	0.045 L	0.040 L
		2. Tri-Deck	0.045 L	0.040 L

* *"Depth" refers to the total structure depth at the point of maximum positive moment, including the deck, where composite. "Span" is defined as the distance between center lines of bearings or the centerlines of piers where double bearings are present or the neutral axes of the vertical components where bearings are absent.*

Note: L = Span Length
S = Slab Span Length

MINIMUM DEPTHS*
(Constant Depth Superstructures)

Figure 13.3D

Type	Structure Description	Subgroup	Range of Girder or Web Spacing
A	Prestressed, Precast Concrete I-Girders	N.A.	1.5 m to 4.5 m
B	Reinforced, Cast-in-Place Concrete Slabs	Haunched	N.A.
C	Composite Steel Welded Plate Girders	N.A.	1.5 m to 4.5 m
D	Composite Rolled Steel Girders	Straight	1.5 m to 4.5 m
E	Post-Tensioned, Concrete I-Girders	Straight	2.5 m to 4.5 m
F	Jointed, Prestressed, Precast Longitudinal Concrete Elements	1. Bulb Tees	1.0 m to 2.0 m
		2. Tri-Deck	1.6 m to 2.6 m

GIRDER SPACING RANGES

Figure 13.3E

Type	Structure Description	Sub Group	For Skew	For Horz. Curve	Seismic*	Aesthetics	False Work Required?	Maintenance	Widening	Cost per Unit Deck Area (1999)
A	Prestressed, Precast Concrete I-Girders	N.A.	OK	OK	OK	OK	No	Good	OK	620
B	Reinforced, Cast-in-Place Concrete Slabs	Haunched	Good	Good	Good	Good	Yes	Good	OK	530
C	Composite Steel Welded Plate Girders	N.A.	OK	Good	Good	OK	No	**	OK	700
D	Composite Rolled Steel Girders	Straight	Good	OK	Good	Good	No	**	OK	650
E	Post-Tensioned, Concrete I-Girders	Straight	OK	No	Good	OK	No	Good	OK	—
F	Jointed, Prestressed, Precast Longitudinal Concrete Elements	1. Bulb Tees	Poor	Poor	OK	OK	No	Good	Good	590
		2. Tri-Deck	Poor	Poor	OK	OK	No	Good	Good	900

**Descriptions in column are for continuous structures. Simply supported structures are always poor.*

*** Good if weathering steel is used. Expensive (i.e., Poor) if painted.*

SUPERSTRUCTURE CHARACTERISTICS

Figure 13.3F

13.3.2 Superstructure Types

13.3.2.1 Type "A": Prestressed, Precast Concrete I-Girders

Because of their local availability, prestressed, precast concrete I-girders are the predominant type of superstructure used in Montana. MDT designations for prestressed, precast concrete I-girders for efficient design with their recommended maximum span lengths are as follows:

1. Type 1 — 17 m
2. Type MT-28 — 23 m
3. Type A — 26 m
4. Type IV — 35 m
5. Type M-72 — 45 m

Figure 13.3G illustrates a typical schematic cross section of prestressed, precast concrete I-girders. See the **MDT Bridge Standard Drawings** for details on the Department's typical designs.

The maximum spacing of girders is approximately 4.5 m. The slab overhang should be as shown in the **MDT Standard Drawings**.

The girders are supported by bearings on the substructure. The LRFD Specifications mandates the use of diaphragms at the supports. The **MDT Standard Drawings** illustrate diaphragm details. Variations from the standards requires approval of the Bridge Engineer.

Precast girders may be made continuous in the longitudinal direction for transient loads. In this arrangement, the girders retain their individual bearings, but their ends are incorporated in a common diaphragm which is cast monolithically with the slab.

13.3.2.2 Type "B": Reinforced, Cast-in-Place Concrete Slabs

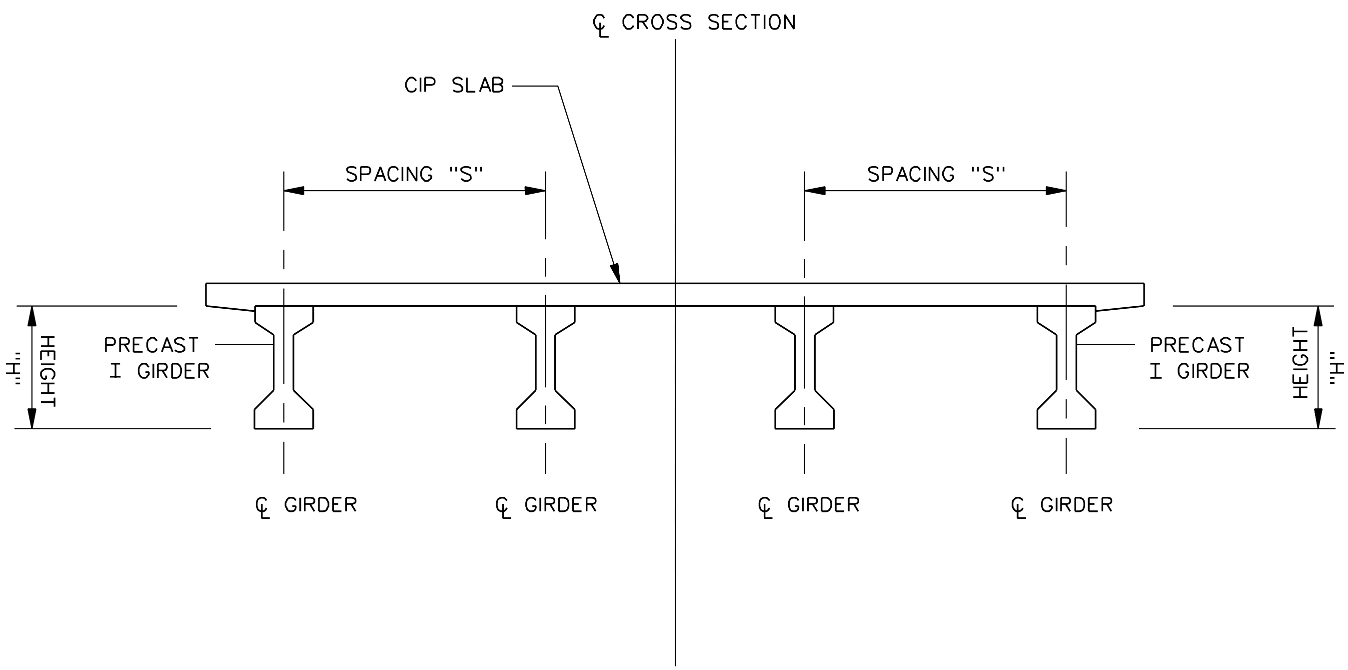
The reinforced, cast-in-place concrete slab is frequently used in Montana because of its suitability for short spans and low clearances and its adaptability to skewed and curved alignments. It is the simplest among all superstructure systems, it is easy to construct, and structural continuity can be achieved without difficulty. Its use is conditional, however, upon the local availability of ready-mix concrete.

For maximum span lengths, MDT uses 7.5 m for simply supported slabs and 10.5 m for continuous slabs. Figure 13.3H depicts the elevation and plan schematic of a three-span, continuous, haunched slab bridge with a significant skew.

In general, haunching is used to decrease maximum positive moments in continuous structures by attracting more negative moments to the haunches and by providing adequate resistance at the haunches for the increased negative moments. It is a simple, effective and economical way to maximize the resistance of thin concrete slabs. Typical MDT practice is to use the straight haunch.

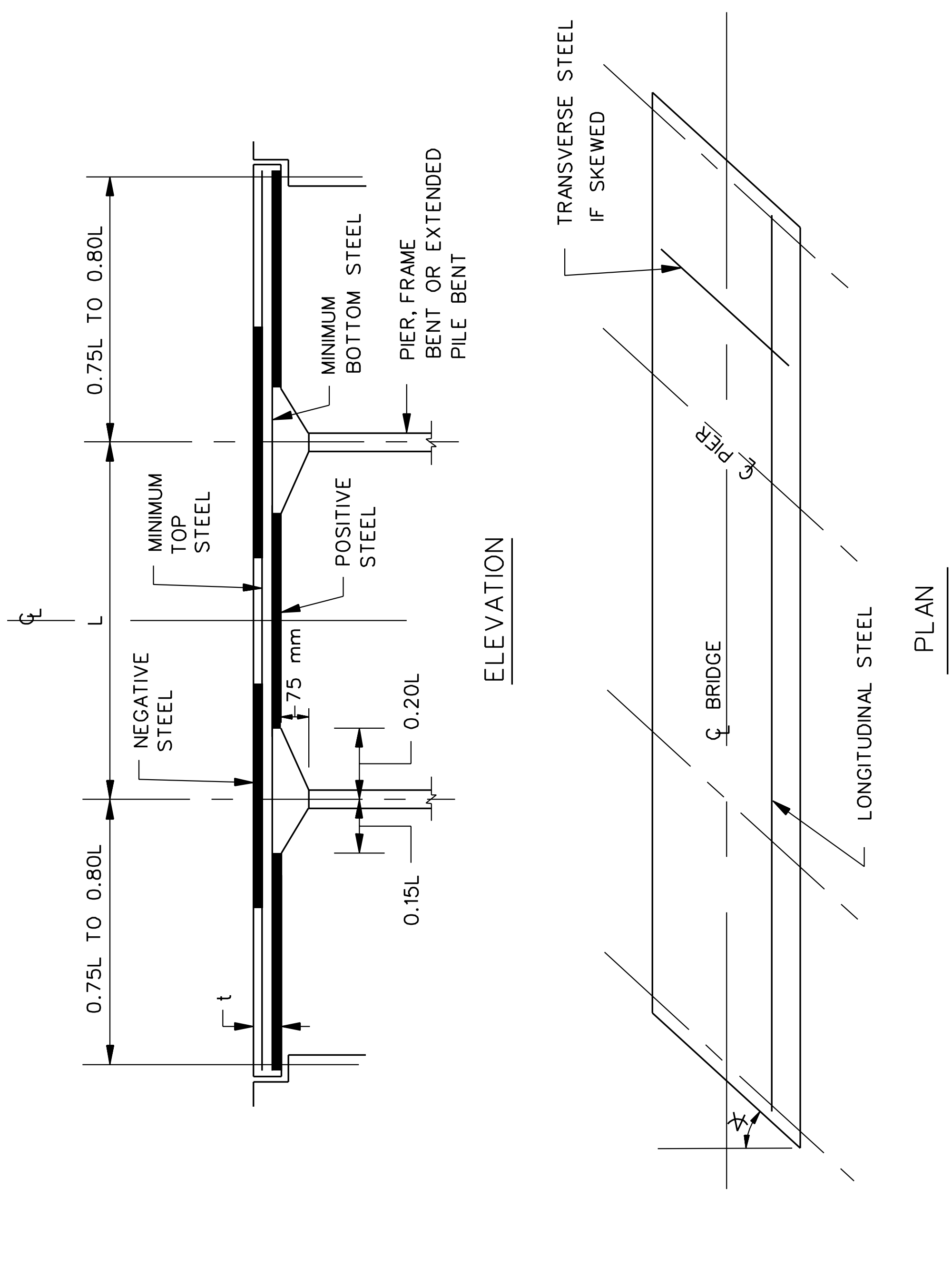
The preferable ratio between end and internal span is approximately 0.75 to 0.80 for economy, but the system permits considerable freedom in selecting span ratios. Except for architectural reasons, the length of the haunch need not exceed the value of 0.20L indicated in Figure 13.3H, where "L" is the length of the center span; longer haunches may be unnecessarily expensive and/or structurally counterproductive.

For interior piers with low height, narrow concrete walls or extended pile bents are recommended; otherwise, a concrete bent is practical. If the wall reinforcement is extended at the top, the deck could be constructed monolithically with the walls. For end supports, the MDT standard stub end bent should be used, resulting in a jointless deck structure.



COMPOSITE SLAB WITH PRESTRESSED, PRECAST AASHTO I-GIRDERS
(Type A)

Figure 13.3G



TYPICAL REINFORCED CONCRETE SLAB
(Type B)

Figure 13.3H

13.3.2.3 Type "C": Composite Steel Welded Plate Girders

MDT typically limits the use of structural steel girder superstructures to longer spans (45 m ≤ L ≤ 85 m), difficult geometrics (e.g., horizontal curves) or limited vertical clearances (e.g., for passage of ice and debris). Figure 13.3I illustrates a typical section for a composite steel welded plate girder superstructure.

Steel plate girders are designed to optimize weight savings and fabrication and erection costs. Top flanges of composite plate girders are typically smaller than their bottom flanges. The flange section is varied along the length of the bridge to save cost by offsetting the increased fabrication costs of welded flange transitions with larger savings in material costs. The most economical location for a flange transition is commonly at a field splice. Typically, only flange thicknesses, not widths, are varied within a field section. The webs of plate girders are typically deeper than the webs of rolled beams. To save in total costs, sometimes web thicknesses are increased to avoid the use of stiffeners.

Due to buckling considerations, the stability of the compression flange (i.e., the top flange in positive-moment regions and the bottom flange in negative-moment regions) must be addressed by providing lateral-brace locations based upon a simple calculation instead of the traditional 7.5-m diaphragm spacings of the former Standard Specifications for Highway Bridges.

On straight bridges (skewed or non-skewed), diaphragms are detailed as secondary members. On curved bridges, diaphragms must be designed as primary members, because curved girders transfer a more significant amount of load between girders through the diaphragms.

13.3.2.4 Type "D": Composite Rolled Steel Girders

Steel girders 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 but are cost effective due to lower fabrication and erection costs. The relatively thick webs preclude the need for web stiffeners. Unless difficult geometrics or limited vertical clearances control, rolled steel girder superstructures are most cost effective in rather short spans, with a maximum limit of approximately 40 m.

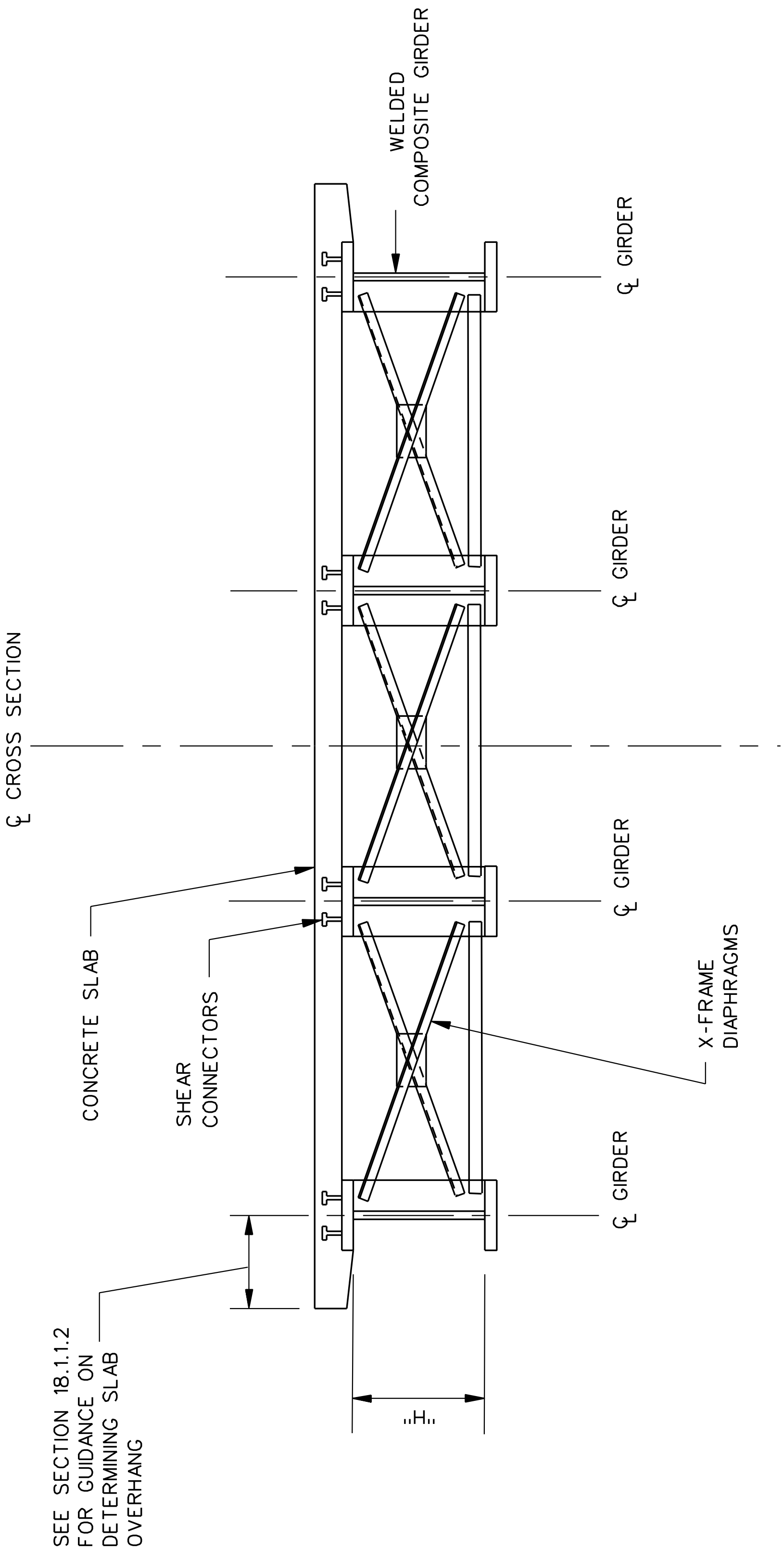
Rolled steel beams are available in depths up to 1 m, with the beams above typical depths rolled less frequently at intervals of about 16 weeks. Before beginning final design, verify with one or more potential fabricators that the section size and length are available.

On straight bridges (skewed or non-skewed), diaphragms are detailed as secondary members. On curved bridges, diaphragms must be designed as primary members, because curved girders transfer a more significant amount of load between girders through the diaphragms.

13.3.2.5 Type "E": Post-Tensioned, Concrete I Girders

The primary advantage of post-tensioned, concrete I-girders, when compared to the traditional prestressed, precast concrete girder (Type A), is its heightened level of structural continuity. The Type A superstructure can be designed to provide continuity for live-load only. For a Type E design with single-stage post-tensioning, the draped post-tensioning cables provide counterforce effects and general continuity. For a Type E design with two-stage post-tensioning (first stage before deck placement and second stage after), the design eases construction and enhances the economy of the single-stage continuity.

Designers should consider the use of post-tensioned I-girder superstructures where the enhanced redundancy of a truly continuous girder is desired or economy dictates. The span length range for Type E is 18 m to 50 m.



TYPICAL CROSS SECTION FOR COMPOSITE STEEL WELDED PLATE GIRDERS
(Type C)

Figure 13.3I

Because the upper limit on span length for both Type A (M-72) girders and Type E post-tensioned bulb-tee girders is 50 m, these two types should be directly compared based upon total economy. In a Type E girder, the post-tensioning tendons are a replacement for many of the prestressing tendons in the M-72 girder.

The designer should consider, the limits of practical hauling from the plant to the job site when selecting the span length and girder type and size. Fabricators should be contacted early in project development for information regarding the availability and feasibility of hauling to a specific site.

Figure 13.3J illustrates a schematic of a post-tensioned concrete I-girder.

13.3.2.6 Type "F": Jointed, Prestressed, Precast Longitudinal Concrete Elements

MDT will only typically use the jointed, prestressed, precast longitudinal concrete superstructure (bulb tee or tri-deck) at sites which meet all of the following conditions:

1. bridges not maintained by the State;
2. remote sites;
3. low clearances;
4. simple geometrics (tangent sections only, skew ≤ 15°);
5. span length ≤ 35 m for bulb tee sections 1.195 m deep, span lengths ≤ 25 m for bulb tee sections 0.890 m deep; for rib decks consult with local producers to determine appropriate span limits; and
6. single-span bridges are the preferred layout for bulb tees because of the difficulty in obtaining a suitable ride, although multi-span tri-deck layouts do not seem to have particular problems with ride quality because of their shorter spans.

MDT normal practice is to use only simply supported designs for Type F. Figure 13.3K illustrates a schematic cross section for this superstructure type.

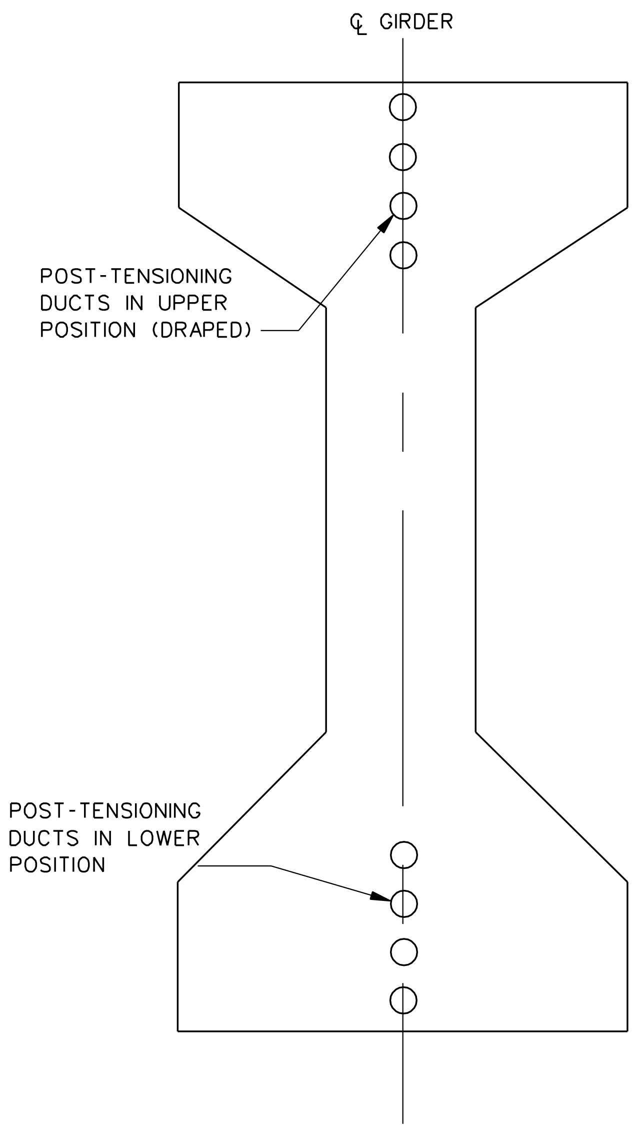
Prestressed, precast concrete longitudinal elements of various cross sections have been used without transverse post-tensioning to create a bridge deck. The long-term performance of these deck systems under heavy traffic is a concern because of possible disintegration and deterioration of longitudinal shear keys between the elements. This could result in potential overloading of the elements and maintenance problems for the deck, which is the reason that these types of bridges are not used on State-maintained facilities.

Typical MDT practice is as follows:

1. Precast elements are designed for a future overlay of 40 mm of plant mix.
2. A traditional trapezoidal key is used with a 10-mm gap between elements.

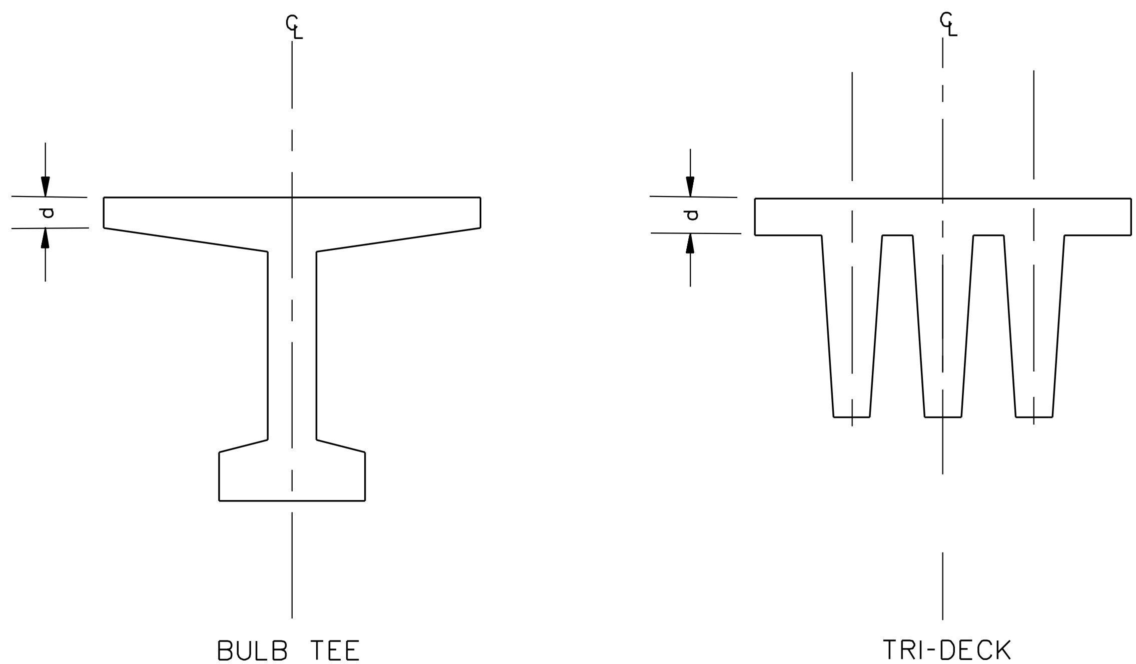
As illustrated in Figure 13.3K, MDT uses two basic precast, prestressed concrete elements that can be assembled into simply supported deck systems economically. The basic idea is that the precast elements either serve as the finished roadway or provide an uninterrupted formwork for a structural concrete overlay.

No variation of this system is applicable to curved structures. Skew is possible, but forming and casting the ends of the element with an angle other than 90° will cause some deterioration of ride quality and difficulty in manufacturing. The desirable limit for skew is 15°; skew angles greater than 30° are not allowed. This system can also be made continuous in the longitudinal direction by using a monolithic diaphragm and continuity steel or by using longitudinal post-tensioning similar to precast concrete girders. Tri-decks, however, lack an effective bottom flange, and they need special measures to improve the compressive strength of the stems at the point of junction.



POST-TENSIONED, CONCRETE I-GIRDER
(Type E)

Figure 13.3J



TYPICAL PRECAST CONCRETE ELEMENTS
(Type G)

Figure 13.3K

Attention must be provided to the treatment of the roadway crown when using this type of element. The order of preference for the MDT is:

1. no crown (deck will be flat);

2. constant and uniform crown across deck; and

3. crown break at a joint between longitudinal elements; the crown break cannot be placed on the top of an element.

13.4 SUBSTRUCTURES AND FOUNDATIONS

13.4.1 Objective

This Section discusses several types of substructure and foundation systems used by the Department, and it presents their general characteristics. The designer should use this information to select the combination of substructures and foundations which are suitable at the site so that the proposed elements will satisfy economically the geometric requirements of the bridge and to safely use the strength of the soil or rock present at the site to carry the anticipated loads. Chapter Nineteen discusses the detailed design of substructure elements, and Chapter Twenty discusses the design of foundations.

13.4.2 Substructure vs. Foundation

The demarcation 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 which are in direct contact with, and transmit loads to, the supporting rock or soil. In this **Manual**, this definition will be used.

13.4.3 Substructure vs. Superstructure

A similar difficulty exists in separating substructure and superstructure where these parts are integrated. This **Manual** will refer to the bearings and any component or element located above the bearings as the superstructure.

13.4.4 Jointless Bridges

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

1. load path,
2. gravity and longitudinal loads,
3. effects of concrete creep and shrinkage and temperature variations,
4. stability of superstructure and substructure during construction and service,
5. skew and curvature effects,
6. the superstructure - abutment - foundation connection design and details,
7. effects of superstructure and substructure stiffness,
8. settlement and earth pressure,
9. effects of varying soil properties and type of foundation, and
10. effect of approach slab and its connection to the bridge.

Jointless bridges in service have demonstrated the ability to perform under the previous considerations. Therefore, in the absence of in-depth analyses, it is reasonable to design a jointless bridge under the following parameters. Exceeding one or more of these parameters will require a more detailed analysis:

1. 50 mm of total movement at the abutment,
2. 20 degree skew or less, and
3. abutment types that are flexible with one row of piles.

13.4.4.1 Load Path

The load path can be described by how a load is distributed from its point of application through the bridge system. This distribution depends upon the relative stiffness of the individual bridge elements and the boundary conditions. It is important to consider the bridge as a complete system that resists the loads applied to it rather than to consider the bridge elements as resisting loads independently of the other elements. For example, the load path for an ice load applied to an intermediate bent includes the superstructure and the other bents of the bridge. The relative stiffness of the superstructure and the bents determine how the ice load is distributed. In most cases, it is conservative to assume the intermediate bent resists the full ice load and no load is distributed to any other elements. However, in some load situations, the distributed load may overstress another element that was not assumed to resist any load.

A longitudinal load path may consist of a superstructure segment transferring all the load to one bent while the other bents are released from loads with expansion bearings. Another load path may consist of transferring the load to all the bents through fixed connections.

Bridges that are symmetrical will respond better to loads. Bridges that are unsymmetrical will have high stress points.

Consideration of the load path due to thermal movement must be investigated to ensure that the actual response of the structure matches the expected response.

13.4.4.2 Longitudinal Loads

Longitudinal loads can be categorized as either internal or external forces. Internal forces such as thermal and shrinkage must be released. External forces such as braking, soil pressure and seismic must be resisted. Because design requirements for internal forces are opposite external forces, it is difficult to satisfy both conditions. Joints and expansion bearings or flexible supports release internal forces, and continuous decks, fixed connections and rigid supports resist external forces.

Bridges with joints and expansion bearings are not very efficient in resisting external loads. Typically, abutments must be constructed to resist backwall pressure or the joints may close. Intermediate bents with expansion bearings become unsupported longitudinally and require additional strength to react as a cantilever. Finally, intermediate bents with fixed bearings resist larger longitudinal loads and require additional strength.

A jointless bridge is efficient in resisting external loads because the load is shared by all bents, and the backwall pressure is resisted by the opposite bridge end. Intermediate bents are supported by the superstructure and abutments so that they do not act like cantilevers. A jointless bridge can be designed to balance the internal force effects with the external force effects. This can be achieved by balancing the longitudinal stiffness required to resist external loads with the stiffness required to release internal loads.

Internal forces in a bridge can be analyzed by segregating the bridge into segments. Each segment is bounded by an expansion joint or the end of the bridge. Internal forces originate from the center of the longitudinal stiffness of a segment, which is not necessarily the center of that segment.

13.4.4.3 Longitudinal Bridge Stiffness

Conceptually, stiffness can be thought of as a spring and is defined as the force required to produce a unit deflection.

Longitudinal bridge stiffness or the stiffness parallel to traffic is a function of the superstructure, bearings or connections, substructure, skew, foundation and soil properties. These variables should be considered when analyzing the longitudinal response of a structure.

Generally, the superstructure axial stiffness is so large that it can be considered rigid compared to the other variables that affect longitudinal stiffness. Therefore, the superstructure will translate before it compresses.

Each connection has six degrees of freedom, which may be released, fixed or partially fixed. The connection can control the continuity of the load path and the stiffness of the overall bridge system. Different connections provide many options to resist or release forces in any degree of freedom. Typically, connections are assumed to be released or fixed, but the actual response may be somewhere in between. For example, an expansion bearing is assumed to be released but, due to friction, will provide some resistance. Partially fixed connections, such as elastomeric bearings, have some advantages that can help balance the loads throughout the bridge system. A partially fixed connection is designed to flex or give so that the load applied to the connected element is limited or reduced.

The substructure stiffness can be expressed as:

$$\alpha EI / L^3$$

Where:

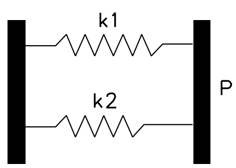
α = determined by the boundary conditions
E = modulus or elasticity
I = moment of inertia
L = effective member length

The boundary conditions are controlled by the connection of the elements. For the ideal fixed-fixed column, α is equal to 12 and, for a fixed-pin column, α is equal to 3. Where ideal conditions are not present because the cap or foundation is not completely fixed, α is somewhere between 12 and 3. The modulus of elasticity is determined from the compression strength which is defined by a specific 28-day strength. Because the actual 28-day strength typically exceeds the specified strength by 20% to 25% and concrete continues to gain strength with age, the actual strength and corresponding modulus are higher. Tests have shown the actual strength to be 1.5 to 2.7 times higher than the specified strength. This should be reflected by increasing the modulus of elasticity by 1.5. For concrete members, the moment of inertia is dependent on whether the concrete is cracked or uncracked. To determine maximum forces, it is conservative to use the gross moment of inertia. To calculate maximum displacements, an effective moment of inertia should be used. It may be too conservative to use the gross moment of inertia to analyze internal forces. The effective member length is the flexible length of the member, not the length based on centerline-to-centerline geometry. The effective member length can be different in the longitudinal direction than the transverse direction. If the substructure is expected to displace under thermal movement, then it should be designed to be flexible and to accommodate the required movement.

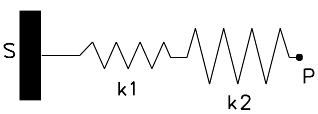
When a bent is skewed, the longitudinal bridge stiffness mobilizes the bent longitudinal and transverse stiffnesses. Typically, the transverse bent stiffness is much higher than the longitudinal bent stiffness. Therefore, the longitudinal bridge stiffness is increased. This increase can be reduced by using a single round column bent that has the same longitudinal and transverse stiffness.

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 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, then it should be flexible.

These individual stiffness variables combine in parallel or series to form an equivalent longitudinal spring. To differentiate between parallel and series, consider the displacement of the two springs. If two springs have the same displacement, then they are in parallel:



If two springs have relative displacements, then they are in series:



13.4.4.4 Skew

Thermal expansion of a jointless superstructure causes compression of the backfill at the abutments. These passive earth forces act on both ends of the jointless superstructure (Figure 13.4A). The forces are eccentric and will tend to rotate the superstructure. This rotational force is resisted by transverse backwall-soil interaction and the abutment substructure. Soil-backwall interaction is considered adequate to resist the superstructure rotation for skew angles less than 15 degrees. For skew angles greater than 15 degrees, additional resistance must be provided by the abutment substructure.

13.4.4.5 Geotechnical Considerations for Jointless Bridges

13.4.4.5.1 Site Conditions

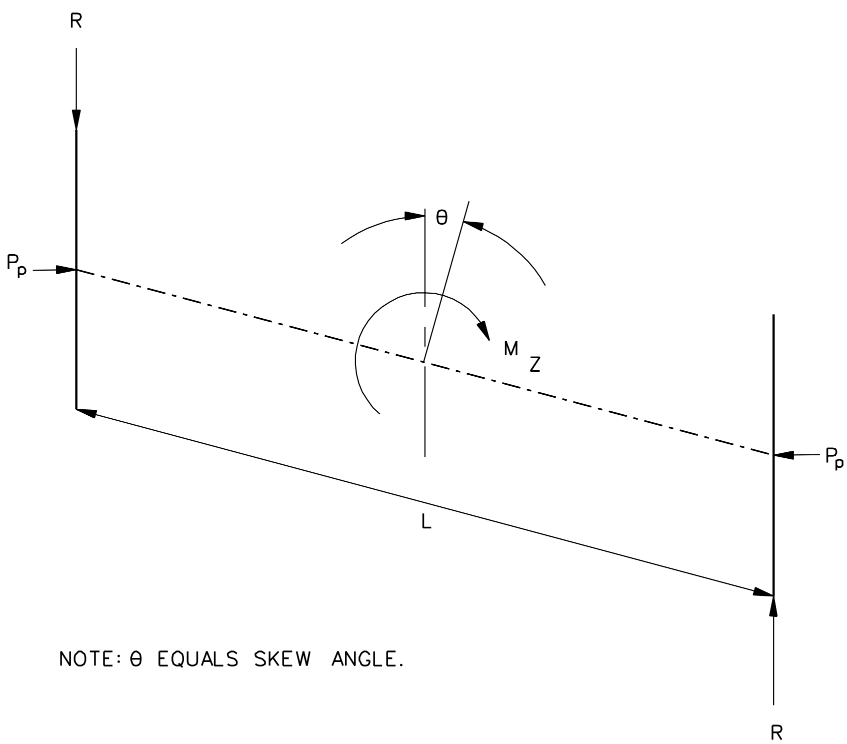
Geotechnical considerations for jointless bridges are generally the same as for jointed bridges, with additional consideration given to soil structure interactions and longitudinal stiffness.

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 Section regarding subsurface conditions at the bridge site. Generally, geotechnical investigations consistent 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. This requires “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 foundations also have an increased risk of significant axial settlement. While longitudinal deflections of the foundations are encouraged, axial settlement is discouraged. Foundations at jointless bridges will generally require a more in-depth geotechnical analysis than jointed bridges.

13.4.4.5.2 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



ROTATION DUE TO THERMAL EXPANSION

Figure 13.4A

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.

The type of foundation used at a jointless bridge will largely be determined by the type of soil at the project site. 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. Deep foundations in these soil deposits will be flexible enough to accommodate large longitudinal movements associated with long jointless bridges. However, high to moderate axial 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 locating 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 for a long jointless bridge. Short jointless bridges, however, may use these types of foundations in these soil deposits, when significant longitudinal movement is not expected. Typically, spread footings can be used in these soil conditions. Spread footings are typically very stiff foundations and can often be considered rigid in soil deposits of this nature. Axial 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 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 bridges. In these soil conditions, the length of the bridge and the foundation type will be critical. Axial settlements may range from negligible to moderate in these soil deposits.

13.4.4.5.3 Abutments

Backfill limits and in-situ soil conditions should be considered very carefully when examining longitudinal abutment movements. Granular backfill consisting of crushed sand and gravel can mobilize full passive pressure at wall movements of approximately ½% - 1% of the height. If abutment movements are expected to achieve full passive pressure of the backfill, the capacity of the structure to move at, and tolerate, full passive pressure needs to be verified. The passive pressure of both the backfill and the in-situ material should be calculated using log spiral methods that incorporate wall friction such as the method developed by Caquot & Kerisel. Abutment movement necessary to develop full passive soil pressure can be estimated using data provided by Clough and Duncan, 1991. The limits of the backfill should be adjusted based on the expected failure surface for the two soils, the expected longitudinal movement, and the amount of passive pressure that can be tolerated by the structure.

Pile stiffness should also be incorporated into the analysis of abutments. The types of piles used at the abutments will depend largely on the in-situ soil conditions and the intent of the design. The Geotechnical Section should be requested to make recommendations regarding pile type and length based on the subsurface investigations. However, it should be noted that flexibility at the abutments is required, especially when integral abutments are used. For this reason, where soil conditions permit, H-piles should be used with integral abutments. Pipe piles may also be acceptable. Special features at the upper portions of the pile may be required to achieve the desired flexibility.

Select backfill should be installed at bridge abutments, where recommended by the Geotechnical Section.

Additional drainage features such as weep holes, drainage mats and drain pipe should be considered for use in areas of cohesive soil or frequent inundations.

13.4.5 Integral Abutments

Integral abutments are end bents where the superstructure is extended directly into the abutment backwall. There is no joint in the bridge deck, the backwall is rigidly connected to the pile cap, and there are no bearings under the beams. Integral abutments 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.

Integral abutments will create negative moments in the slab-abutment zone. Additional reinforcement details are required.

Integral abutments are limited by the translational movement of the piles.

There can not be any settlement in the piles because the superstructure can not be raised for maintenance. If there is a possibility of settlement, consider a semi-integral abutment.

13.4.6 Semi-Integral Abutments

Semi-integral abutments are similar to integral abutments except there is a pinned connection between the backwall and the pile cap and the beams rest on a bearing. This is MDT's typical stub abutment configuration. Expansion bearings can be used to reduce translation in the substructure. The pin joint between the backwall and the cap allows the superstructure to be raised if needed.

13.4.7 Substructures (Intermediate Supports)

13.4.7.1 Type Selection

The following summarizes MDT typical practice for the selection of intermediate supports for bridges:

1. Highway/Water Crossings. If lateral forces (e.g., seismic, debris, ice) are light, an extended pile bent is the preferred selection for the intermediate support. Otherwise, use a solid shaft pier or drilled shaft depending on soil conditions.

2. Highway/Meandering Streams. Use single round columns with hammerhead caps.

3. Highway/Highway Crossings. Use multi-column bents with caps.

4. Highway/Railroad Crossings. Use multi-column bents with caps or a single column pier with a hammerhead cap and a crash wall, if required by railroad clearance policies.

The following sections briefly describe the intermediate supports used by MDT.

13.4.7.2 Extended Pile or Shaft Bents

Under certain conditions, the economy of substructures can be enhanced by extending the deep foundation above ground level to the superstructure. These conditions exclude the presence of large horizontal forces which may develop due to seismic activity, collision by vehicles, ice, or stream flow intensified by accumulated debris.

The extended piles or shafts always need a cap-beam for structural soundness. This cap-beam may be an integral part of the superstructure.

13.4.7.3 Piers

Figures 13.4B and 13.4C provide schematics in the plan and elevation views of various pier types. Generally, the round column (Figure 13.4B(a)) is the most economical, because it is easy to construct and performs well seismically.

In debris-prone or ice-prone streams, the wall-type pier or single column with hammerhead is preferred.

Piers located in waterways susceptible to ice accumulation should be fitted with steel ice protection (Figure 13.4B(e)).

13.4.7.4 Frame Bents

Concrete frame bents are favored to support a variety of steel and concrete superstructures. The columns of the bent can be either circular or rectangular in cross section.

Figure 13.4D illustrates the most common type of concrete bent consisting of vertical columns and a cap beam, which is typically used for highway grade separation structures.

13.4.8 Foundations

13.4.8.1 Coordination with Geotechnical Section

The selection of the foundation type is a collaborative effort between the Bridge Bureau and Geotechnical Section based on the Geotechnical Report, expected superstructure type, scour potential, etc.

The Bridge Bureau typically provides the Geotechnical Section with the applicable loads and an initial recommendation for foundation type. The Geotechnical Section reviews the foundation type recommended by the Bridge Bureau and provides the Bridge Bureau with the engineering data for foundation design.

See Chapter Two “Bridge Project Development Process” of the **Montana Structures Manual** for the timing between the Geotechnical Section and Bridge Bureau for foundation design.

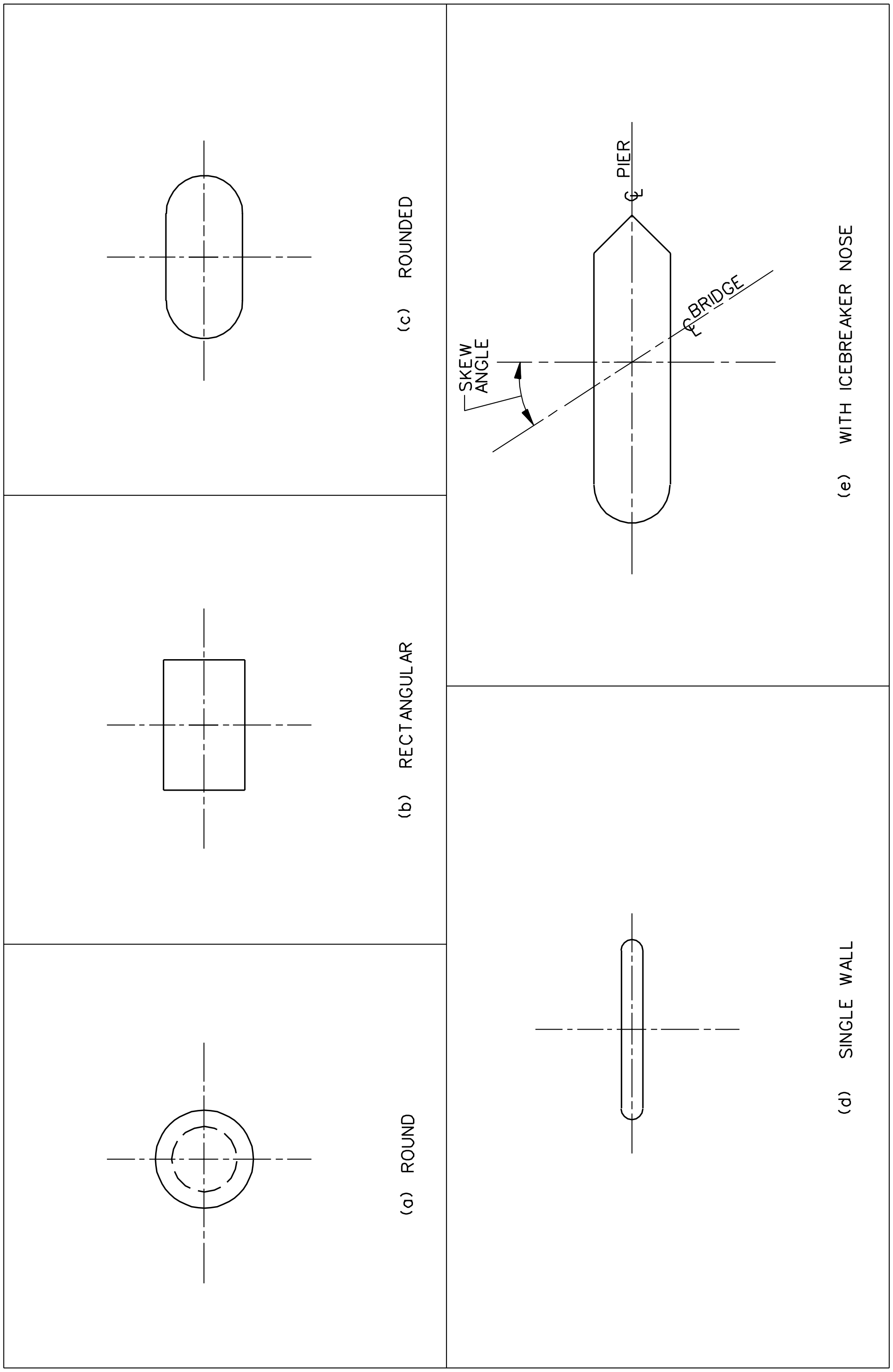
13.4.8.2 Impact on Superstructure Type

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.

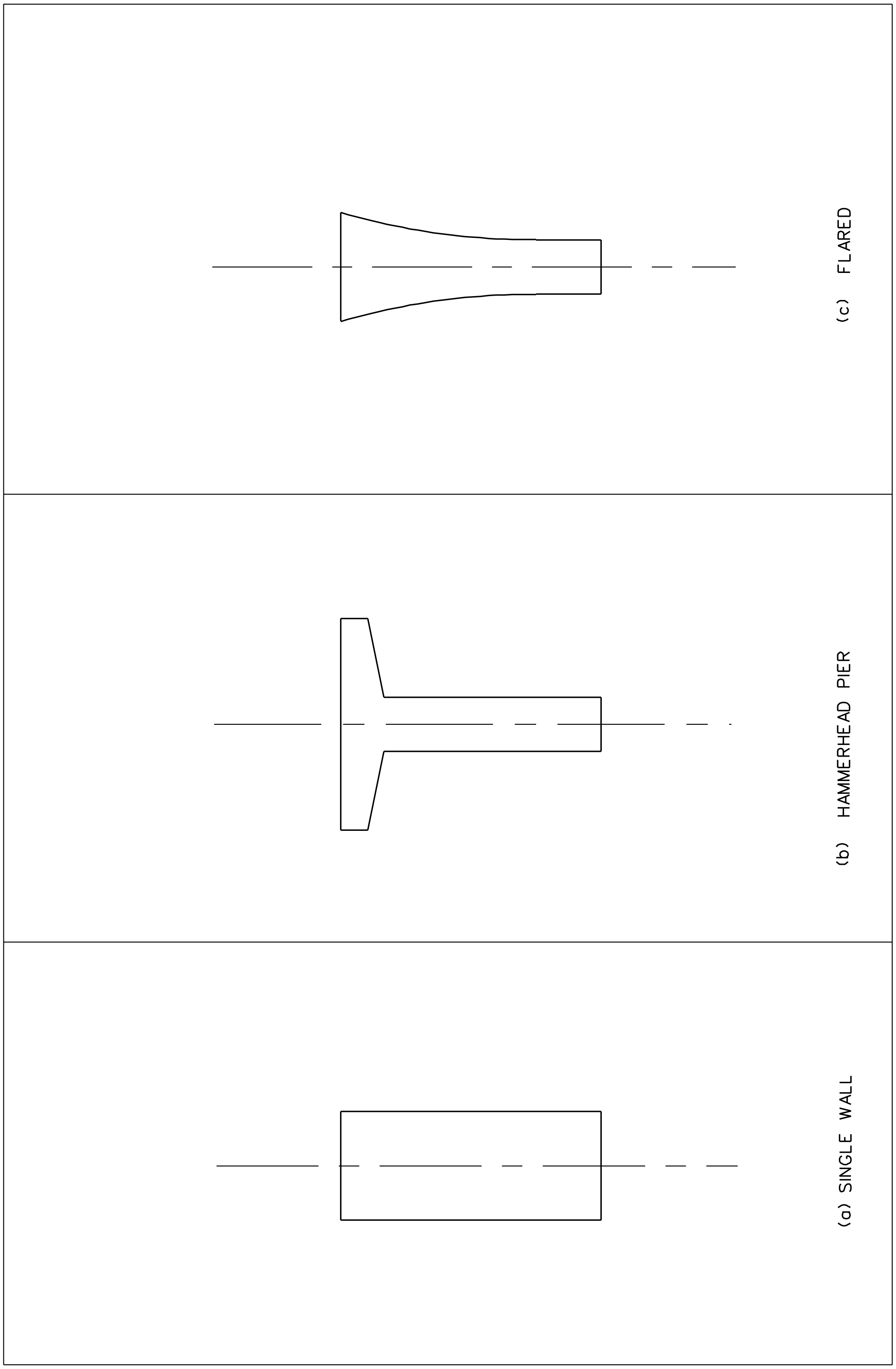
2. Dead Load. When foundation conditions are generally poor, or seismic loads are high, the economics of using structural steel over concrete should be considered.

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.



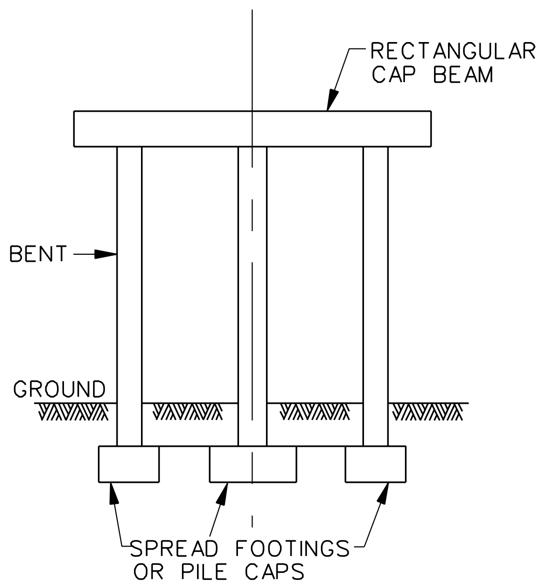
PIER STEM AND COLUMN CONFIGURATIONS
(Plan View)

Figure 13.4B



STEM CONFIGURATION OF PIERS
(Elevation View)

Figure 13.4C



CONCRETE BENT

FRAME BENTS

Figure 13.4D

13.4.8.3 Usage

The following summarizes MDT typical practices for the selection of the type of foundation:

1. Spread Footings. Use if the anticipated depth of scour is not excessive; however, do not use in fills. Spread footings are not recommended for use at stream crossings where they may be susceptible to scour. The use of spread footings requires firm bearing conditions. Spread footings normally are thick, concrete slabs whose geometry is determined by structural requirements and the characteristics of supporting components, such as soil or rock. Their primary role is to distribute the loads transmitted by piers, bents or abutments to suitable soil strata or rock at relatively shallow depths.

2. Piles. Use in soft soils or for deep bedrock; use where the anticipated depth of scour is excessive; use to control settlement. 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. MDT typically uses steel pipe piles and H-piles.

3. Drilled Shafts. Use as a deep foundation where cofferdams are a problem, where significant scour is expected, where there are limits on in-stream work or where driven piles are not economically viable due to high loads or obstructions to driving. Limitations on vibration or construction noise may also dictate the selection of this foundation type.

Figure 13.4E illustrates the basic types of foundations used by MDT. The following provides additional information with respect to interior supports at stream crossings.

13.4.8.4 Foundations For Intermediate Supports

For intermediate supports at stream crossings, MDT typically uses piles, either extended piles or piles with a pile cap footing. Where excessive scour is not expected and good load-bearing soil is close to the surface, the use of spread footings located below the anticipated depth of scour may be considered as an alternative.

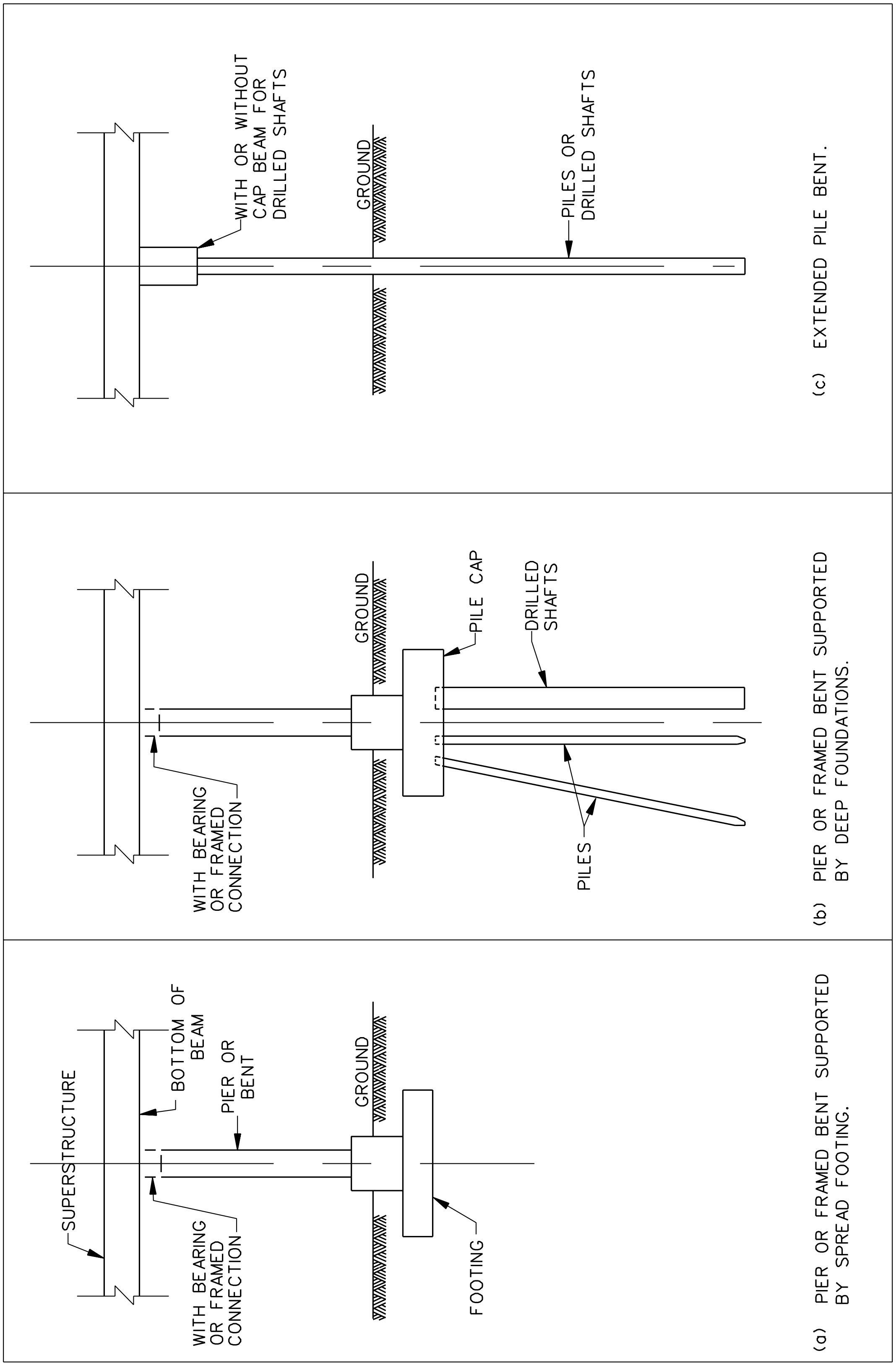
13.4.8.4.1 Supported by Spread Footing

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.

In general, spread footings require a reasonably good foundation material close to the ground surface. In all cases, the bottom of spread footings on soil should be below the frost level which, in Montana, is considered 1.5 m.

13.4.8.4.2 Supported by Deep Foundation

Where conditions that permit the use of spread footings are not present, deep foundations, such as drilled shafts or piles, should be considered.



TYPICAL FOUNDATION TYPES

Figure 13.4E

13.5 ROADWAY DESIGN ELEMENTS

The **Montana Road Design Manual** documents MDT'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 road designer and bridge designer to identify and resolve any problems. Section 13.5 of the **Structures Manual** provides roadway design information which is directly relevant to determining the structural dimensions for bridge design and to provide the bridge designer with some background in road design elements.

13.5.1 General Procedures

13.5.1.1 Division of Responsibilities

Determining the roadway design for a bridge or underpass is a collaborative effort between the Bridge Bureau and Road Design Section. At this stage of project development (i.e., determining the dimensions of the structure), the basic process is:

1. Preliminary Alignment. The road designer provides the Bridge Bureau with preliminary horizontal and vertical alignments.

2. Structural Dimensions. The bridge designer determines a preliminary structure length and depth of superstructure, and the bridge designer provides approximate bridge end elevations.

3. Final Alignment. The road designer modifies the alignment as necessary, based on the preliminary grade recommendations from the bridge designer. The Bridge Bureau reviews and comments on the proposed roadway geometrics.

4. Roadway Cross Section. See Section 13.5.4 for the determination of the roadway cross section (e.g., width, cross slope).

13.5.1.2 Coordination in Project Development

Chapter Two "Bridge Project Development Process" of the **Montana Structures Manual** documents the project development process for bridge projects when the Bridge Bureau is the lead unit for project development. The project networks in Chapter Two illustrate the timing of the interaction between the Road Design Section and Bridge Bureau in determining the roadway design across a bridge and through an underpass. The bridge designer should refer to Chapter Two for coordination in project development.

Chapter One "Road Design Process" of the **Montana Road Design Manual** documents the project development process for roadway projects when the Road Design Section is the lead unit for project development. Where a bridge is within the limits of a road-lead project, the bridge designer should refer to Chapter One for coordination.

13.5.1.3 Scope of Bridge Work

The determination of the roadway design for a bridge is based on the scope (or extent) of the proposed structural work. See Section 13.1.1.

Chapter Thirteen of the **Montana Structures Manual** provides roadway design criteria only for a new bridge and bridge replacement projects. Chapter Twenty-two provides roadway design criteria for all other scopes of bridge work.

13.5.2 Roadway Definitions

Chapter Twenty-one of the **Montana Road Design Manual** provides an in-depth glossary of terms which are used in road design. The following defines selected roadway elements which often have an application to the roadway design portion of a bridge:

1. Average Annual Daily Traffic (AADT). The total yearly volume in both directions of travel divided by the number of days in a year.

2. Average Daily Traffic (ADT). The total traffic volumes in both directions of travel in a time period greater than one day and less than one year divided by the number of days in that time period.

3. Bridge Roadway Width. The clear width of the structure measured at right angles to the center of the roadway between the bottom of curbs or, if curbs are not used, between the inner faces of parapet or railing.

4. Cross Slope. The slope in the cross section view of the travel lanes, expressed as a percent, based on the change in vertical compared to the change in horizontal.

5. Design Exception. The process of receiving approval from the FHWA or MDT Preconstruction Engineer for using geometric design criteria which does not meet the criteria set forth in the **Montana Road Design Manual**.

6. Design Speed. The selected speed used to determine the various geometric design features of the roadway.

7. Grade Slope. The rate of slope between two adjacent VPIs expressed as a percent. The numerical value for percent of grade is the vertical rise or fall in meters for each 100 m of horizontal distance. Upgrades in the direction of stationing are identified as plus (+). Downgrades are identified as minus (-).

8. K-Values. For a crest or sag vertical curve, the horizontal distance (in meters) needed to produce a 1% change in longitudinal gradient.

9. Median. The portion of a divided highway separating the two traveled ways for traffic in opposite directions. The median width includes both inside shoulders.

10. Normal Crown (NC). The typical cross section on a tangent section referenced to centerline with equal downslope to the edge of pavement.

11. Profile Grade Line. A series of tangent lines connected by vertical curves. It is typically placed along the roadway centerline of undivided facilities and at the edges of the two roadways on the median side on divided facilities.

12. Roadway. The portion of a highway, including shoulders, for vehicular use. A divided highway has two roadways.

13. Superelevation. The amount of cross slope or "bank" provided on a horizontal curve to help counterbalance the outward pull of a vehicle traversing the curve.

14. Superelevation Transition Length. The distance required to transition the roadway from a normal crown section to the full superelevation. Superelevation transition length is the sum of the tangent runout and superelevation runoff distances.

15. Traveled Way. The portion of the roadway for the through movement of vehicles, exclusive of shoulders and auxiliary lanes.

13.5.3 Highway Systems

Section 8.2 of the **Montana Road Design Manual** discusses the functional classification system and the Federal-aid system. Because of their impact on the roadway design elements of a structure, the following discussion presents a summary of these two systems.

13.5.3.1 Functional Classification System

The functional classification concept is one of the most important determining factors in highway design. The system recognizes that the public highway network serves two basic and often conflicting functions — travel mobility and access to property. In the functional classification scheme, the overall objective is that the highway system, when viewed in its entirety, will yield an optimum balance between its access and mobility purposes.

The functional classification system provides the guidelines for determining the geometric design of individual highways and streets. Based on the function of the facility, the designer can select an appropriate design speed, roadway width, roadside safety elements, amenities and other design values. The **Montana Road Design Manual** is based upon this systematic concept to determining geometric design.

The Rail, Transit and Planning Division has functionally classified all public roads and streets within Montana. For road design, it is necessary to identify the predicted functional class of the road for the selected design year (e.g., 20 years beyond the project completion date). The Rail, Transit and Planning Division will provide this information to the designer.

The following briefly describes the functional characteristics of the various classifications.

13.5.3.1.1 Arterials

Arterial highways are characterized by a capacity to quickly move relatively large volumes of traffic and an often restricted function to serve abutting properties. The arterial system typically provides for high travel speeds and the longest trip movements. The arterial functional class is subdivided into principal and minor categories for rural and urban areas.

Principal arterials provide the highest traffic volumes and the greatest trip lengths. The freeway, which includes Interstate highways, is the highest level of arterial. In rural areas, minor arterials will provide a mix of interstate and interregional travel service. In urban areas, minor arterials may carry local bus routes and provide intra-community connections.

13.5.3.1.2 Collectors

Collector routes are characterized by a roughly even distribution of their access and mobility functions. Traffic volumes will typically be somewhat lower than those of arterials. In rural areas, collectors serve intra-regional needs and provide connections to the arterial system. In urban areas, collectors act as intermediate links between the arterial system and points of origin and destination.

13.5.3.1.3 Local Roads and Streets

All public roads and streets not classified as arterials or collectors are classified as local roads and streets. These facilities are characterized by their many points of direct access to adjacent properties and their relatively minor value in accommodating mobility.

13.5.3.2 Federal-Aid System

The Federal-aid system consists of those routes within Montana which are eligible for the categorical Federal highway funds. The Department, working with the local governments and in cooperation with FHWA, has designated the eligible routes. The following briefly describes the components of the Federal-aid system.

13.5.3.2.1 National Highway System

The National Highway System (NHS) is a system of those highways determined to have the greatest national importance to transportation, commerce and defense in the United States. It consists of the Interstate highway system, logical additions to the Interstate system, selected other principal arterials, and other facilities which meet the requirements of one of the subsystems within the NHS.

13.5.3.2.2 Surface Transportation Program

The Surface Transportation Program (STP) is a block-grant program which provides Federal-aid funds for any public road not functionally classified as a minor rural collector or a local road or street. The STP replaced a portion of the former Federal-aid primary system and replaced all of the former Federal-aid secondary and urban systems, and it includes some collector routes which were not previously on any Federal-aid system. Collectively, these are called Federal-aid Roads. In addition, bridge projects using STP funds are not restricted to Federal-aid Roads but may be used on any public road. The basic objective of the STP is to provide Federal funds for improvements to facilities not considered to have significant national importance with a minimum of Federal requirements for funding eligibility.

13.5.3.2.3 Highway Bridge Replacement and Rehabilitation Program

Because of the nationwide emphasis on bridges, the Highway Bridge Replacement and Rehabilitation Program (HBRRP) has its own separate identity within the Federal-aid program. HBRRP funds are eligible for work on any bridge on a public road regardless of its functional classification. Chapter Twenty-two of the **Montana Structures Manual** briefly discusses the MDT implementation of the HBRRP within the context of bridge rehabilitation projects. The use of HBRRP funds for bridge removal is not appropriate.

13.5.4 Roadway Cross Section (Bridges)

Section 13.6 presents criteria for roadway widths across rural bridges based on the type of highway, and it presents several typical bridge sections. Section 13.5.4 presents additional information on the roadway cross sections for bridges.

13.5.4.1 Montana Road Design Manual

Chapters Eleven and Twelve of the **Montana Road Design Manual** provide the MDT 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. Section 11.7 of the **Road Design Manual** provides numerous typical sections for various combinations of functional classification, rural/urban location, type of median and multilane/two-lane roadways. Chapter Twelve provides detailed tables of geometric design criteria for various classes of highway and rural/urban location. Sections 13.5.4 and 13.6 of the **Montana Structures Manual** provide MDT criteria for roadway cross section elements specifically across bridges.

13.5.4.2 Profile Grade Line

The location of the profile grade line on the bridge must match the location of the profile grade line on the approaching roadway. The profile grade line location varies according to the functional class of the highway, divided versus undivided, type of median and median width. See Section 10.2.3.2 of the **Montana Road Design Manual** for MDT criteria.

13.5.4.3 Cross Slopes and Crowns

All bridges on tangent sections provide a uniform cross slope of 2% from the crown line to the edge of the bridge curb, parapet or rail. If the traveled way crown slope on the approaching roadway is other than 2%, the roadway must be transitioned to a uniform 2% slope before it reaches the bridge; this is the responsibility of the road designer when designing the roadway approaches. If the roadway section is superelevated, the bridge cross slope will match the superelevation rate of the roadway.

13.5.4.4 Width

The Bridge Bureau determines the bridge width according to the criteria presented in Sections 13.5.4 and 13.6. However, this width must not be less than the roadway width presented in Chapter Twelve of the **Montana Road Design Manual**.

The bridge width will be determined by:

1. the functional class of the highway;
2. the approaching roadway width;
3. the presence of sidewalks and/or bikeways;
4. the presence of auxiliary lanes;
5. for divided facilities, whether a single or dual structure is used; and
6. AADT and DHV.

See Section 13.6 for specific bridge width criteria.

13.5.4.5 Sidewalks

13.5.4.5.1 Guidelines

Sidewalk requirements on bridges will be determined jointly by the Bridge Bureau, the Road Design Section and the District. On bridge rehabilitation projects, the need for sidewalks will be considered on a case-by-case basis. The following guidance will be used to determine the need for sidewalks on a bridge:

1. <u>Sidewalks Currently Exist</u>. If a bridge with an existing sidewalk is replaced or reconstructed, the sidewalk will normally be replaced.
2. <u>Bridge Without Sidewalk/Roadway With Sidewalk</u>. If a bridge without a sidewalk will be replaced and if existing sidewalks approach the bridge, a sidewalk will normally be included in the bridge project. Even if not currently on the approaching roadway, sidewalks may still be necessary on the bridge if the approach roadway is a candidate for future sidewalks.

   As a more general statement of MDT policy, bridge projects within urban areas will have a sidewalk where pedestrians are legally allowed, unless there is a compelling reason not to provide a sidewalk. In addition, bridges at interchanges near urban areas should normally include sidewalks to accommodate the commercial development that typically occurs in the immediate vicinity of interchanges.
3. <u>One Side vs. Two Sides</u>. 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.
4. <u>Approval</u>. For all projects in urban areas, the final decision on sidewalk requirements will be made by the Preconstruction Engineer.

13.5.4.5.2 Cross Section

The typical sidewalk configuration is shown in Figure 13.6D.

13.5.4.6 Bikeways

The bicycle is classified as a vehicle according to the **Montana Codes Annotated**, and bicyclists are granted all of the rights and are subject to all of the duties applicable to the driver of any other vehicle. Section 18.2 of the **Montana Road Design Manual** provides definitions for types of bikeways (i.e., bicycle path, bicycle lane and widened shoulders) and provides criteria for bikeway design.

A bridge may need to be configured to accommodate bicycle traffic. One possible accommodation is to provide wider traffic lanes (i.e., a 4.2-m minimum width). The preferred accommodation is to provide a shoulder wide enough to accommodate bicycles. Although a 1.2-m wide shoulder is considered adequate for bicycle traffic, this needs to be increased by 300 mm to provide a shy distance where curbs or barriers are present. Therefore, a 1.5-m wide shoulder is considered the minimum shoulder width for bridges that are anticipated to carry bicycle traffic.

If the approaching roadway includes a separate bicycle lane, then the width of the lane will be carried across the bridge. Requests for and consideration of anticipated future bicycle lanes are only warranted when they are part of the Master Transportation Plan for the local government. Bicycle issues must be discussed at the Preliminary Field Review to establish a consensus on the level of bicycle accommodation that may be required on specific projects.

13.5.4.7 Medians

For divided 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. This will be determined on a case-by-case basis. As a general rule, 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. See Section 11.3 of the **Montana Road Design Manual** for more information on medians.

13.5.5 <u>Alignment at Bridges</u>

13.5.5.1 Horizontal Alignment

The road designer will determine the horizontal alignment at the bridge based on Chapter Nine of the **Montana Road 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. From 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, any transitions should not be located on the bridge or its approach slabs. This includes both superelevation transitions and spiral transitions. This will result in a uniform cross slope (i.e., the design superelevation rate) and a constant rate of curvature 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 which 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.

13.5.5.2 Vertical Alignment

As discussed in Section 13.5.1, the road designer and bridge designer will collaborate on the vertical alignment or profile of the roadway across a bridge. Chapter Ten of the **Montana Road Design Manual** provides the Department's criteria. The following applies specifically to the vertical alignment at bridges:

1. Minimum Gradient. For bridges with a parapet rail, the minimum longitudinal gradient is 0.2%. For bridges with an open rail, the minimum longitudinal gradient is 0.0%.

2. Maximum Grades. See Chapter Twelve of the **Montana Road Design Manual** for the Department's maximum grade criteria based on the highway system and rural/urban location.

3. Vertical Curves. Vertical curves will be designed according to Chapter Ten of the **Montana Road Design Manual**. Where bridges are located on sag or crest vertical curves, consideration must be provided to haunch depths and shear connector heights.

13.5.5.3 Skew

The maximum skew angle on a bridge without approval is 35°. The Bridge Area Engineer must approve the use of greater skew angles. Also, the bridge skew should not match the angle of a snowplow, which is 35° to 37° right.

13.5.6 Roadway Cross Section (Underpasses)

For highway bridges over highways, the design of the underpassing roadway will determine the length of the overpassing bridge. Section 13.6 presents several typical sections for bridge underpasses. Section 13.5.6 presents additional information on roadway design elements for underpasses.

13.5.6.1 Roadway Section

The approaching roadway cross section, including any auxiliary lanes, should be carried through the underpass. Chapters Eleven and Twelve of the **Montana Road Design Manual** present the MDT criteria for roadway widths based on highway system and rural/urban location.

13.5.6.2 Roadside Clear Zones

Desirably, the roadside clear zone applicable to the approaching roadway section will be provided through the underpass. Chapter Fourteen of the **Montana Road Design Manual** provides MDT criteria for clear zones, which are based on design speed, traffic volumes and side slope configuration. If this is impractical, an alternative is to provide roadside barrier protection for piers, walls, abutments, etc., located within the clear zone.

13.5.6.3 Sidewalks/Bikeways

The principles and design criteria expressed in Section 13.5.4.5 and 13.5.4.6 for sidewalks and bikeways on bridges also apply to underpasses.

13.5.6.4 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. Chapter Twelve of the **Montana Road Design Manual** presents the Department's vertical clearance criteria for underpassing roadways based on type of highway and rural/urban location.

13.5.6.5 Future Expansion

When determining the cross section width of an underpass, the designer should also consider the likelihood of future roadway widening. Widening an existing underpass can be extremely expensive, and it may be warranted, if some flexibility is available, to allow for possible future roadway expansion in the initial bridge construction. Therefore, the designer should evaluate the potential for further development in the vicinity of the underpass which would significantly increase traffic volumes. If appropriate, a reasonable allowance for future widening may be to provide sufficient lateral clearance for one additional lane in each direction.

13.6 STRUCTURE DIMENSIONS (Design Aids)

Section 13.6 presents the following design aids to assist in determining the dimensions of the structure for preliminary design:

1. design criteria for widths on rural bridges,

2. typical sections for bridges and underpasses,

3. calculating structure lengths for stream crossings and highway crossings, and

4. end bent dimensioning and configuration.

13.6.1 Rural Bridge Widths

MDT has produced the **Montana Bridge Design Standards**, which is a separate document. These Standards are among very few formally approved "Standards" currently in use by the Department. There is not total agreement among the bridge widths shown on these standards and the roadway widths in Chapter Twelve of the **Montana Road Design Manual**. Within some broad parameters, virtually all information in the **Montana Road Design Manual** is considered guidance. When deviating from the **Montana Bridge Design Standards**, formal design exception approval from the Bridge Engineer must be secured.

13.6.2 Typical Sections

Section 13.6.2 presents typical section figures for bridges and underpasses as follows:

1. Figure 13.6A "Bridge Cross Section (Freeways/Interstates)."

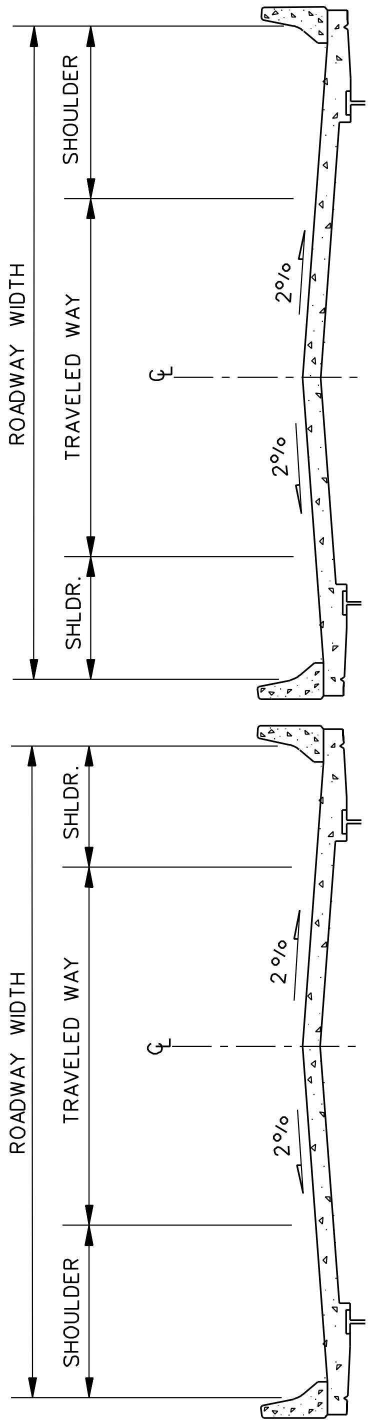
2. Figure 13.6B "Bridge Cross Section (Multi-lane Highways — Single Structure)."

3. Figure 13.6C "Bridge Cross Section (Rural, Two-Lane, Two-Way Highway)."

4. Figure 13.6D "Bridge Cross Section (Urban, Two-Lane, Two-Way Highway)."

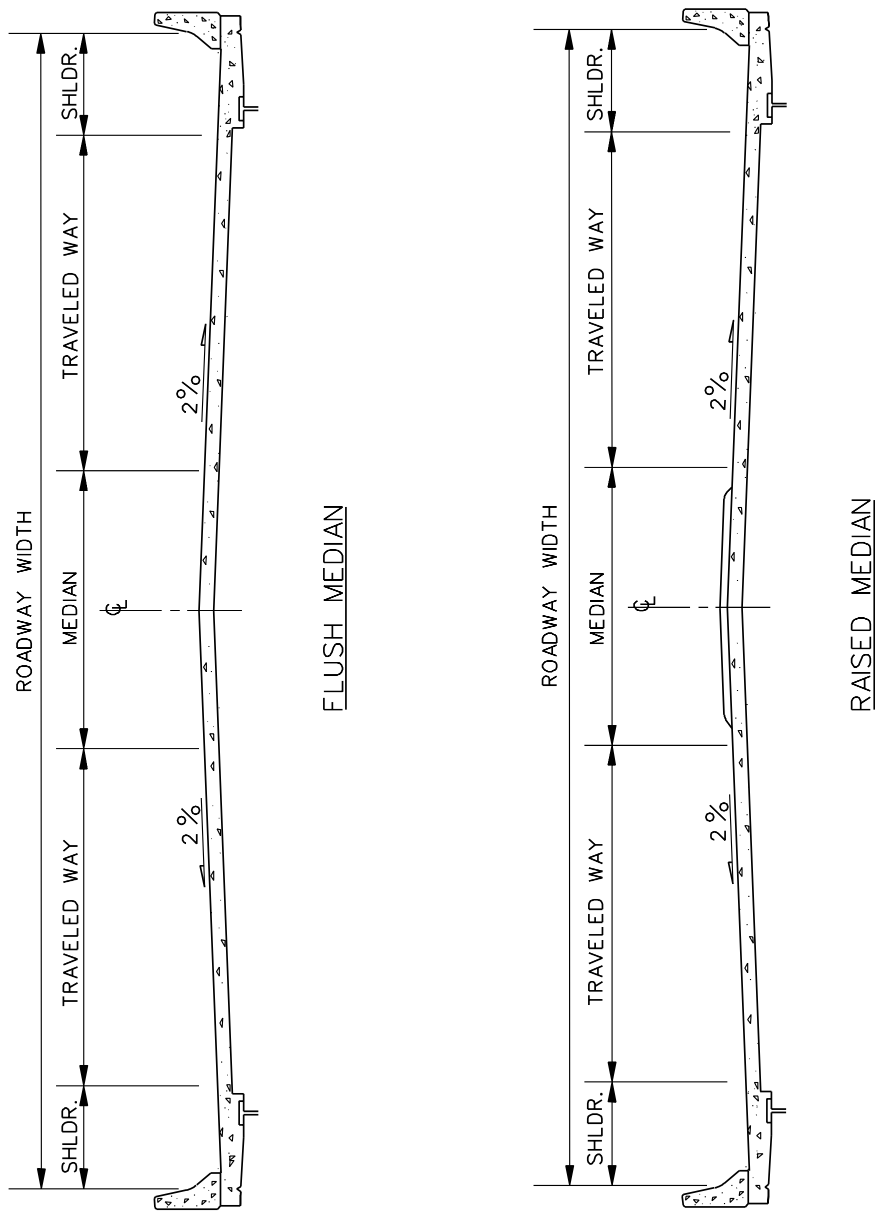
5. Figure 13.6E "Freeway Underpass Cross Section."

6. Figure 13.6F "Non-Freeway, Two-Lane Underpass Cross Section."



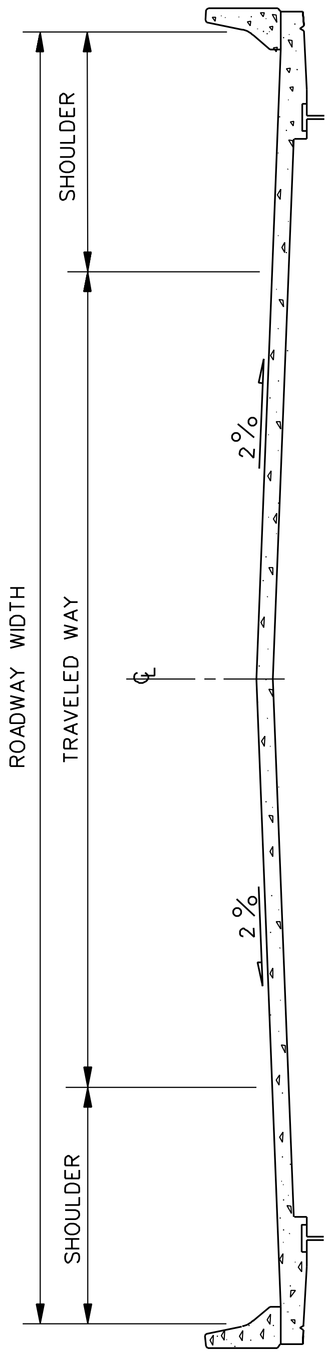
BRIDGE CROSS SECTION
(Freeways/Interstates)

Figure 13.6A



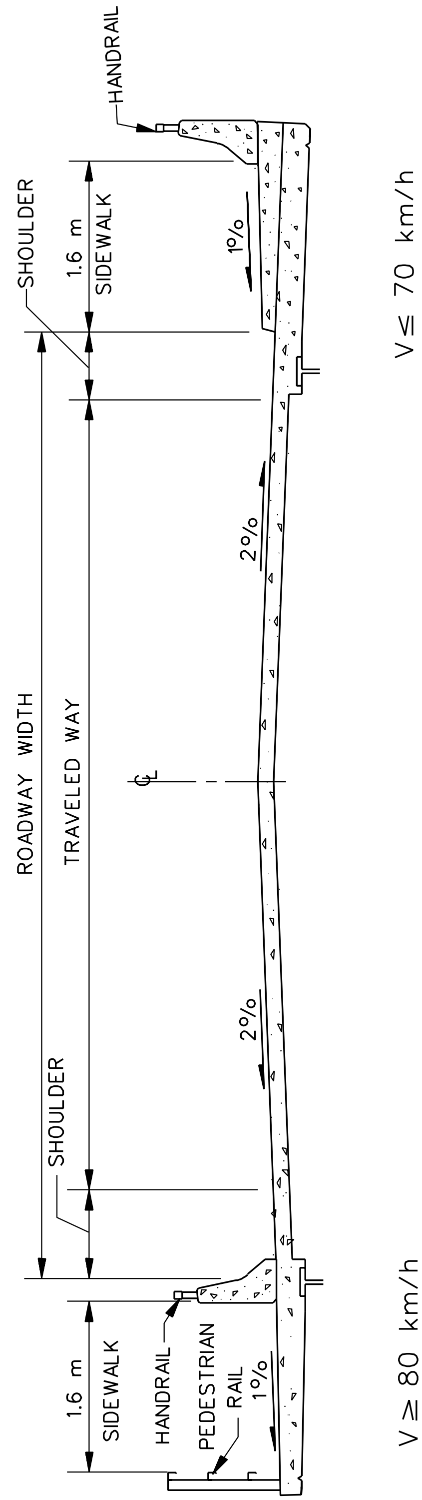
BRIDGE CROSS SECTION
(Multi-Lane Highways — Single Structure)

Figure 13.6B



BRIDGE CROSS SECTION
(Rural, Two-Lane, Two-Way Highway)

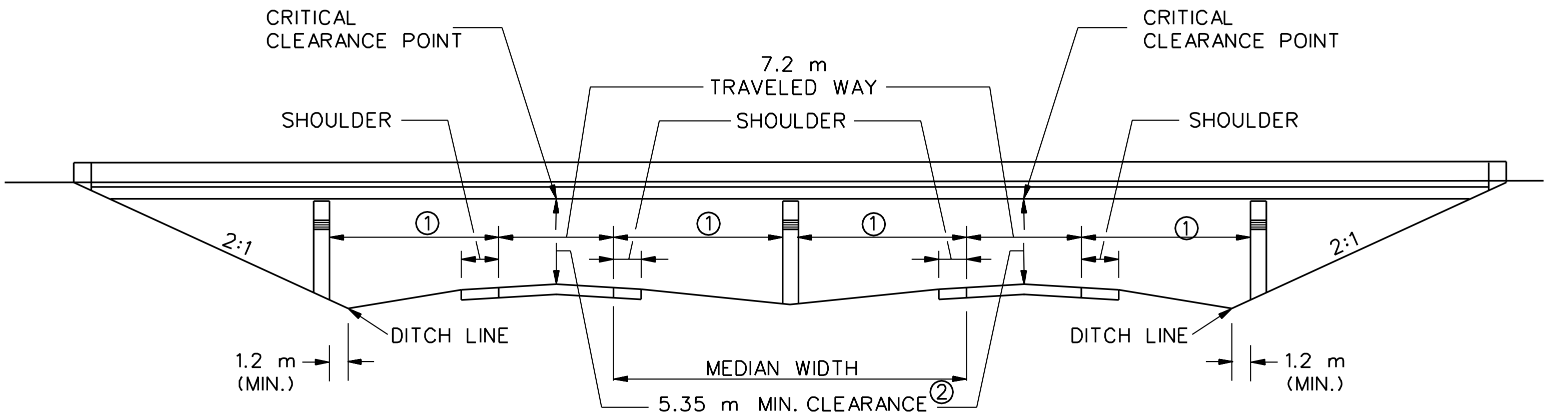
Figure 13.6C



NOTE: USE RAISED SIDEWALK ONLY IF ADEQUATE SHOULDER WIDTH IS PROVIDED. CONSIDER AADT AND DESIGN SPEED WHEN DETERMINING ADEQUATE SHOULDER WIDTH.

BRIDGE CROSS SECTION
(Urban, Two-Lane, Two-Way Highway)

Figure 13.6D

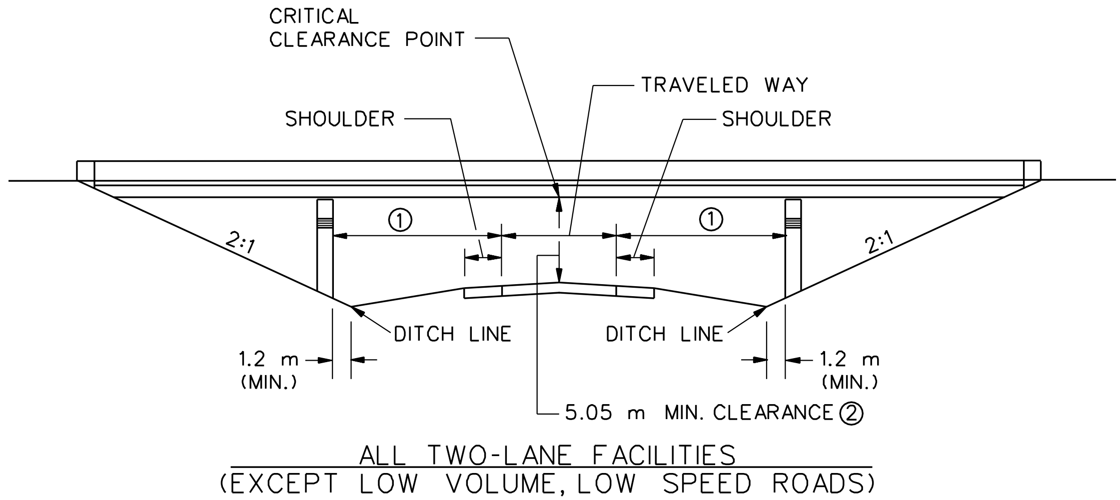


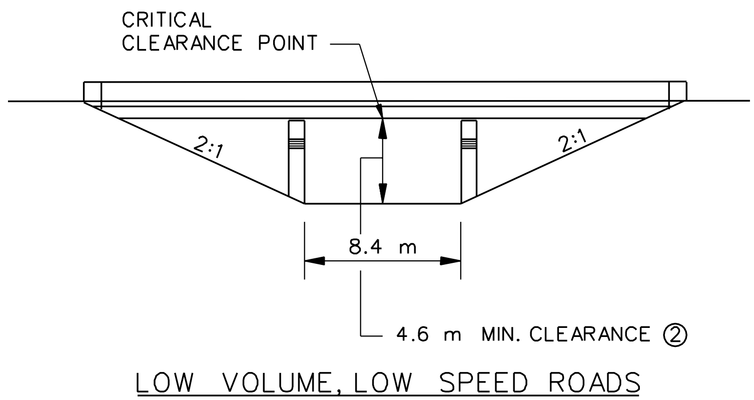
① CLEAR ZONE (SEE CHAPTER 14 MDT ROAD DESIGN MANUAL). IF CLEAR ZONE IS NOT AVAILABLE OR FEASIBLE, USE ROADSIDE BARRIER IN ACCORDANCE WITH "MDT STANDARD DRAWINGS".

② MINIMUM ALLOWABLE CLEARANCE IS 4.9 m BUT PROVIDE 5.35 m FOR INITIAL DESIGN TO ALLOW FOR FUTURE OVERLAYS AND SNOWPACK. WITH THE HIGHER CLEARANCE, UP TO 150 mm OF SURFACING MAY BE PLACED WITHOUT THE NEED TO REVISE ROADWAY GRADES. CLEARANCES LESS THAN 4.9 m WILL BE POSTED IN ACCORDANCE WITH THE VERTICAL CLEARANCE POSTING POLICY.

FREEWAY UNDERPASS CROSS SECTION
(New Bridges/Bridge Replacements)

Figure 13.6E





① CLEAR ZONE (SEE CHAPTER 14 MDT ROAD DESIGN MANUAL). IF CLEAR ZONE IS NOT AVAILABLE OR FEASIBLE, USE ROADSIDE BARRIER IN ACCORDANCE WITH "MDT STANDARD DRAWINGS".

② UP TO 150 mm OF SURFACING MAY BE PLACED WITHOUT THE NEED TO REVISE ROADWAY GRADES. CLEARANCES LESS THAN 4.9 m WILL BE POSTED IN ACCORDANCE WITH THE VERTICAL CLEARANCE POSTING POLICY.

NON-FREEWAY, TWO-LANE UNDERPASS CROSS SECTION
(New Bridges/Bridge Replacements)

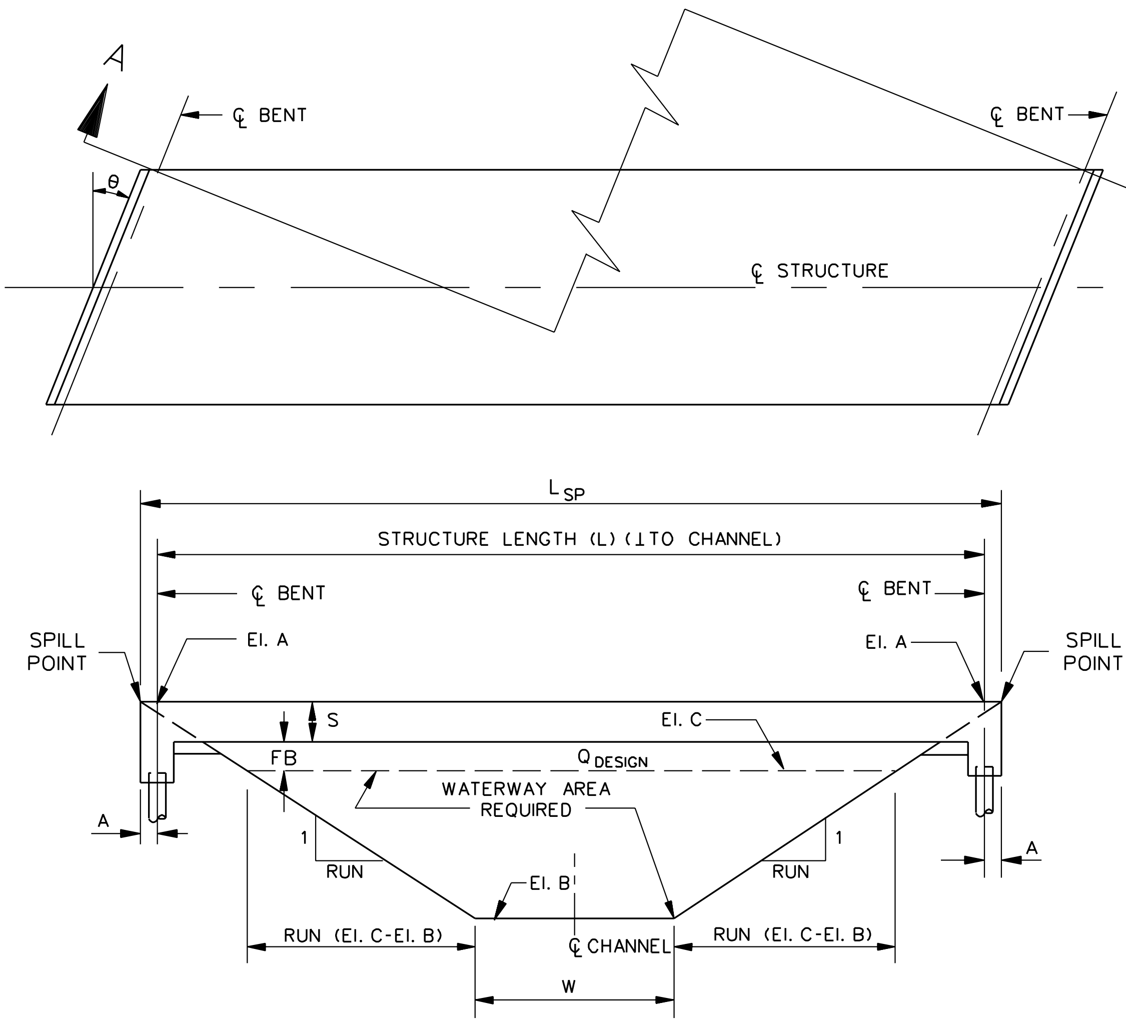
Figure 13.6F

13.6.3 Structure Length

Among other factors, structure length is determined by considering local topography, hydraulic recommendations and road design recommendations. See Figure 13.6G for an example reinforced concrete slab with an integral abutment.

To determine the approximate locations and elevations of abutments for stream crossings, use Figure 13.6G and obtain the hydraulic and road design recommendations. Use the channel bottom width, channel slopes, skew and base flood stage elevation with backwater to determine the basic bridge length.

Structure lengths for bridges over highways are determined similarly to those over stream crossings. See Chapter Twenty-one for structure lengths for highway bridges over railroads.



SECTION A-A
(PERPENDICULAR TO CHANNEL)

θ	=	Skew (right skew shown)
A	=	Spill point to centerline of bearing
S	=	Anticipated thickness of superstructure
FB	=	Distance from flood stage to bottom of superstructure
W	=	Width of channel (perpendicular to channel)
El. A	=	Elevation of top of slab
El. B	=	Bottom of channel elevation
El. C	=	Elevation of Water at Q_{DES}

Note: Minimum Waterway Area Required will be furnished by the waterway opening analysis.

Notes:

1. *Estimate minimum finished roadway grade elevation (FE):*

   FE = EI.C + backwater + minimum freeboard (0.3 m) + proposed superstructure depth

2. *Structure length (L_{SP}) (along centerline roadway, spill point to spill point):*

   L_{SP} = [(FE – channel bottom elevation) x 2 sides x run of slope + channel bottom width]/cos θ

3. *Structure length (L) (along centerline roadway from centerline bent to centerline bent):*

   $L = L_{SP} - 2A$

STRUCTURE LENGTH FOR STREAM CROSSINGS
(Integral Abutment, Reinforced Concrete Slab)

Figure 13.6G

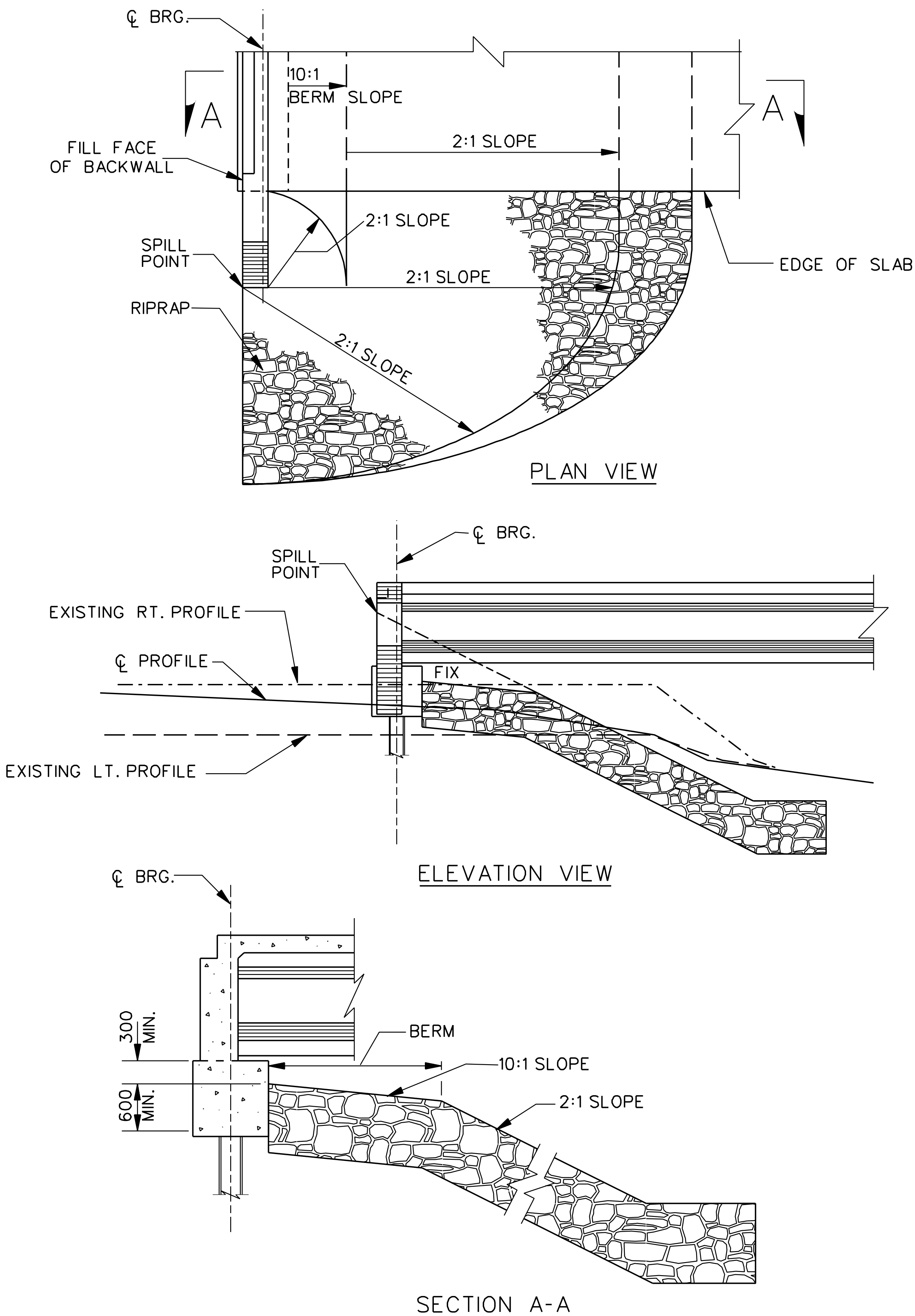
13.6.4 End Bents

End bent configuration and dimensioning has a significant impact on the required bridge span length. MDT end bents for either slab or girder bridges are typically constructed with either turn back or standard wing configurations. Turn back wings are located at and parallel to the roadway shoulders. Standard wings are constructed perpendicular to the centerline of roadway or, for a skewed bridge, parallel to the centerline of bearing. Either wing configuration is acceptable. Depending on specific site criteria and the proposed structure type, one may have advantages over the other. This must be thoroughly evaluated by the designer during the bridge layout process. Figures 13.6H, 13.6I, 13.6J and 13.6K illustrate the basic application of standard and turn back wings:

1. Berms. When standard wings are used, the end bent will typically require a berm. The berm is located in front of the cap and is constructed on a 10:1 slope to drain away from the front face of the cap. The berm length is dependent on the superstructure depth, cap width and relative difference between the berm slope and fill slope. The berm length will be determined by calculating the mathematical point of intersection of the berm slope and fill slope. The berm slope and cap slope will typically be located 300 mm below the low beam seat on the cap. Bridges with turn back wings will typically not require a berm.

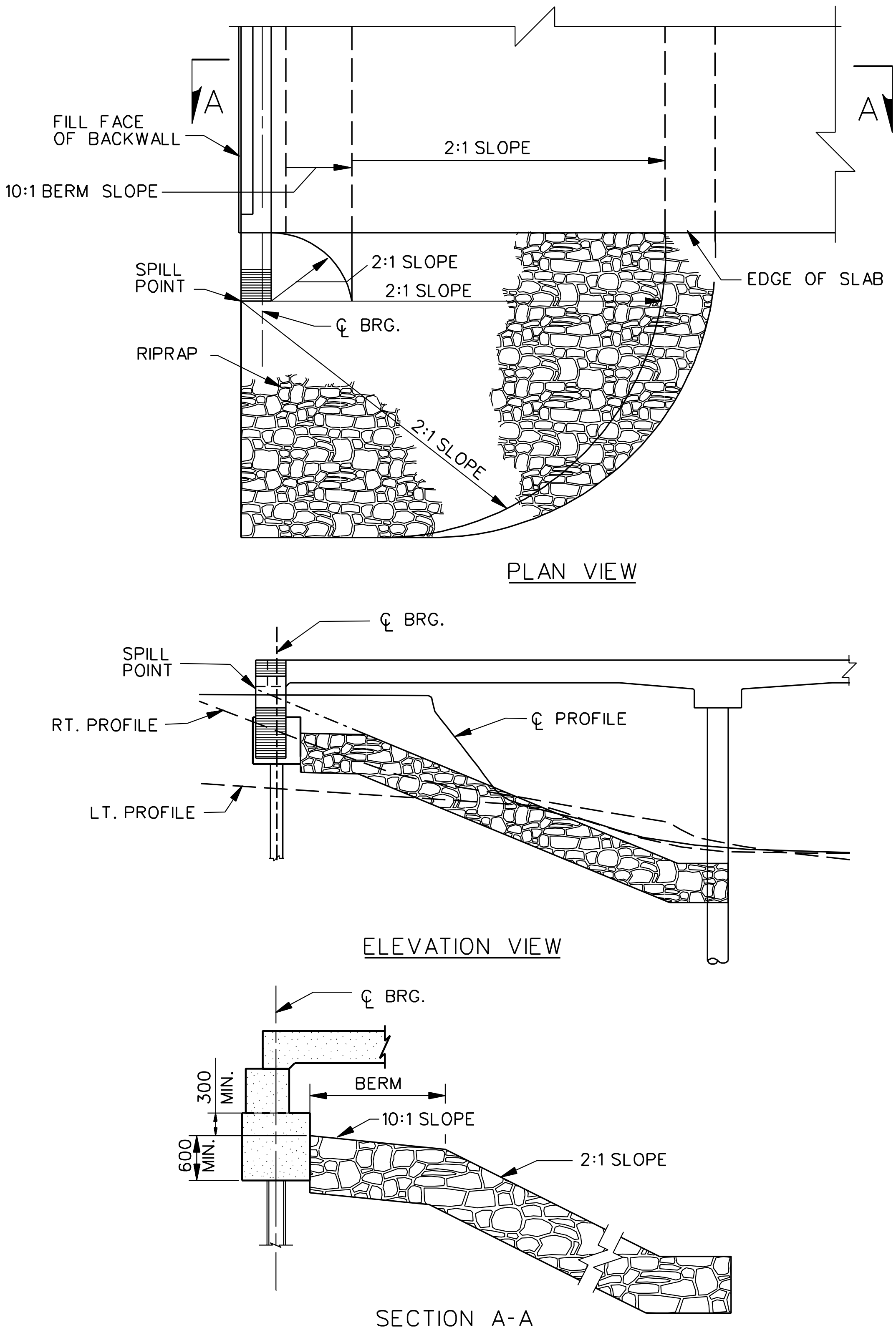
2. Slope. The fill slope is typically 2:1. This will typically be specified in the Hydraulics Report for stream crossings or by the Geotechnical Section elsewhere. In some cases, fill slopes can be increased to 1.5:1 with approval from the Hydraulics or Geotechnical Section. Slopes steeper than 1.5:1 will be engineered slopes.

3. Wingwalls. Wingwall type and length will be determined for each specific structure by the designer. Standard wing lengths are a direct function of slope and superstructure depth and are determined mathematically by the distance required for a slope running along both sides and the end of the wingwall to catch the end of the cap 300 mm below the low beam seat. The slope along the fill face of the wing out to the spill point will match the roadway prism at the bridge end including provisions for guardrail widening. The slope from the spill point across the end and near the face of the wing will be the fill slope. Turned back wing lengths can be established as needed to achieve the required bridge length. The minimum length of a turned back wing is that required for the fill slope to intersect the front face of the cap 300 mm below the low beam seat; i.e., the distance from the front of the cap to the end of the wing will typically be twice the vertical distance between the spill point at the end of wing and the fill slope intersection at the front face of the cap. If additional bridge length is needed, the walls can be lengthened but, as the wall length increases, the required cap depth will also increase. Walls exceeding 2 m in length may require piles or added support at the end of the wing.



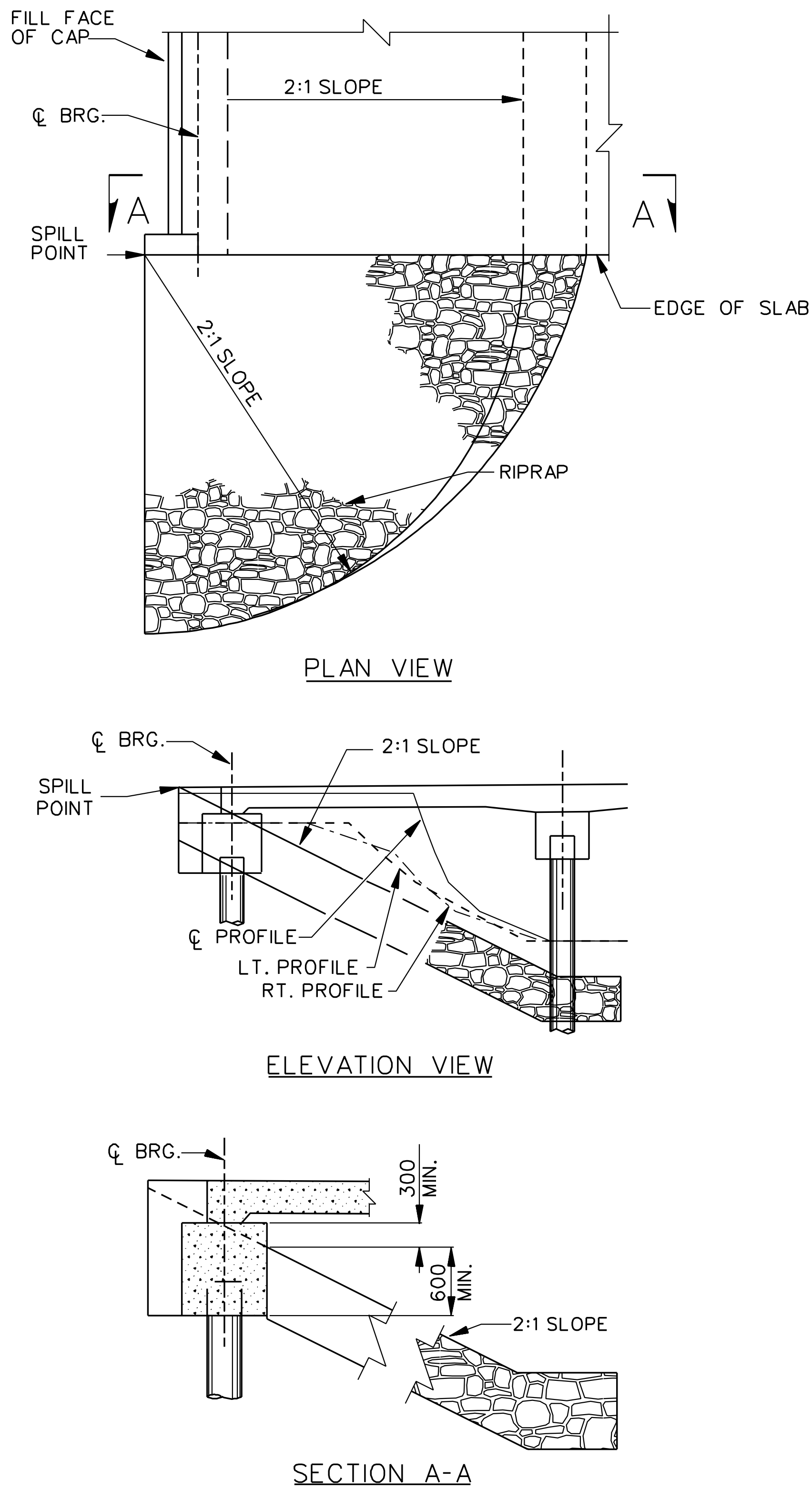
GIRDER BRIDGE WITH STANDARD WINGS

Figure 13.6H



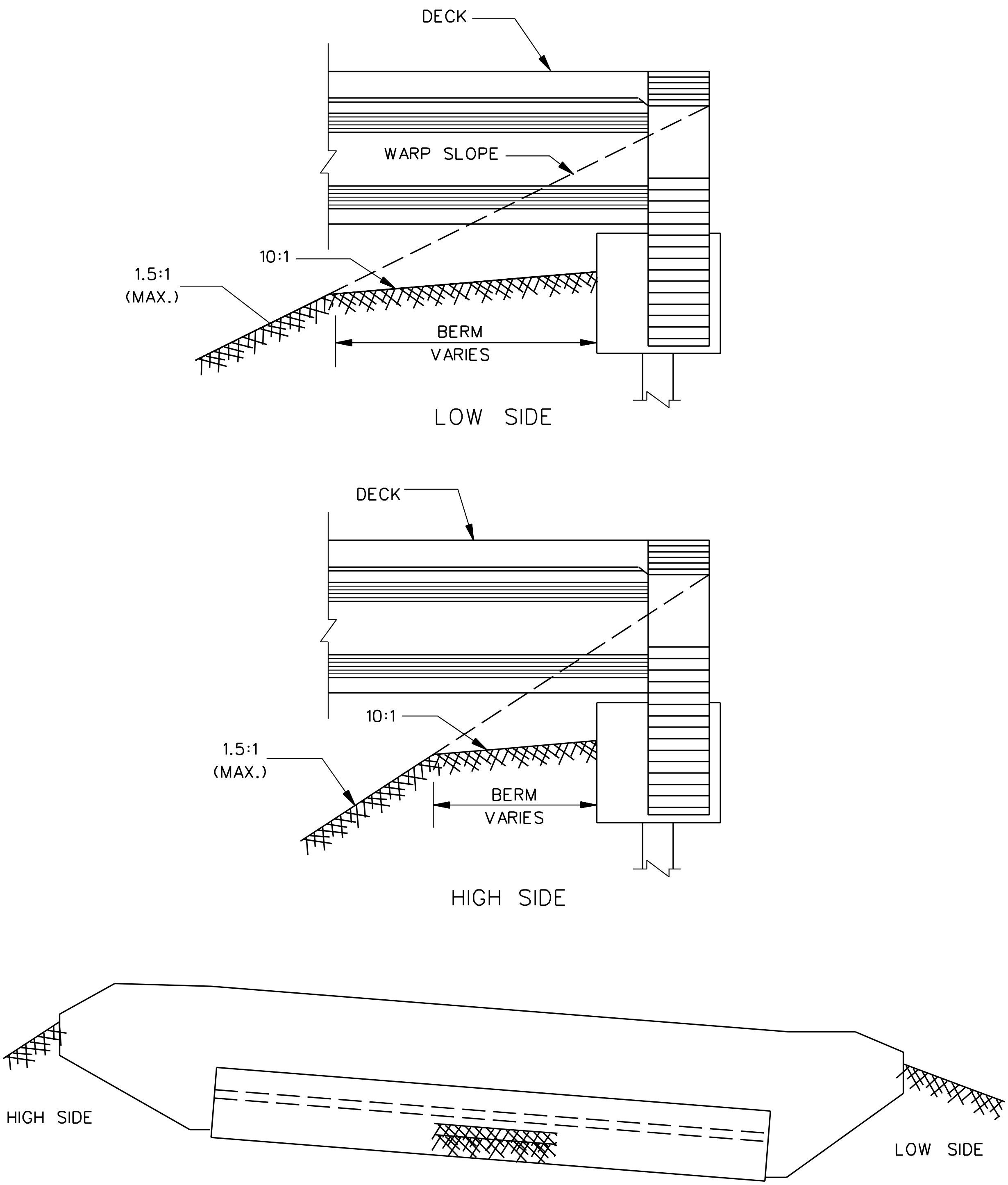
FLAT SLAB WITH STANDARD WINGS

Figure 13.6I



FLAT SLAB WITH TURN BACK WINGS

Figure 13.6J



BERM TREATMENT ON SUPERELEVATED CURVES

Figure 13.6K

13.7 HYDRAULICS

The **Montana Hydraulics Manual** documents MDT's hydraulic design criteria for roadways and bridge waterway openings. In general, a bridge over a waterway must be dimensioned to meet the applicable hydraulic criteria, which is a blend of Federal and State requirements (e.g., environmental, floodplains) and Department practices. This process will require proper communication between the Hydraulics Section and bridge designer to identify and resolve any problems. Section 13.7 of the **Structures Manual** provides basic hydraulic design criteria which applies to bridge waterway openings to provide the bridge designer with some background in hydraulic elements.

13.7.1 <u>General Procedures</u>

13.7.1.1 Division of Responsibilities

The Hydraulics Section is responsible for hydrologic and hydraulic analyses for both roadway drainage appurtenances and bridge waterway openings. The Hydraulics Section will perform the following for the design of bridge waterway openings for new bridges:

1. the hydrologic analysis to calculate the design flow rates based on the drainage basin characteristics;
2. the hydraulic analysis to determine the necessary dimensions of the bridge waterway opening to pass the design flood, to meet the backwater allowances and to satisfy any regulatory floodplain requirements; and
3. the hydraulic scour analysis to assist in determining the proper foundation design for the new bridge.

Based on the hydraulic analysis, the Hydraulics Section will provide the following to the Bridge Bureau for new bridges:

1. the water surface elevation for the design-year flood,
2. a suggested low beam elevation,
3. the necessary bridge waterway opening dimensions, skew angle and channel centerline station, and
4. the results of its hydraulic scour analysis.

The Hydraulics Section is also responsible for determining that the bridge design is consistent with regulations promulgated by the Federal Emergency Management Agency (e.g., development within regulatory floodplains).

The Hydraulics Section will submit the necessary information to the Bridge Bureau documenting its recommendations for the hydraulic design of the bridge typically via a memorandum. The bridge designer will incorporate these details into the bridge design.

13.7.1.2 Coordination in Project Development

Chapter Two "Bridge Project Development Process" of the **Montana Structures Manual** documents the project development process for bridge projects. The project networks in Chapter Two illustrate the timing of the interaction between the Hydraulics Section and Bridge Bureau for waterway openings. For a new bridge/bridge replacement project, the Hydraulics Section will perform its hydraulic analysis before the Bridge Bureau prepares the preliminary bridge layout and establishes bridge end elevations.

13.7.2 <u>Hydraulic Definitions</u>

The following presents selected hydraulic definitions which have an application to bridge design:

1. Auxiliary Waterway Openings. Relief openings provided for streams in floodplains through the roadway embankment in addition to the primary bridge waterway opening.

2. Backwater. The incremental increase in water surface elevation upstream of a highway facility.

3. Base Flood. The flood having a 1% change of being exceeded in any given year.

4. Base Floodplain. The area subject to flooding by the base flood.

5. Bridge Waterway Opening. The opening provided in the roadway embankment intended to pass the stream flow under the design conditions.

6. Design Flood Frequency. The flood frequency selected for determining the necessary size of the bridge waterway opening.

7. Flood Frequency. The number of times a flood of a given magnitude can be expected to occur on average over a long period of time.

8. Freeboard. The clearance between the water surface elevation based on the design flood and the low chord of the superstructure.

9. Hydrology. The science which explores the interrelationship between water on the earth and in the atmosphere. In hydraulic practice for highways, hydrology is used to calculate discharges for a given site based on the site characteristics. Hydraulic methodologies include:

    a. Rational Method,

    b. USGS Regression Equations,

    c. NRCS (formerly SCS) Unit Hydrograph, and

    d. HEC I.

10. Maximum Allowable Backwater. The maximum amount of backwater which is acceptable to the Department for a proposed facility based on State and Federal laws and on Department policies.

11. Maximum Allowable Velocity. The maximum acceptable velocity through the waterway opening during the design flood.

12. 100-Year Flood Frequency. A flood volume (or discharge) level which has a 1% chance of being equaled or exceeded in any given year.

13. Overtopping Flood. That flood event which produces a discharge which will overtop the elevation of the bridge.

14. Peak Discharge (or Peak Flow). The maximum rate of water flow passing a given point during or after a rainfall event or snow melt. The peak discharge for a 100-year flood is expressed as Q_{100}.

15. Recurrence Interval (Return Period). The average number of years between occurrences of a discharge that equals or exceeds that discharge. For example, the recurrence interval for a 100-year flood discharge is 100 years.

16. Regulated Floodway. The floodplain area that is reserved in an open manner by Federal, State or local requirements (i.e., unconfined or unobstructed either horizontally or vertically) to provide for the discharge of the base flood so that the cumulative increase in water surface elevation is no more than a designated amount as established by the Federal Emergency Management Agency (FEMA) for administering the National Flood Insurance Program (NFIP).

17. Review Flood Frequency. A frequency other than the design frequency used to assess flood hazards for the proposed

structure as part of the evaluation of the bridge waterway opening and foundation design.

18. River Stage. The water surface elevation above some elevation datum.

19. Scour. The action at a bridge foundation in which the movement of the water erodes the channel soil which surrounds the foundation. There are several types of scour:

    a. Contraction. A constriction of the channel (i.e., the flow area) which may be caused, for example, by bridge piers.

    b. Local. Removal of material from around piers, abutments, embankments, etc., due to high local velocities or flow disturbances such as eddies and vortices.

    c. Natural. Long-term aggradation and degradation of the stream bed due to natural phenomena.

20. Stream Morphology. The form and shape of the stream path created by its erosion and deposition characteristics. Streams are generally considered one of the following types:

    a. Braided. One consisting of multiple and interlacing channels.

    b. Straight. One in which the ratio of the length of the path of deepest flow to the length of the valley proper is less than 1.5. This ratio is called the sinuosity of the stream.

    c. Meandering. One consisting of alternating bends of an S-shape.

21. Thalweg. The path of deepest flow.

22. Water Surface Profile (WSPRO) Analysis. The hydraulic analysis model typically used by MDT for analyzing waterway openings. WSPRO is an “energy” model which models pressure flow through the bridge, embankment overtopping and flow through multiple openings.

13.7.3 Hydraulic Design Criteria

The following presents MDT’s hydraulic criteria used for the design of bridge waterway openings:

1. Design Flood Frequency. Typically, the 100-year flood frequency is used for design.

2. Review Flood Frequency. In some cases, the impacts of the 500-year flood (or super flood) on the surrounding area may be evaluated as part of the analysis.

3. Maximum Allowable Backwater. On delineated floodplains, no backwater may be introduced by the structure. For all other sites, the maximum allowable backwater shall be limited to an amount which will not result in damage to upstream property or to the highway. The Hydraulics Section will determine the allowable backwater for each site.

4. Freeboard. Where practical, a minimum clearance of 300 mm should be provided between the design water surface elevation and the low chord of the bridge to allow for passage of ice and debris. Where this is not practical, the clearance should be established by the designer based on the type of stream and level of protection desired. For example, 150 mm may be adequate on small streams that normally do not transport drift. Urban bridges with grade limitations may not provide any freeboard. A freeboard greater than 300 mm is desirable on major rivers which may carry large debris. On bridge replacement projects, efforts should be made to match pre-existing low beam elevations. For new crossings on waterways that have substantial use by recreational boaters, consideration may need to be given to provide adequate freeboard for floaters and fishermen to pass at flows not more than Q_2.

5. Substructure Displacement. When the Hydraulics Section provides required waterway openings, an allowance has already been made for the area displaced by the substructure. Therefore, the area of piers and bents below the Q_{100} elevation should not be deducted from the gross waterway area given.

13.7.4 Good Hydraulic Practices

Before the bridge designer determines the type of structure, identifies its location and dimensions, and prepares the preliminary bridge layout and grade, he/she will have received the Hydraulics Report from the Hydraulics Section. At a minimum, the bridge waterway opening must conform to the basic hydraulic design criteria presented in Section 13.7.3.

Hydraulic considerations in site selection are numerous because of the many variations in flow conditions encountered and the many water-related environmental considerations. Section 13.7.4 presents general, good hydraulic practices which should be incorporated at this stage of project development, where practical.

Compliance with the maximum backwater allowance should not be the sole criterion for determining the hydraulic acceptability of a proposed design at a stream crossing. The total performance of a highway-stream crossing system is sensitive to the waterway opening, roadway profile and elevation, pier location and orientation, environment considerations, highway skew and stream morphology. The total system will have significant effects on velocities, flow distribution, stream environment, scour, risks and construction costs. These are discussed in Section 13.7.4.

13.7.4.1 Environmental Considerations

Many aspects of the environmental assessment with respect to the site are also related to the hydraulic design of a stream crossing. These include the effects on the aquatic life in the stream; effects on other developments, such as a domestic or irrigation water supply intake; and the effects on floodplains.

Biological considerations at the site include the effects on habitat and ecosystems in the floodplain and the effects on aquatic ecosystems in the stream and wetlands. Some of the factors to consider include the cost to replace lost marsh or wetland areas; circulation of fresh water in marshes; and the feasibility of providing mitigating measures for the loss of invertebrate populations.

The preservation of wetlands must also be considered in the design of a stream crossing. The importance of wetlands is recognized because of their high productivity of food and fiber; beneficial effects on flooding, pollution and sediment control; and the wildlife habitat they support. Stream crossings must be located and designed so that important wetlands will not be destroyed or their value diminished unnecessarily.

It should also be noted that the evaluation of the typical hydraulic engineering aspects of bridge design are interrelated with environmental impacts. These include the effects of the crossing on velocities, water surface profiles, flow distribution, scour, bank stability, sediment transport, aggradation and degradation of the channel, and the supply of sediment to the stream or water body.

The environmental process for stream crossing projects may also precipitate the need for several State and Federal permits and approvals which are water related. These include:

1. the Stream Preservation Act Permit,

2. Section 402 “Temporary Erosion Control Permit,”

3. U.S. Army Corps of Engineers Section 404 Permit,

4. approvals from U.S. Fish and Wildlife, and

5. approvals related to floodplain encroachments.

The bridge designer should consider the future requirements for these permits and approvals in the preliminary bridge design stage.

13.7.4.2 Stream Types

Section 13.7.2 defines the three basic types of streams — braided, straight and meandering.

Hydraulic analysis of braided streams is extremely difficult because of the inherent instability and unpredictable behavior of such streams. Constricting a braided channel into one channel or placing roadway fill between subchannels may change sediment transport capacity at some locations. Where practical, an alternative crossing site at a reach of stream which is not braided should be selected.

A straight reach of stream channel in an otherwise meandering stream may be viewed as a transient condition. Aerial photographs and topographic maps should be examined for evidence of past locations of the channel and of tendencies for meanders to form in the straight reach.

For meandering streams, the concave bank of a bend (i.e., the bank with the longer radius of curvature) presents the greatest hazard to highway facilities because the stream attacks that bank. The design of crossings at bends is complex because it is difficult to predict flood flow distribution. The stream is usually deeper at that bank, velocities are higher and the water surface is superelevated. The location of a structure in the overbank area may encourage a cutoff and, if the bend system is moving, approach fills and abutments will be subjected to attack as the bend moves downstream.

13.7.4.3 Roadway Alignment

The horizontal and vertical roadway alignment at the bridge will impact the hydraulic performance of the bridge. For example, the accumulation of debris or ice on the upstream side of the structure can increase the effective depth of the superstructure, impose larger hydraulic forces on the bridge superstructure and increase scour depths. Because no relief from these forces is afforded, crossings on zero gradients and in sag vertical curves are more vulnerable than those with profiles which provide an alternative to forcing all water through the bridge waterway.

13.7.4.4 Location of Waterway Openings

The choice of a location for a waterway opening at a stream crossing site with limited floodplain widths is not difficult because it is readily apparent that one opening will suffice. The location of waterway openings is more complex for designs for rare floods and at sites with extensive floodplains. An auxiliary opening(s) may be warranted at these sites.

Several factors influence decisions on the location of the waterway opening to provide for flood passage. These include local drainage, the possibility of causing a cutoff in a meander bend, other transportation facilities in the vicinity, floodplain use, and the horizontal and vertical alignment of the highway.

Basic objectives in choosing the location(s) of auxiliary opening(s) include maintenance of flow distribution and flow directions as practical, provision for relatively large flow concentrations in the floodplains, avoidance of diversion of floodplain flow along roadway embankments for long distances, and considerations of backwater and scour damage to the highway and other property. Site conditions, economics, budgetary constraints, and the horizontal alignment of the highway may limit the extent to which these objectives can be met.

13.7.4.5 Pier Location/Shape

The number of piers in a channel should be limited to a practical minimum, and piers in the channel of small streams should be avoided. Piers properly oriented with the flow do not contribute significantly to bridge backwater, but they do contribute to general scour. In some cases, severe scour may develop immediately downstream of bridges because of eddy currents and because piers occupy a significant area in the channel.

Piers should be aligned with flow direction at flood stage to minimize the opportunity for drift to be trapped, to reduce the contraction effect of piers in the waterway, to minimize ice forces and the possibility of ice dams forming at the bridge, and to minimize backwater and local scour. Pier orientation is difficult where flow direction changes with stage or time. Circular piers, or some variation, are probably the best alternative if orientation at other than flood stage is critical.

Piers located on a bank or in the stream channel near the bank are likely to cause lateral scouring of the bank. Piers located near the stream bank in the floodplain are vulnerable because they can cause bank scour. They are also vulnerable to failure from undermining by meander migration. Piers which must be placed in locations where they will be especially vulnerable to scour damage should be founded at elevations safe from undermining.

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

Where ice is a problem, piers are armored and may be battered to facilitate breaking up ice floes which otherwise would crush against the leading edge of the pier.

13.8 ENVIRONMENTAL ISSUES

13.8.1 General

Environmental Services will perform the environmental studies for the proposed bridge project. Section 3.1.2 discusses the necessary coordination between Environmental Services and the Bridge Bureau on the following:

1. NEPA/MEPA requirements;
2. Sections 4(f), 6(f) and 106;
3. mitigation;
4. early coordination;
5. permits/approvals;
6. hazardous waste;
7. erosion control during construction; and
8. wetland mitigation.

Chapter Two documents the project development process for bridge projects when the Bridge Bureau is the lead unit for project development. The project networks illustrate the timing of the interaction between Environmental Services and the Bridge Bureau in evaluating the environmental impacts of the proposed project. As illustrated in Chapter Two, most of the coordination on the above issues occurs after the structure type selection. However, the bridge designer must anticipate and evaluate the likely environmental consequences (both procedural and technical) when selecting the structure type, configuration and size.

13.8.2 Environmental Procedures

The Engineering Bureau within Environmental Services is responsible for ensuring that all MDT projects comply with the National Environmental Policy Act (NEPA) and the Montana Environmental Policy Act (MEPA). The key element in this process is to identify the project's environmental Class of Action based on the expected project environmental impacts. Three classifications exist:

1. Categorical Exclusion (CE). A category of actions which do not individually or cumulatively have a significant effect on the human environment for which, therefore, neither an Environmental Assessment nor an Environmental Impact Statement is required.

2. Environmental Assessment (EA). A document that serves to briefly provide sufficient evidence and analysis for determining whether to prepare an Environmental Impact Statement or a Finding of No Significant Impact (FONSI).

3. Environmental Impact Statement (EIS). A detailed written statement, prepared for major Federal actions significantly affecting the quality of the human environment, which discusses the environmental impact of the proposed action; any adverse environmental effects which cannot be avoided should the proposal be implemented; alternatives to the proposed action; the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity; and any irreversible and irretrievable commitments of resources which would be involved if the proposed action should be implemented.

In general, the process for an EA is more involved than a CE, and an EIS is more involved than a CE or EA. The environmental process involves many other activities in addition to the Class of Action determination (e.g., early coordination, identifying cooperating agencies, public involvement, selecting and evaluating alternatives). Section 1.3.3 provides a summary of the functions and responsibilities of Environmental Services. The bridge designer should contact Environmental Services for more information on environmental procedures.

13.8.3 Environmental Impacts

In general, any bridge project should, within reason, attempt to minimize the environmental impacts, especially in sensitive areas (e.g., wetlands). The Resources Bureau within Environmental Services is, in general, responsible for identifying all environmental resources within the proposed project limits and for evaluating the potential project impacts on these resources. The following sections briefly discuss potential environmental impacts precipitated by a bridge project.

13.8.3.1 Water Related

Any bridge over a stream or other water resource has the potential for water-related environmental impacts. These include fish habitat, other aquatic life, water quality, wetlands, floodplains and sediment transport. Section 13.7.4 "Good Hydraulic Practices" provides more discussion on environmental considerations with respect to bridges over water resources.

13.8.3.2 Historic Bridges

Based on Section 106 of the National Historic Preservation Act of 1966 (as amended), MDT must consider the effects of the project on properties included in or eligible for inclusion in the National Register of Historic Places (NRHP). Where such properties will be affected, the Advisory Council on Historic Preservation (ACHP) must be afforded a reasonable opportunity to comment on the undertaking. MDT must implement special efforts to minimize harm to any property on or eligible for the NRHP that may be adversely affected by the proposed project. The mitigation is accomplished through written agreements among MDT, the ACHP and the Montana State Historic Preservation Officer (SHPO).

MDT has identified those historic bridges within the State that are on or eligible for the NRHP. See Figures 13.8A and 13.8B. MDT must comply with the Section 106 procedures for any work on these bridges or bridge work which impacts these bridges.

13.8.3.3 Hazardous Waste

The Hazardous Waste Bureau within Environmental Services is responsible for identifying and evaluating hazardous waste sites and for determining the needed mitigation measures. Three specific types of hazardous waste which may require treatment for a bridge project include:

1. <u>Paint Removal</u>. Removal of lead-based paint from an existing bridge.

2. <u>Timber Removal</u>. Salvaging or disposing of timber from an existing bridge.

3. <u>Plates</u>. Asbestos blast plates on railroad overpasses.

13.8.3.4 Construction

Restrictions on contractor access in environmentally sensitive areas should be established and negotiated early in project development.

13.8.3.5 Local Considerations

The project may be subjected to local environmental considera-tions (e.g., restrictions may be imposed on the areas in which the contractor may work).

13.8.3.6 Other Environmental Impacts

Occasionally, a proposed bridge project may precipitate other environmental impacts. These include Section 4(f), Section 6(f), Section 106 (other than historic bridges), threatened and endangered species and the need for a TERO (Tribal Employment Rights Office) Agreement. Contact Environmental Services for more information.

BRIDGE	MDT ID NUMBER	SMITHSONIAN #	COUNTY	DOC
Browne's Bridge		24BE526	Beaverhead	1916
Beaverhead River (Selway)	L01279000+04001	24BE1738	Beaverhead	1916*
Big Horn River	Abandoned	24BH2464	Bighorn	1911
Milk River (w. of Dodson)	L03068002+05001	24BL1209	Blaine	1916
Milk River (e. of Harlem)	L03068000+05001	24BL1204	Blaine	1914
Clark's Fork at Fromberg	L05307000+07001	24CB1223	Carbon	1914*
Clark's Fork (s. of Belfry)	Abandoned		Carbon	1925
Missouri River (10th Street Bridge)	Non-system	24CA308	Cascade	1920
Milwaukee Rd O'pass/Great Falls	U05217001+05401	24CA331	Cascade	1914
Sand Coulee Cr. (s. of Great Falls)	S00226001+05191	24CA258	Cascade	1937
Heppler Coulee (w. of Simms)	L07561002+00001	24CA256	Cascade	1934
Simms Creek (w. of Simms)	L07561004+04001	24CA257	Cascade	1934
Missouri River at Fort Benton	City-owned	24CH335	Chouteau	1888
Yellowstone River at Fort Keogh	N/A	24CR668	Custer	1902
Tongue River at Miles City	L09054000+01001	24CR679	Custer	1897*
Cottonwood Creek	L09004003+01001	24CR643	Custer	1928
Cottonwood Creek (s. of Joe)	S00242005+05001	24FA2321	Fallon	1934
Big Spring Creek Bridge	Relocated by county	24FR824	Fergus	1908
Flathead River (Old Steel Bridge)	L15091000+05001	24FH463	Flathead	1894*
Flathead River at Columbia Falls	Abandoned	24FH464	Flathead	1911
Gallatin River (Nixon Bridge)	L16216002+02001	24GA393	Gallatin	1891
Gallatin River (Cameron Bridge)	N/A	24GA829	Gallatin	1891
Jefferson River	L16201000+07001	24GA831	Gallatin	1894
St. Mary River at Babb	L18224002+08001	24GL186	Glacier	1915
Musselshell River	L19217000+03001	24GV144	Gold. Valley	1900
Boulder River (Red Bridge)	L22304000+03001	24JF479	Jefferson	1899*
Dearborn River High Bridge	L25300009+00001	24LC130	L&C	1897
Missouri River at Wolf Creek	L25003011+00001	24LC131	L&C	1933
Missouri River at Craig	L25013000+03001	24LC3001	L&C	1903*
10 Mile Cr. Helena (Williams St.)	L25549000+01001	24LC128	L&C	1894
Little Prickly Pear Creek	L25233000+03001	24LC127	L&C	1897
Ten Mile Creek (N. Montana Ave.)	U05809002+09631	24LC1546	L&C	1933*
Flat Creek (se. of Augusta)	P00009023+05901	24LC767	L&C	1931
Marias River (Pugsley Bridge)	L26038005+01001	24LT76	Liberty	1951
Kootenai River at Troy	L27411000+01001	24LN64	Lincoln	1912
Blaine Spring Creek Bridge	S00249007+05001	24MA780	Madison	1892
Madison River (Varney Bridge)	S00249007+08001	24MA779	Madison	1897
Big Hole River Overflow Bridge	L29141015+07001	24MA413	Madison	1907*
Jefferson River at Silver Star	S00422000+01001	24MA412	Madison	1913*
Wisconsin Creek	P00029037+02091	24MA714	Madison	1938
Cherry Creek	P00029053+06001	24MA795	Madison	1935
Clark Fork River (Van Buren Street)	N/A	24MO248	Missoula	1895
Orange Street Bridge	U08107001+05401	24MO553	Missoula	1936*
Milwaukee Road Overpass	U08107001+04101	24MO554	Missoula	1935*

MONANTA HIGHWAY BRIDGES ON OR ELIGIBLE FOR THE NATIONAL REGISTER OF HISTORIC PLACES (June 2000)

Figure 13.8A

BRIDGE	MDT ID NUMBER	SMITHSONIAN #	COUNTY	DOC
Stockpass (w. of Musselshell)	P00014182+04001	24ML245	Musselshell	1937*
Carter Bridge	S00540031+06621	24PA777	Park	1921
Milk River at Wagner	S00363001+03001	24PH3216	Phillips	1910*
Assiniboine Creek	S00242006+00001	24PH2669	Phillips	1936
Como Bridge	L41600000+01001	24RA523	Ravalli	1917
Wolf Point Bridge	Non-system	24RV438	Roosevelt	1930
Yellowstone River at Reed Point	L48083000+07001	24ST216	Stillwater	1911*
Stillwater River (Kern's Crossing)	L48128000+04001	24ST215	Stillwater	1902
Dry Wash (n. of Augusta)	P00057217+07911	24TT120	Teton	1936
Drainage	P00009059+01911	24TT121	Teton	1936
Drainage	P00003057+07501	24TT122	Teton	1929
Drainage	P00003059+01911	24TT123	Teton	1929
Jones Coulee (s. of Pendroy)	P00003059+07801	24TT125	Teton	1929
Buckingham Coulee	S00311019+00001	24TE44	Treasure	1936*
Milk River at Tampico	L53507000+03001	24VL722	Valley	1911*
Yellowstone R. at Pompeys Pillar	S00568000+09601	24YL784	Yellowstone	1915

***Bridge has been programmed for replacement.**

MONANTA HIGHWAY BRIDGES ON OR ELIGIBLE FOR THE NATIONAL REGISTER OF HISTORIC PLACES (June 2000)

Figure 13.8A
(Continued)

BRIDGE	MDT ID NUMBER	SMITH. #	COUNTY	DOC	ON
Frying Pan Gulch	L01311005+01001	24BE548	Beaverhead	1929	X
Poindexter Slough 2	FWP	24BE1401	Beaverhead	1929	
Limekiln Canyon	L01309014+09001	24BE537	Beaverhead	1931	X
Poindexter Slough	S00222002+07511	24BE538	Beaverhead	1936	X
UPRR Overpass	S00222002+08611	24BE539	Beaverhead	1936	X
Two Leggin Canal	L02313021+06001	24BH1981	Bighorn	1931	X
Big Horn R/Hardin	S00348000+05101	24BH376	Bighorn	1942	X
Little Big Horn R. 3	S00451008+06371	24BH2872	Bighorn	1955	X
Lodge Grass Creek	S00451015+07741	24BH2873	Bighorn	1955	X
Little Big Horn R. 1	I00090511+06051	24BH1642	Bighorn	1956	X
Little Big Horn R. 2	I00090517+05021	24BH1643	Bighorn	1956	X
Lodge Creek Bridge	P00001404+05791	24BL1050	Blaine	1942	X
Allen/Wills Ditch	County	24CB1508	Carbon	1911	
Bluewater Creek	L05302008+06001	24CB1309	Carbon	1913	
East Bench Canal	Private	24CB1356	Carbon	1915	
West Canal	Private	24CB713	Carbon	1915	
E. Rosebud Cr/Roscoe	L05503000+01001	24CB1310	Carbon	1915	
Willow Creek Bridge	P00023126+04531	24CT593	Carter	1955	X
Belt Creek	P00060040+03761	24CA641	Cascade	1921	X
Novak Creek Bridge	L07604005+00001	24CA394	Cascade	1931	X
Fort Shaw Canal	L07561003+04001	24CA395	Cascade	1934	X
GNRR Overpass	P00080000+02091	24CH983	Chouteau	1953	X
Poplar River Bridge	S00248043+03531	24DN7	Daniels	1940	X
Bad Route Creek	L11109020+03001	24DW423	Dawson	1921	
Warm Springs Creek	L12163000+01001	24DL485	Deer Lodge	1912	
Silver Bow Creek	L12079000+02001	24DL707	Deer Lodge	1928	X
Opportunity Drainage	L12146002+06001	24DL705	Deer Lodge	1931	X
Clark Fork River	L12146001+01001	24DL706	Deer Lodge	1931	X
Willow Creek Bridge	L12146001+02001	24DL680	Deer Lodge	1931	X
Big Spring Creek	U07104001+00801	24FR801	Fergus	1920	
Milwaukee Road Overpass	P00057079+06521	24FR803	Fergus	1936	X
Abbot Creek	L15689000+04001	24FH498	Flathead	1931	X
GNRR Overpass	P00001167+05251	24FH441	Flathead	1956	X
Baker Creek	S00205013+00791	24GA800	Gallatin	1921	
Drainage	S00205008+03441	24GA1069	Gallatin	1931	X
NPRR Overpass/Logan	S00205005+00671	24GA1070	Gallatin	1934	X
Gallatin River	P00050049+08111	24GA1511	Gallatin	1952	X
S. Fk. Cut Bank Creek	P00058012+09171	24GL236	Glacier	1927	X
S. Fk. Milk River	P00058021+00281	24GL237	Glacier	1928	X
Two Medicine River	P00001210+01961	24GL935	Glacier	1941	X
Fred Burr Creek Bridge	P00019035+03141	24GN844	Granite	1931	X
Big Sandy Creek	P00001376+02951	24HL1120	Hill	1954	X
Cataract Creek Bridge	L22099008+00001	24JF547	Jefferson	1933	X
Boulder River Bridge	L22099004+03001	24JF1599	Jefferson	1933	X

REINFORCED CONCRETE BRIDGES ELIGIBLE FOR THE NATIONAL REGISTER OF HISTORIC PLACES (June 2000)

Figure 13.8B

BRIDGE	MDT ID NUMBER	SMITH. #	COUNTY	DOC	ON
Whitetail Creek Bridge	P00069000+07621	24JF767	Jefferson	1955	X
Coyote Creek	L23204002+01001	24JT299	Judith Basin	1934	
Mud Creek	L24009003+08001	24LA207	Lake	1920	
Mission Creek	M24100000+00101	24LA226	Lake	1929	
Elk Creek Overflow	L25309000+01001	24LC1599	L & C	1920	
Prickly Pear Creek	M25037000+00301	24LC504	L & C	1920	X
Wegner Creek	L25003016+05001	24LC133	L & C	1930	X
Sheep Creek	L25003005+02001	24LC1157	L & C	1933	X
McLeod Creek Bridge	Abandoned	24LC1226	L & C	1933	
Elk Creek Bridge	L25400000+02001	24LC550	L & C	1935	X
Curley Creek Bridge	L27043000+03001	24LN1599	Lincoln	1930	
Rock Creek Bridge	L31179000+05001	24MN302	Mineral	1931	
12 Mile Creek Bridge	L31179001+09001	24MN244	Mineral	1931	
Rattlesnake Creek	U08110000+05751	24MO706	Missoula	1932	X
Vine Street Bridge	M32081000+01071	24MO522	Missoula	1945	
Ferry Creek	L34003001+07001	24PA1077	Park	1921	
NPRR Overpass	P00059000+00611	24PA1137	Park	1954	X
GNRR Overpass	P00001459+03301	24PH3177	Phillips	1936	X
Little Powder River	L38665004+05001	24PR1837	Powder River	1947	
Conley St. /Deer Lodge	M39031000+00401	24PW608	Powell	1914	
Racetrack Creek Bridge	L39242006+06001	24PW697	Powell	1930	X
Cottonwood Creek	S00275001+00951	24PW607	Powell	1933	X
Big Blackfoot River	L39001011+04001	24PW700	Powell	1954	
Yellowstone River	L40114001+05001	24PE618	Prairie	1945	X
Powder River	L40004006+02001	24PE1810	Prairie	1945	X
Tin Cup Creek	County	24RA521	Ravalli	1915	
Wolf Creek	P00001588+08561	24RV655	Roosevelt	1956	X
Smoke Creek Bridge	L43205005+09001	24RV295	Roosevelt	1950	
Armells Creek	L44311005+07001	24RB500	Rosebud	1932	X
Cabinet Gorge/Heron	L45025001+00001	24SA471	Sanders	1952	
Silver Bow Cr/Nissler	Abandoned	24SB581	Silver Bow	1915	
BPR Overpasses	I00015124+00371	24SB616	Silver Bow	1955	X
Dale Creek	S00419018+02001	24ST286	Stillwater	1945	X
Stillwater River/Nye	S00419019+09001	24ST289	Stillwater	1945	X
Big Ditch Bridge	L48245011+05001	24ST275	Stillwater	1955	X
American Fork Bridge	P00045033+00271	24WL155	Wheatland	1942	X

REINFORCE CONCRETE BRIDGES ELIGIBLE FOR THE NATIONAL REGISTER OF HISTORIC PLACES
(June 2000)
Figure 13.8B

(Continued)

13.8.4 Permits/Approvals

A proposed bridge project may precipitate the need for one or more environmental permits or approvals. Except for floodplains (which are the responsibility of the Hydraulics Section), Environmental Services is responsible for coordinating with the applicable Federal or State agency and acquiring the permit or approval. This will require considerable coordination with the Bridge Bureau. The following sections briefly discuss these permits/approvals.

13.8.4.1 Montana SPA Permit

The Montana Stream Preservation Act (SPA) requires that MDT secure a 124 SPA Permit for work in *any* named stream/waterbody or tributary to a stream, lake, pond or other waterbody. The requirement for this Permit extends to ephemeral streams if the work proposed is within 30 m of a named or unnamed perennial or intermittent tributary to a stream, lake, pond or other waterbody. The Permit requirement, however, does not extend to wetlands.

Because of the environmental sensitivities associated with all stream crossings, early coordination with the regulatory agencies is essential on bridge projects. Do not expend man-hours designing a bridge that does not have the necessary approvals from the regulatory agencies. The project development networks in Chapter Two illustrate how the SPA Permit interacts with the bridge process.

13.8.4.2 U.S. Army Corps of Engineers Section 404 Permit

The Section 404 Permit is required for the discharge of dredge or fill material into any waters of the United States, including wetlands. The purpose of Section 404 is to restore and maintain the chemical, physical and biological integrity of the Nation's waters through the prevention, reduction and elimination of pollution.

For identification, the "waters of the United States" includes all wetlands and areas within a blue solid line or a blue dashed line on the USGS quadrangle maps. Each river, stream, creek, intermittent tributary, pond, impoundment, lake or wetlands is considered part of the waters of the United States. More commonly, the waters of the United States are usually interpreted as any named stream or waterbody and unnamed intermittent tributaries that have "defined gravel bottoms."

Wetlands are also described as bogs, marshes, sloughs and swamps. Floodplains, or areas where water stands on, at or near the groundline, may be considered suspected wetlands. Guidelines as established by the U.S. Army Corps of Engineers indicate that a wetland must have all of the following characteristics:

1. a preponderance of water-tolerant plants;
2. hydric soils; and
3. water on, at or near the surface of the ground during a specified portion of the growing season.

Where Section 404 applies, the project either may be covered by one of the nationwide permits or may require an individual Section 404 Permit. In general, if a project will not involve more than minor water quality impacts, it may be eligible for a nationwide Section 404 Permit. Contact Environmental Services, which has guidelines on nationwide versus individual Permits, for a determination on this issue.

13.8.4.3 Section 401 Water Quality Certification

Pursuant to Section 401 of the Federal Water Pollution Control Act of 1972 (as amended), the Section 401 Water Quality Certification is issued by the Montana Department of Environmental Quality based on regulations issued by the U.S. Environmental Protection Agency. The purpose of the Section 401 Permit is to restore and maintain the chemical, physical and biological integrity of the Nation's waters through prevention, reduction and elimination of pollution. A Section 401 Certification (or waiver of Certification) is required in conjunction with any Federal permit (e.g., a Section 404 Permit) to conduct any activity which may result in any discharge into waters of the United States.

13.8.4.4 Section 402 NPDES Permit

Pursuant to Section 402 of the Federal Water Pollution Control Act of 1972 (as amended), the Section 402 National Pollutant Discharge Elimination System (NPDES) Permit is issued by the Montana Department of Environmental Quality based on regulations issued by the U.S. Environmental Protection Agency. The purpose of the Section 402 Permit is to restore and maintain the chemical, physical and biological integrity of the Nation's waters through prevention, reduction and elimination of pollution.

13.8.4.5 U.S. Coast Guard Section 10 Permit

Pursuant to Section 10 of the Rivers and Harbors Act of 1899, the Section 10 Permit is issued by the U.S. Coast Guard. The purpose of the Section 10 Permit is to protect and preserve the navigable waterways of the United States against any degradation in water quality. The Permit is required for structures or work (other than bridges or causeways) affecting a navigable waterway (tidal or non-tidal). Examples of work include dredging, channelization and filling. In Montana, the following are navigable waterways:

1. the Missouri River,
2. the Yellowstone River below Emigrant, and
3. the Kootenai River above Jennings.

13.8.4.6 Floodplains Encroachment

Pursuant to Executive Order 11988 "Floodplain Management," MDT must seek approval from the Federal Emergency Management Agency (FEMA) for any Federally funded/regulated project which produces a significant floodplain encroachment. If a project will have a significant floodplain encroachment, the project will require either an Environmental Assessment (EA) or Environmental Impact Statement (EIS). A proposed action which includes a significant floodplain encroachment will not be approved unless FHWA finds (pursuant to 23 CFR650A) that the proposed action is the only practical alternative.

The intent of Executive Order 11988 is to:

1. encourage a broad unified effort to prevent uneconomic, hazardous or incompatible use and development of floodplains;
2. avoid significant encroachments, where practical;
3. minimize impacts of actions which adversely affect base floodplains;
4. restore and preserve the natural and beneficial floodplain values that are adversely impacted by proposed actions;
5. avoid support of incompatible floodplain development; and
6. be consistent with the intent of the Standards and Criteria of the National Flood Insurance Program (NFIP), where appropriate.

The Hydraulics Section is responsible for determining that the bridge design is consistent with the regulations promulgated by FEMA and by FHWA (23 CFR 650A) and, where necessary, the Section prepares a Floodplain Study and/or a Floodplain Finding.

13.8.4.7 Other Montana State Permits

In addition to the SPA Permit, the following State permits may also be required on bridge projects:

1. Section 402 Montana Pollutant Discharge Elimination System (MPDES) Authorization. This is also commonly called the stormwater discharge permit. This authorization is required for projects that have over 0.4 ha of "disturbance" within 30 m of "State waters," or over 2 ha of "disturbance" anywhere in Montana. "State waters" are considered to be *any* named stream or waterbody, including irrigation systems and unnamed perennial or intermittent tributaries to a stream lake, pond or other waterbody, including wetlands. Ephemeral streams qualify if the proposed work is within 30 m of a named or unnamed perennial or intermittent stream. Note that "State waters" do not include streams on Indian Reservations. National Pollutant Discharge Elimination System (NPDES) and Stormwater Pollution Prevention Plan (SWPP) authorization must be secured for work proposed on an Indian Reservation.

2. Aquatic Lands Permits (ALPO). The ALPO Permit is needed for work in *any* named stream or waterbody or any unnamed perennial or intermittent tributary to a stream, lake, pond or other waterbody on certain Indian Reservations. Ephemeral streams also need this Permit if work occurs within 30 m of a named or unnamed perennial or intermittent stream or tributary. The enabling ordinance for this Permit is the Aquatic Lands Conservation Ordinance (ALCO). This is also called an ALCO Permit. As of this date, the only tribal governments to enact this ordinance have been the Blackfeet and the Flathead.

3. Montana Asbestos Abatement Project Permit and National Emission Standards for Hazardous Air Pollutant Demolition/ Renovation Notification. These requirements apply to structures with known asbestos treatments.

13.9 STRUCTURE TYPE, SIZE AND LOCATION

The intent of the preliminary layout design is to select a structure type, size and location that addresses all of the aspects discussed in Chapter Thirteen of the **Montana Structures Manual**. The preliminary layout design is reviewed by other design units (Road Design, Hydraulics, Geotechnical, etc.), Environmental Specialists, the District and Resource Agencies (Fish, Wildlife and Parks, Department of Environmental Quality, Corps of Engineers). Once concurrence has been received from all areas, it is risky to change the layout. Changes can result in higher design cost and time delays for the project.

The preliminary layout design should be summarized in a Structure Type, Size and Location Report. The Report should document all issues considered in the design of the layout and include structural design parameters.

Items to be included in the Structure Type, Size and Location Report include:

1. hydraulics,
2. environmental,
3. roadway alignment,
4. bridge length and width,
5. bridge beam type,
6. geometrics,
7. riprap,
8. fit of bridge to site,
9. proposed substructure,
10. geotechnical/core logs,
11. proposed foundation site,
12. seismic, and
13. alternative structure types.

For guidance on the content and format of the Structure Type, Size and Location Report, use the information in Section 4.1.3 on the Design Parameters Report.