
CHAPTER 9 BRIDGES AND OTHER STRUCTURES

9-1.0 GENERAL

9-2.0 BRIDGES

- 9-2.01 Bridge Design Process
 - 9-2.01.01 General
 - 9-2.01.02 Bridge Design Standards
 - 9-2.01.03 Preliminary Bridge Plan
 - 9-2.01.04 Final Bridge Plan
 - 9-2.01.05 Visual Quality
 - 9-2.01.06 Cost Estimating
- 9-2.02 Bridge Geometrics – Alignment and Grades
 - 9-2.02.01 Alignment
 - 9-2.02.02 Grades
- 9-2.03 Bridge Geometrics – Deck Sections
 - 9-2.03.01 Mainline Bridges
 - 9-2.03.01.01 Mainline Bridge – Deck Section
 - 9-2.03.01.02 Mainline Bridge – Underpass Section
 - 9-2.03.02 Ramp Bridges
 - 9-2.03.02.01 Ramp Bridge – Deck Section
 - 9-2.03.02.02 Ramp Bridge – Underpass Cross Section
 - 9-2.03.03 Local Road Bridges
 - 9-2.03.03.01 Local Road Bridge – Deck Section
 - 9-2.03.03.02 Local Road Bridge – Underpass Cross Section
 - 9-2.03.04 Railroad Bridges
 - 9-2.03.04.01 Railroad Bridge – Deck Section
 - 9-2.03.04.02 Railroad Bridge – Underpass Cross Section
- 9-2.04 Water Crossing
 - 9-2.04.01 Navigable Waterways
 - 9-2.04.02 Non-Navigable Waterways

9-3.0 LARGE HYDRAULIC STRUCTURES

- 9-3.01 Design Responsibility

- 9-3.02 Structures
 - 9-3.02.01 Box Culverts
 - 9-3.02.02 Large Circular Pipe
 - 9-3.02.03 Pipe Arches
 - 9-3.02.04 MnDOT Precast Concrete Arch
 - 9-3.02.05 Three-Sided Bridge Structures
 - 9-3.02.06 Metal Long Span Structures

9-3.03 End Treatments

9-3.04 Energy Dissipaters

9-4.0 WALLS

9-4.01 Design Responsibility

9-4.02 Design Types (Conventional)

- 9-4.02.01 Cantilever Walls
- 9-4.02.02 Counterfort and Buttress Walls
- 9-4.02.03 Precast Panels Walls

9-4.03 Design Types (Alternate)

- 9-4.03.01 General
- 9-4.03.02 Site Restrictions
- 9-4.03.03 Design Parameters
- 9-4.03.04 Material Properties
- 9-4.03.05 Retaining Wall Aesthetics
- 9-4.03.06 Traffic Safety Aspects
- 9-4.03.07 Acceptance Procedure
- 9-4.03.08 Approved MSE Retaining Wall Systems

9-5.0 MISCELLANEOUS STRUCTURES

9-5.01 Foundations for Signs, Signals, and Illumination Poles

9-5.02 Utility Bridges and Vaults

9-5.03 Tunnels

- 9-5.03.01 General
- 9-5.03.02 Design Considerations

9-5.04 Underpass Structures

- 9-5.04.01 Livestock Underpasses
- 9-5.04.02 Pedestrian Underpasses

CHAPTER 9 BRIDGES AND OTHER STRUCTURES

9-1.0 GENERAL

This chapter addresses the basic geometry and design requirements for bridges, retaining walls, large drainage structures and other structures referred to the Bridge Office for design. It is not to be a complete coverage of the structure design process but is provided to assist the District roadway designer in coordinating the development of these project elements.

A more detailed treatment of design requirements for bridges and other structures is contained in the MnDOT Load and Resistance Factor Design (LRFD) Bridge Design Manual. The sections of the MnDOT LRFD Bridge Design Manual that will be of particular interest to the roadway designer are:

- Section 1 – Introduction;
- Section 2 – General Design and Location Features; and
- Section 13 – Railings.

The design of bridges and other structures is a centralized function within MnDOT that supports the project delivery efforts of the District Offices. The Bridge Office provides the following design-related services:

1. Support to transportation planning efforts,
2. Assistance with project scoping,
3. Management of bridge design schedules,
4. Hydraulic design for bridges and large hydraulic structures,
5. Support to District hydraulic staff for roadway drainage and minor hydraulic structures,
6. Preliminary bridge design and plan production,
7. Final bridge design and plan production,
8. Bridge cost estimating, and
9. Maintenance of Standards for bridges and other structures.

The Bridge Office provides guidance and engineering services for all bridge/structure construction and maintenance activities in the State. Complete information on the policies and procedures related to bridge design can be found in the MnDOT LRFD Bridge Design Manual.

THIS PAGE LEFT INTENTIONALLY BLANK

9-2.0 BRIDGES

Minnesota State Statute (Rule 8810.8000) defines a bridge as "...a structure...having an opening measured horizontally along the center of the roadway of ten feet or more between undercopings of abutments, between spring line of arches, or between extreme ends of openings for multiple boxes. Bridge also includes multiple pipes where the clear distance between openings is less than half of the smaller contiguous opening."

The Commissioner of Transportation delegates authority to the State Bridge Engineer for approval of preliminary bridge plans for state projects and final bridge plans for State, County and City projects. The State Bridge Engineer must approve plans for the construction or reconstruction of any bridge meeting the following criteria:

1. On the Trunk Highway system;
2. Crossing the Trunk Highway system; and
3. On County and City highway projects using State funds.

All bridges in the State are identified by a bridge number which is shown on bridge and roadway design plans. The bridge number identifies the structure during project delivery and serves as a unique identifier for ongoing bridge inspection and management efforts. The bridge numbering system is maintained by the MnDOT Bridge Office.

The bridge types commonly used on Minnesota's State and Local transportation system are listed below:

1. Beam span with prestressed concrete beams,
2. Beam span with structural steel beams,
3. Slab span with cast-in-place concrete,
4. Reinforced concrete box culvert, and
5. Precast three-sided bridge structures.

Other structure types are considered where appropriate.

9-2.01 Bridge Design Process

9-2.01.01 General

Bridge Office involvement in the project delivery process begins in the planning stage. The Regional Bridge Construction Engineers from the Bridge Office assist the District with decision-making in regard to preservation, improvement, rehabilitation, and replacement of District bridges. The MnDOT Bridge Preservation, Improvement and Replacement Guidelines provide the basis for the consideration of bridge renovation or replacement options.

When any project containing bridges is programmed, the Bridge Office should be notified so that a Bridge Project Manager can be assigned and a design schedule established in Program and Project Management System (PPMS).

The Preliminary Bridge Plans Unit will be the primary point of contact for project coordination during project scoping, predesign, and the early stages of final design. During this stage, the scope of bridge and structure work within a project is determined. Bridge survey and foundation investigations are conducted to support the bridge design effort. The type, size, and location of bridges is established and documented on the preliminary bridge plan, and a preliminary bridge estimate is produced.

After the preliminary bridge plan is signed, a Bridge Final Design Unit will produce the detailed bridge plans and specifications, and the Bridge Final Design Unit leader will be the point of contact for project coordination. The Bridge Final Design Unit also supports roadway plan production with design services for box culverts, retaining walls, non-standard traffic barriers, and other minor structures. The production of final bridge plans will normally coincide with the later stages of final roadway design and roadway plan preparation.

9-2.01.02 Bridge Design Standards

The standards and policies governing bridge and structure design are contained in the following documents:

1. AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specifications;
2. MnDOT Load and Resistance Factor Design (LRFD) Bridge Design Manual;
3. MnDOT Bridge Preservation, Improvement, and Replacement Guidelines;
4. MnDOT Bridge Standard Plans;
5. MnDOT Bridge Details Manual Part I;
6. MnDOT Bridge Details Manual Part II;
7. MnDOT Bridge Construction Manual;
8. MnDOT Bridge Maintenance Manual;
9. Other Parts of this Manual; and
10. MnDOT Drainage Manual.

9-2.01.03 Preliminary Bridge Plan

The preliminary bridge plan serves as a collaboration document for the coordination of bridge design with other functional areas (hydraulics, roadway design, foundations, visual quality, utilities, etc.). Upon signature by the State Bridge Engineer, the preliminary bridge plan serves to document the main features of the bridge (location, structure dimensions, type of construction, geometrics, aesthetics, etc.). This information is used for final bridge design, for obtaining approvals, and for preliminary cost estimating. The preliminary bridge plan is especially important for stream crossings, railroad crossings (over or under) and structures requiring special aesthetic treatment.

It is the responsibility of the bridge and district project managers to ensure that details are consistent between roadway and bridge design. Some key points of coordination during preliminary design are:

1. Depth of the structure to set grades;
2. Roadway classification, design speed, and forecasted traffic volumes to establish required bridge geometrics;
3. Coordinates and elevation of any retaining walls that tie into abutment walls or wingwalls;
4. Aesthetic treatments for bridges, retaining walls, and noise walls; and
5. Staging considerations that impact bridge and bridge embankment construction.

9-2.01.04 Final Bridge Plan

When all approvals have been obtained, the preliminary plan is used as the basis for the preparation of final detailed plans and specifications. Important coordination points between road design and final bridge design are:

1. Footing elevations;
2. Locations of signals or lighting;
3. Bridge mounted utilities and conduits;
4. End of bridge stations;
5. Approach panel details and quantities;
6. Approach treatments, guardrails, and guardrail transitions to bridge rail;
7. Coordinates and elevation of any retaining walls that tie into abutment walls or wingwalls; and
8. Aesthetic treatments for bridges, retaining walls, and noise walls.

9-2.01.05 Visual Quality

Aesthetics is an integral part of bridge and structure design. The Preliminary Bridge Plans Engineer and the District Project Manager coordinate the process of determining the appropriate aesthetic level and soliciting stakeholder review and input on bridge aesthetics. Three broad levels of bridge aesthetic treatment are identified:

- Level A - intended for high profile bridges with major cultural or regional significance.
- Level B - used for mid-level structures, including highway corridors.
- Level C - used for routine bridges.

For many large or high-profile projects, architectural and aesthetic design guidelines are prepared by the Landscape Architecture Unit. The result of this effort is the preparation of an "Aesthetic Design Guide" or "Visual Quality Manual" which establishes a visual theme to be continued throughout a highway corridor or within a specific project.

Refer to the MnDOT Aesthetic Guidelines for Bridge Design for a comprehensive treatment of bridge aesthetics. Refer to the MnDOT Policy on Guidelines for Cooperative Construction Projects for details on cost sharing and agreements.

9-2.01.06 Cost Estimating

The Bridge Office provides estimated bridge construction costs to the District. The Bridge Office may also assist in estimating construction costs for other structures (retaining walls, noise walls, box culverts, etc.). The Estimating Unit in the MnDOT Office of Technical Support is the primary resource for construction cost estimates of all non-bridge components.

As preliminary bridge design progresses, the bridge cost estimate is adjusted to reflect any changes to scope, layout, staging, etc. Three distinct bridge cost estimates are normally provided:

1. The initial or Scoping Estimate is provided when a project is programmed. This estimate is updated during preliminary design as design decisions are finalized.
2. The Preliminary Estimate is provided at the completion of the preliminary bridge plan. This formal estimate is signed by the State Bridge Engineer.
3. An Engineer's Estimate is provided at the completion of the final bridge plan and is incorporated into the project bid documents.

On certain structures, where alternate types of construction and span arrangements may be equally feasible, the difference in cost of the alternates cannot be readily evaluated from an assumed unit cost per square meter (**square foot**) of bridge deck area. In these cases, partial designs are made in sufficient detail to develop preliminary quantities and produce a more refined cost estimate for each alternate.

9-2.02 Bridge Geometrics – Alignment and Grades

9-2.02.01 Alignment

Alignment on bridges requires careful consideration for reasons of safety and economy. It is desirable to simplify roadway alignments to the extent possible.

A high skew angle will increase the required bridge length and structural depth. It will also increase substructure length, which greatly adds to the cost and complexity of the structure. Skew angle between roadway alignment and bridge substructures should be minimized where possible.

It is desirable to maintain a tangent alignment over bridges. Ending or beginning a curve on a bridge is of concern as the deck of a bridge can frost faster than the adjacent roadway; it also complicates bridge design and construction. When horizontal curvature is unavoidable, the limits of the bridge should fall entirely within the body of the flattest practical simple curve. Horizontal curves that begin or end near a bridge should ideally be located so that no part of the superelevation transition and tangent runoff extends onto the bridge. A uniform deck section across the entire bridge (either fully superelevated or in normal crown) is the most economical to design and construct.

When a single bridge is used for a divided roadway, one controlling alignment across the bridge is preferred. When separate structures are used on a divided highway, the centerline alignment should be on the crown or "hip-point" of each roadway.

If any part of a taper extends onto a bridge, some adjustment of the taper may be necessary during preliminary bridge design. It is desirable to begin or end tapers at the centerline of piers or abutments. In some cases, it may be desirable to extend the taper the full length of the bridge or build a wider constant width bridge with paint stripes defining the taper.

9-2.02.02 Grades

Final grades for roadways on a bridge or under a bridge should be established through coordination with the Preliminary Bridge Plans Unit. The profile grade line for any bridge must consider the required vertical clearance under the bridge plus the total thickness of the girder and deck (structural depth). For setting rough grades during layout preparation, the depth of structure can be estimated as 5.0 percent of the span length.

The detailed guidance on required vertical clearances can be found in the MnDOT LRFD Bridge Design Manual. For stream crossings, the Bridge Hydraulics Unit will establish the minimum allowable low member elevation.

For profile grades on a bridge, the drainage of stormwater from the bridge deck is an important consideration. For bridges less than 150 m (**500 ft**) in length, deck drainage is usually carried longitudinally along the structure and discharged into catch basins or flumes at the bridge ends. Steeper longitudinal slopes, steeper cross slopes or wider shoulders may be employed to minimize the spread of stormwater onto the roadway. Intermediate deck drains can be provided, but their use is strongly discouraged. MnDOT does not normally discharge water directly into a river or stream and stormwater piping systems on a bridge are costly and problematic to maintain. Consult the MnDOT Drainage Manual for additional details on deck drainage.

Some other key requirements for bridge grades are as follows:

1. Vertical curves shall provide a minimum slope of 0.25 percent for not more than 30.0 m (**100 ft**);
2. On tangent profiles, the desirable minimum gradient is 0.5 percent;
3. Low points on sag vertical curves should be located off the bridge and approach panel;
4. A single controlling grade is preferred when a divided roadway crosses a single bridge; and
5. Minimum grades should only be used where required by geometric constraints.

For pedestrian and bicycle bridges the maximum continuous grade allowed by the Americans with Disabilities Act (ADA) is 5.0 percent. This grade can be increased to 8.33 percent if periodic level platforms are provided.

Roadways should not have their low point located directly under bridges due to roadway icing under the shadow of the bridge. See Chapter 3 of this manual.

9-2.03 Bridge Geometrics – Deck Sections**9-2.03.01 Mainline Bridges**

Mainline bridges are those bridges that carry through traffic lanes for freeways, expressways, primary highways, and secondary highways. The width of the bridge deck and the typical section at the bridge undercrossing are determined by the classification and geometrics of the approaching roadway. This width should be carried over and under the bridge to the maximum practical extent.

Rural design is considered the desirable design and will be used in all rural areas and in urban areas where sufficient right-of-way is available or can be obtained. The geometrics of urban design (with curbed roadways) are slightly more restrictive, and are used at locations where excessive right-of-way costs or other unusual conditions are controlling factors.

Chapter 4 of this manual and Section 2 of the MnDOT LRFD Bridge Design Manual contain detailed guidance and specific geometric details of bridge and highway cross sections.

9-2.03.01.01 Mainline Bridge – Deck Section

The current design standards for bridge width shall be provided for all new construction and rehabilitation projects (where a bridge is reconstructed to conform to minimum standards). For bridge improvement projects, minimum criteria for widening are found in the MnDOT Bridge Preservation, Improvement, and Replacement Guidelines.

1. Width

Due to economic factors, bridge widths are generally narrower than the roadway clear zone of the approach roadway. This typically results in the bridge railing being within the roadway clear zone. Table 9-2.03A provides typical bridge shoulder widths that strike a balance between roadway safety and bridge cost considerations. Final bridge shoulder widths can be adjusted to specific conditions.

Additional width criteria may be needed in the following areas:

- a. Where a ramp bridge is on radius of 58.0 m (**190 ft**) or less, or when the truck volume is 10 percent or greater, increase the effective traffic lane from 4.8 m to 5.4 m (**16 ft to 18 ft**) to accommodate truck-turning movements.
- b. For curved bridges longer than 30.0 m (**100 ft**), check the horizontal stopping sight distance, and increase the shoulder width on the inside of the curve up to a maximum of 3.0 m (**10 ft**). See Section 2 of the MnDOT LRFD Bridge Design Manual, for the proper shoulder width required for a continuously curving bridge to eliminate or simplify a taper or curvature.

2. Cross Slope

The cross slope on bridge traffic lanes is the same as the approaching roadway lanes, normally 0.02 m/m (**0.02 ft/ft**). The shoulder cross slope on the bridge may continue at 0.02 m/m (**0.02 ft/ft**) to simplify design and construction. For improved deck drainage, the shoulder cross slope may be 0.005 m/m (**0.005 ft/ft**) greater than the adjacent lane. When the bridge deck is superelevated, the shoulders shall have the same slopes as the adjacent bridge traffic lanes.

3. Bridge Medians and Median Barriers

On divided highways with a separate bridge for each roadway, a minimum opening of 2.4 m (**8 ft**) between bridges is normally provided for access by bridge inspection vehicles.

For roadways where a tall “glare screen” median barrier is continued across a bridge, a split median barrier is provided on the bridge. The base width of this split median barrier is larger than the approach barrier, and will slightly decrease inside shoulder width on the bridge.

4. Bridge Railing

Railings should be provided at the edge of bridges for the protection of traffic on the bridge as well as for the protection of any traffic under the bridge. Traffic railings, traffic barrier to bridge rail transition, and end treatments must meet the requirements for crash testing of National Cooperative Highway Research Program (NCHRP) Report 350 with the appropriate test level.

Common standard railing types are the Type F concrete barrier adjacent to traffic lanes and concrete parapet with ornamental metal railing adjacent to sidewalks or trails.

Careful attention must be given to the treatment of railing at the bridge ends. The ends of bridge railing must be protected from impact for all roads with speeds 60 km/h (**40 mph**) and greater. The protective device used normally is a plate-beam guardrail transition found in the Standard Plans, Series 600. See Chapter 10 for further information.

For bridges with sidewalks spanning over roadways or railroads, protective screening (fencing or ornamental railing) is required to discourage the dropping or throwing of objects from the bridge.

See Sections 2 and 13 of the LRFD Bridge Design Manual for a detailed discussion of bridge railings.

5. Gore Areas on Bridge

Gore areas on elevated structures that result in blunt concrete surfaces or exposed bridge rail ends present a hazard to errant vehicles. Gore areas on bridges should be avoided unless there is adequate space for the installation of an impact attenuator. For a description of impact attenuators and the determination of adequate space for installation, see Chapter 10.

6. Bridge Sidewalks

Where warranted by pedestrian or bicycle traffic, sidewalks on one or both sides of the traveled way may be required. Bridge sidewalks are normally elevated 200 mm (8 in.) above deck level on a raised concrete slab. When the speed limit on the roadway is 70 km/h (45 mph) or higher, a concrete barrier shall be provided between the roadway and the sidewalk. In this configuration, the walkway or trail can be at deck level and a raised walk will not be required.

A minimum sidewalk width of 1.8 m (6 ft) is required as measured at right angles to the longitudinal centerline of the bridge from the face of concrete parapet or extreme inside portion of the handrail to the bottom of the curb. For designated bicycle trails, a width of 3.0 m (10 ft) minimum, up to 3.6 m (12 ft) desirable, shall be provided.

When a sidewalk is included in the bridge design, the roadway design engineer may need to provide ramping at the ends of the sidewalk off the bridge. In those cases, a berm 0.3 m (1 ft) wider than the bridge sidewalk should be provided on the approaching roadway section.

**Table 9-2.03A (Dual Units)
BRIDGE SHOULDER WIDTHS**

HIGHWAY TYPE		BRIDGE SHOULDER WIDTH	
2-LANE	RURAL		Usable shoulder width of approach roadway to a maximum of 3.6 m. (1.2 m min.) (12 ft. (4 ft min.)). Width must meet federal appraisal rating of 6.
	URBAN		Shoulder width of approach roadway. Minimum shoulder width 1.2 m (4 ft) to barrier rail, 0.6 m (2 ft) to sidewalk. Widths shown are for low speed roadways. Increase widths by 0.6 m (2 ft) each for high-speed roadways.
FREEWAY*	RURAL	LEFT	1.8 m (6 ft) for 4-lane, 3.6 m (12 ft) for 6-lane or more.
		RIGHT	3.6 m (12 ft), 2.4 m (8 ft) next to auxiliary lane.
	URBAN	LEFT	1.8 m (6 ft) for 4-lane, 3.0 m (10 ft) for 6-lane or more.
		RIGHT	3.0 m (10 ft), 1.8 m (6 ft) next to auxiliary lane.
MULTI-LANE* DIVIDED (HIGH SPEED)	RURAL	LEFT	1.8 m (6 ft) for 4-lane, 3.6 m (12 ft) for 6-lane or more.
		RIGHT	3.6 m (12 ft), 2.4 m (8 ft) next to auxiliary lane.
	URBAN	LEFT	1.8 m (6 ft) for 4-lane, 3.0 m (10 ft) for 6-lane or more.
		RIGHT	3.0 m (10 ft), 1.8 m (6 ft) next to auxiliary lane.
MULTI-LANE DIVIDED (LOW SPEED)	URBAN	LEFT	Shoulder width of approach roadway. Minimum width is 1.2 m (4 ft) to barrier rail, 0.6 m (2 ft) to sidewalk or raised median.
		RIGHT	
MULTI-LANE UNDIVIDED (LOW SPEED)	URBAN	LEFT	Shoulder width of approach roadway. Minimum width is 1.2 m (4 ft) to barrier rail, 0.6 m (2 ft) to sidewalk or raised median.
		RIGHT	

*For buses on shoulders, use 3.5 m (11.5 ft) minimum, 3.6 m (12 ft) desirable. 3.6 m (12 ft) is required with new construction or reconstruction. Buses run on right shoulders only.

9-2.03.01.02 Mainline Bridge – Underpass Section

Bridge substructure units (piers and abutments) must be located to accommodate the cross section of the undercrossing highway. The lateral and vertical clearances and drainage of the undercrossing highway are the primary concerns.

1. **Lateral Clearances**

The lateral clearances for bridge underpasses should provide a clear zone recovery area beside the roadway that is free from hazards. Normally, a clear zone of 10 m (**30 ft**) from edge of lane to toe of abutment end slope is considered a practical maximum.

When piers or abutments are located within the clear zone, they shall be protected by a suitable guardrail or barrier. In all cases, the minimum clearances stated in Section 2 of the MnDOT LRFD Bridge Design Manual shall be provided.

Chapter 4 discusses the clear zone in detail and provides the required clear zone distances.

2. **Vertical Clearances**

The vertical clearances shown in Section 2 of the MnDOT LRFD Bridge Design Manual and RDM Chapter 3 apply to roadway design.

3. **Sight Distance**

Abutments and piers along the inside of curves should be located to provide adequate sight distances. See Chapter 3 for detailed discussion of sight distance requirements.

4. **Pier Protection**

Bridge piers that are within the clear zone require protection from vehicle collision. Piers within 10 m (**30 ft**) of high-speed, high-volume roadways shall be either designed for a vehicle impact or protected with a suitable test level traffic barrier. Details of pier protection should be coordinated with the Bridge Office.

9-2.03.02 Ramp Bridges

At certain types of interchanges bridges will be required to carry ramps or loops over the mainline roadway or in close proximity to the mainline roadway. The design of these ramp bridges and underpasses should follow the general design standard (urban or rural) being applied to the project.

Chapter 6 of this Manual discusses the geometric design of ramp roadways. The following sections identify requirements for ramp bridge and underpass geometrics and give minimum dimensions for clearances. Section 2 of the LRFD Bridge Design Manual provides design details.

9-2.03.02.01 Ramp Bridge – Deck Section

1. **Width**

On rural ramp bridges, the dimension from edge of lane to the gutter is reduced to prevent the appearance of having a 2-lane bridge on a 1-lane ramp roadway. The dimension between bridge gutters should be 7.8 m (**26 ft**) which provides for a 4.8 m (**16 ft**) traffic lane on the approach roadway plus 1.8 m (**6 ft**) from edge of lane to the gutter on the right, and 1.2 m (**4 ft**) from edge of lane to the gutter on the left.

When an auxiliary lane, a ramp, or a taper extends onto a mainline bridge, the basic width is determined as for a mainline bridge decks with the following additional controls:

- a. For approaching ramps or tapers without curbs, the distance from the edge of ramp or taper to the gutter line is 2.4 m (**8 ft**).
- b. For approach ramps with curbs, the distance from the edge of ramp or taper to gutter line is 1.8 m (**6 ft**).
- c. Tapers should begin or end at a pier or an abutment or may continue across the entire length of the structure.

When a ramp bridge is on curvature of 60 m (**200 ft**) radius or less, the traffic lane is increased from 4.8 m to 5.4 m (**16 ft to 18 ft**) in width. The horizontal stopping sight distance for the design speed proposed should also be checked and additional inside shoulder width added if required. Chapter 3 provides guidance on sight distance.

2. **Cross Slope**

Normally a uniform cross slope between the bridge curbs, with a slope 0.02 m/m (**0.02 ft/ft**) to the right is used unless the ramp is superelevated.

9-2.03.02.02 Ramp Bridge – Underpass Cross Section

Where ramp and loop alignments extend under a bridge, it is advantageous to keep them as close as possible to the mainline roadway to minimize bridge span length. Where possible, the beginning of a taper to a ramp should be relocated to remove it entirely from under the bridge.

Where a ramp under a bridge is independent of the mainline roadway, bridge piers adjacent to the ramp may be required. In most cases this will be within the ramp or mainline clear zone, and will normally require shielding with a barrier or crash cushion. Barriers or guardrail should be placed no closer than the edge of the ramp shoulder, normally 1.8 m (**6 ft**) from the edge of ramp lane.

Clear zone for the ramp is generally calculated with the assumption that the design speed is less than the mainline.

9-2.03.03 Local Road Bridges

Bridges and underpasses that carry local road traffic are designed using the same procedures followed for the mainline structures, with the similar requirements for safety, aesthetics, and economy. The following sections discuss design features that are applicable to local roads.

Local bridges at an interchange with a trunk highway are designed to trunk highway standards between the ramp terminals on the local road.

Complete coverage of local State Aid route standards are contained in the State Aid Manual and the Chapter 8820 of the Minnesota Rules. Further guidance on State Aid Rules is available from the State Aid Office and State Aid Bridge Unit.

9-2.03.03.01 Local Road Bridge – Deck Section**1. Width**

For CSAH and other local roads, the shoulder and driver reaction dimensions are governed by ADT. Section 2 of the MnDOT LRFD Bridge Design Manual gives geometric standards for rural undivided Federal-Aid Secondary, County State Aid Highways, and other local roads.

For urban design, the bridge gutter lines should usually be aligned with the curb line on the approaching roadway but not less than the minimums established in the MnDOT LRFD Bridge Design Manual. Parking bays need not be carried across the structure.

2. Cross Slope

Cross slopes for local road bridges will be the same as for bridges on trunk highways.

9-2.03.03.02 Local Road Bridge – Underpass Cross Section

The basic cross section of the local road should be carried through the underpass. The required clear zone or lateral clearance to any obstructions can be determined from the procedure presented in Chapter 4 of this manual.

Section 2 of the LRFD Bridge Design Manual provides the design details for a local road underpass. On local urban streets, the face of piers or abutments should be located on or beyond the property lines. This will provide for future development of the section by local authorities. A minimum distance of 1.8 m (**6 ft**) from the face of curb to the face of pier or abutment must be provided.

Vertical clearances are the same as for a major road underpass unless otherwise noted in State Aid Manual.

9-2.03.04 Railroad Bridges

For negotiation and coordination of agreements with any railroad company, the Office of Freight and Commercial Vehicle Operations should be contacted. The coordination process can be lengthy and discussions with the railroad company should occur as early as possible in the design process. It is desirable to submit a draft version of the Preliminary Bridge Plan to the railroad as soon the basic bridge configuration is established.

Staging for the construction of railroad bridges is often complicated. Detour routes for rail traffic are not generally available and the track must remain in service for the passage of trains during construction. A shoofly track (temporary diversion alignment) may need to be constructed before any work on an in-place railway bridge can begin. Where a roadway crosses a railroad, bridge construction in close proximity to railway traffic requires close coordination with railroad operations personnel.

When considering a new railroad/highway grade separation, it is usually desirable to place the highway over the railroad. Reasons to not place a railroad over a highway include:

1. Bottlenecks are created for railroad operators.
2. Widening the highway is difficult.
3. Controversies over cost participation in construction may develop.
4. Temporary tracks are usually required.
5. Railroad concern may develop over structure maintenance and liability.

9-2.03.04.01 Railroad Bridge – Deck Section

Because of the heavy design loading, railroad bridges generally have shorter spans and larger structural depths than highway bridges. Although each railroad has preferred details, the superstructure system (deck-girder) is essentially the same for most railroad bridges with steel girders supporting a concrete or steel deck. The deck (or ballast pan) has curbed edges to retain the required depth of ballast rock and the track structure. For cases where the required structural depth can be accommodated, this structure type can be economical for spans up to about 30 m (**100 ft**).

A rule of thumb for calculating structural depth of a deck-girder railroad bridge is as follows: span length (in feet) plus 10 = depth of structure (in inches). For example, a 90-foot span would require 90+10 = 100 inches of depth from top of rail to base of girder.

For longer spans (up to about 60 m (**200 ft**)) a through-girder superstructure is normally required; with a through-girder, the main longitudinal load-carrying members extend above the track elevation. This superstructure type can span a much longer distance with a relatively shallow structural depth; however, this type of structures is generally discouraged by railroad companies due to the risk of damage to the girders in the event of a derailment.

9-2.03.04.02 Railroad Bridge – Underpass Cross Section

Section 2 of the MnDOT LRFD Bridge Design Manual provides the cross section design details for railroad underpasses. The minimum statutory horizontal opening is 5.2 m (**17 ft**). A minimum clearance of 5.4 m (**18 ft**) from the centerline of track to face of pier or abutment is normally used except in congested urban areas where this is impractical. Typical sections will probably be wider and may have enough clearance for a 2.4 m (**8 ft**) off-track access roadway for railroad maintenance vehicles.

Often the railroad will request accommodation for the potential construction of a future track. The location and spacing between in-place and future tracks should be established early in the design process so that the appropriate span length can be provided.

Backslopes should be 1:2, and should pass through the "backslope control point" shown in Section 2 of the MnDOT LRFD Bridge Design Manual. The dimension to the "backslope control points" indicates the maximum extent of federal participation in the construction and should not be exceeded.

Backslopes steeper than 1:2 can be considered where the existing track is in a cut section that has greater than 1:2 slopes. Where provision for an off-track maintenance road has been justified (as verified by the Office of Freight and Commercial Vehicle Operations, Railroads and Waterways Section), the dimension to the "backslope control point" can be increased by up to 2.4 m (**8 ft**).

Side piers are placed 1.2 m (**4 ft**) in from the backslope control point (5.5 m (**18 ft**) clear to the centerline of track for a cut section without a maintenance road). MnDOT and FHWA have agreed to the horizontal clearance shown in the MnDOT LRFD Bridge Design Manual, for Mainline BNRR tracks at sites meeting the following conditions:

1. When the standard will not increase the costs by more than \$50,000.
2. When sufficient vertical clearance exists between the track and existing or proposed roadway profile to accommodate the structure depth necessary for longer spans typically required by the standard.

If these conditions cannot be met, a letter should be submitted by the Bridge Office to the Office of Freight and Commercial Vehicle Operations, along with the signed plan stating the reasons the standard cannot be met, including an estimate of the increased cost if applicable.

The minimum statutory vertical clearance between the railroad and highway is 6.7 m (**22 ft**). For design purposes, a 7.0 m (**23 ft**) minimum should be used. This distance is measured from the top of rail to the bottom of the superstructure on the highway bridge.

9-2.04 Water Crossing

During preliminary route determination, water crossing locations must be selected to minimize construction, maintenance, and replacement costs. Stream characteristics such as meanders should be studied to determine the need for channel changes, river training works and other techniques that could reduce erosion and prevent possible loss of the structure. On wide floodplains, the lowering of approach embankments is an option that can provide overflow sections for the passage of low frequency, catastrophic floods over the highway. If relief bridges are required to maintain natural flow distribution and reduce backwater, the size and location of structure must be selected with caution in order to avoid undue scour or changes in the course of the main river channel.

The determination of adequate waterway openings for trunk highway stream crossings is the responsibility of the Bridge Hydraulics Engineer. A waterway analysis will determine the drainage area to the crossing, compute the applicable discharges and water surface elevations, establish backwater and mean velocities for various combinations of waterway openings and road profile elevations, and determine scour depths if appropriate. With the use of risk assessment and/or risk analysis, the Bridge Hydraulics Engineer will recommend a waterway opening, minimum low member elevation, and road profile elevation if appropriate, to the District and Bridge Project Managers and establish the necessary hydraulic data to design the bridge and obtain the required permits.

9-2.04.01 Navigable Waterways

Preliminary bridge plans are used as a basis for preparing permit drawings to accompany applications to the U.S. Coast Guard and U.S. Army Corps of Engineers for permits to construct structures and approaches over navigable waters of the United States. Requirements for such plans are given in Section 2 of the MnDOT LRFD Bridge Design Manual. Correspondence to the Coast Guard or Corps of Engineers is prepared for submission by the State Bridge Engineer.

The Preliminary Bridge Plans Engineer should be consulted when establishing vertical and horizontal clearance requirements over navigable waterways. Generally, navigable waterways that require a construction permit from the Coast Guard are as follows:

1. Mississippi River downstream from the Coon Rapids Dam;
2. Minnesota River downstream from Chaska;
3. St. Croix River downstream from Taylors Falls;
4. International boundary waters; and
5. Lake Superior and the St. Louis River downstream from Oliver, Wisconsin.

These waterways generally require an 18.3 m (**60 ft**) minimum vertical clearance above normal pool, except Lake Superior and the St. Louis River that require additional clearance. Refer to CFR 650 – Part H for additional information on navigational clearances for bridges over navigable waterways.

Bridges that cross other waterways may require a certain vertical clearance to provide for local pleasure boat traffic. Vertical clearance for these bridges will be determined on an individual basis based on local needs. The District Office will normally make this determination based on a survey of boats using the waterway or by consultation with the local DNR Office. As a general guideline, provide 1 m (**3 ft**) of vertical clearance above the 50-year flood stage for bridges, and 1 m (**3 ft**) of vertical clearance above the ordinary high water level (top of bank) for other structures.

9-2.04.02 Non-Navigable Waterways

The waterway opening and the highway profile together determine the capacity of the system to pass floods. The effects of the roadway profile on the adequacy of the waterway opening should be considered when establishing the profile and when designing the bridge waterway. Several profile alternatives are available for consideration, dependent upon site topography, traffic requirements, and flood damage potential. The alternatives range from crossings that are designed to overtop frequently, to crossings that are designed to overtop rarely or never. The alternative selected will depend upon the criteria established for the design: construction costs, risks, stage-discharge-duration relations, flow distribution, flood insurance study (FIS), flood damage potential, and scour considerations.

The most desirable profile is the one where the valley width is sufficient to utilize a profile that allows the roadway to overtop without the superstructure of the bridge being submerged. Variations of this profile may be used in locations where the stream channel is located on one side of the flood plain and the profile allows overtopping of the approach roadway on only one side. The difference between the low point in the roadway profile and low member of the bridge superstructure can be varied, within geometric constraints, to meet requirements for maintaining clearance under the bridge and to accommodate passage of ice, debris, and drift.

The most critical profile is where the bridge is located at the low point of a sag vertical curve. Without an adequate opening and under a large flood event, the bridge superstructure and piers will be submerged which will accentuate scour. Floodwater, debris or ice drift can produce high impact forces on the structure, increasing the risk of structural failure, especially if scour has affected the foundations. If a sag vertical curve cannot be avoided, and there is even a small probability of overtopping, it is advisable to avoid solid barriers and use open-type railing with this profile in order to minimize damage. Bridges on sag vertical curves, with low points on the bridge, are also undesirable with regard to deck drainage, because ponding will occur on the deck if inlets have insufficient capacity to intercept the flow or become clogged with ice or debris. Drains on bridges should only be used if no other feasible alternative is found.

A level profile has the same disadvantages of a sag vertical for all floods with stages below the profile elevation of the roadway and bridge deck. Variations in this profile include a slight crest vertical curve on the bridge to establish a camber in the superstructure for deck drainage.

Freeboard clearances over non-navigable streams will depend on the high water elevation, history of ice and debris problems, and roadway geometrics.

When hydraulically feasible, it can be advantageous to replace an existing bridge with a box or pipe culvert. A buried structure requires less maintenance and eliminates the need for guardrail transitions and bridge railings within the clear zone. Generally, the headwall of the culvert is located outside the clear zone of the roadway. Wide roadways, tall embankments, and high skew angles will require additional culvert length. Future maintenance costs, up-front construction costs, and environmental requirements, should be considered when making this decision.

THIS PAGE LEFT INTENTIONALLY BLANK

9-3.0 LARGE HYDRAULIC STRUCTURES

Large concrete, steel, and aluminum drainage structures are suitable structure types for some projects. These types of drainage structures include concrete or metal box culverts, large concrete or metal circular pipe, large concrete or metal pipe arches, three-sided bridge structures, and metal long spans.

Large hydraulic structures are open-ended conduits that carry runoff and other flow under the roadway and have a span greater than 1200 mm (**48 in.**). Large hydraulic structures with span width greater than or equal to 3 m (**10 ft**) are considered bridges and shall be identified by a unique bridge number. The designer shall notify the Bridge Office that a new bridge is being proposed so that a number can be assigned.

Large hydraulic structures may be classified as rigid, semi-rigid, or flexible, depending on the type of material. Major considerations for the designer when determining the design type are: hydraulic performance, structural stability, serviceability, durability, and economics. Discussion of these considerations and other detailed information is presented in the MnDOT Drainage Manual, MnDOT LRFD Bridge Design Manual, AASHTO "Highway Drainage Guidelines," American Iron and Steel Institute (AISI) "Handbook of Steel Drainage & Highway Construction Products," American Concrete Pipe Association "Concrete Pipe Design Manual," and FHWA Hydraulic Design Series.

9-3.01 Design Responsibility

The road design engineer should prepare plans for the large hydraulic structures in a manner similar to other hydraulic structures showing the stationing, elevations, etc. However, because of the structure size, the road design engineer should coordinate the design of large hydraulic structures as follows:

1. The hydraulics engineer will provide a hydraulic recommendation that typically includes hydraulic data, conduit size and shape, invert elevations, and energy dissipation measures.
2. The structural design information is contained in the MnDOT Standard Plates Manual for the majority of design cases. The road designer can use these plates to identify the pipe class, gauge, and other pertinent information. If the structural criteria (fill height, size, loading, etc.) are outside the table values, the road design engineer shall request a structural design from the Bridge Office. The Bridge Office will prepare and submit the design plans and special provisions to the road design engineer. Structural design responsibility for all structures is a function of the Bridge Office. All structures shall be designed in accordance with the MnDOT LRFD Bridge Design Manual.
3. A geotechnical investigation may be required for these large hydraulic structures (refer to the MnDOT Geotechnical and Pavement Manual). The road design engineer should discuss the geotechnical needs for the project with the district soils engineer. If a geotechnical investigation is needed, the road designer should submit the request in a timely manner so the information is available during the design process. Typically, three to six months are needed to collect the soil samples, analyze the data, and prepare the report.

9-3.02 Structures

The basic types of large drainage structures used by the Minnesota Department of Transportation are discussed below.

9-3.02.01 Box Culverts

Structure plans for all box culverts located on the trunk highway system shall be prepared by the Bridge Office or by consultants from the approved list for inclusion in the roadway plan. This includes plans for new box culverts and modifications or extensions to existing boxes. Structure plans developed using the design tables and Bridge Standard Plan sheets are to be certified by the professional engineers, licensed in the State of Minnesota, in charge of the box culvert design.

Box culverts are usually constructed of precast or cast-in-place reinforced concrete. Metal box culverts are also available for use. For more information on these or other material types, contact the Bridge Office.

Standard precast concrete box culvert designs tables and plan sheets are located in the MnDOT Bridge Standard Plans Manual. Refer to the Bridge Standard Plans Manual for details on maximum fill heights since they are dependent on culvert size. Special designs for culvert sizes not found in the standard tables may be requested from the Bridge Office.

The road design engineer should furnish appropriate data to the bridge design engineer using the Culvert Request Form (see Figure 9-3.02A). The most current form can be obtained from the MnDOT Bridge Office website. Attachments to the request form should include: a roadway cross section at the roadway/box culvert intersection, the roadway profile, and a plan view showing the box culvert length and orientation to the roadway.

The Bridge Office will prepare a box culvert plan for inclusion in the roadway plan. The culvert request form should be submitted 6 months prior to the contract letting. If necessary, the Bridge Design Engineer will work with road design engineers in meeting shorter plan development schedules.

Currently, culvert plans only detail precast concrete box culverts. This is because of the greater efficiencies in designing, detailing, and installation times that precast has over cast-in-place concrete box culverts. If desired, the road designer may request plans for a cast-in-place concrete box culvert, however, additional time will be needed for plan production and construction. Extension to existing culverts may require some cast-in-place concrete. Some limitations on the use of precast concrete box culverts are:

1. When fill height is less than 300 mm (**12 in.**), a cast-in-place box or other structure type is required.
2. When fill height is greater than 300 mm (**12 in.**) but less than 600 mm (**24 in.**), a 150 mm (**6 in.**) distribution slab is required.
3. When the culvert skew is greater than 45 degrees, a cast-in-place box is required.
4. In the case of multiple barrels, a separation of 600 mm (**24 in.**) of compacted embankment shall be maintained between the barrels. Under certain conditions the minimum separation can be reduced to 150 mm (**6 in.**). Contact the Bridge Office for details.
5. In installations where large settlements are anticipated, the joints between the barrel sections shall be sealed and covered with geotextile.

Although the amount of steel reinforcement varies with fill height, roadway designers are discouraged from requesting multiple designs for a single line of pipe. Any initial savings in material costs quickly disappear if the weaker sections need to be replaced or strengthened during future widening or bypass projects. In addition, using a single overflow design eliminates any possibility that weaker segment designs may be overlooked during future work.

Minnesota Department of Transportation

Memo

Transportation District 8
 2505 Transportation Rd.
 P.O. Box 768
 Willmar, MN 56201

Office Tel: 320-231-5195
 Fax No: 320-231-5168

[date]

To: Kevin L. Western
 Bridge Design Engineer, M.S. 610

SAMPLE

From: Paul Rasmussen
 Design/Hydraulics Engineer

Phone: 320-214-3708

Subject: S.P. 6420-20 (T.H. 19)

Please prepare a design for concrete box culvert. Tabulated below and attached is the information required to prepare plans. The letting date for this project is 11/17/00. Please submit completed plans to this office before 07/01/00.

State Project No. 6403-30		Func. 2 Work Authority: T80057	
Location Description ⁽¹⁾ : T.H. 19 over JD #33, 11.3 Mi. West of Redwood Falls			
Reference: 59+00.83		Station: 342+91.07	
Section: 1	Range: 38W	Township: 112N	Township Name: Vesta
Stream Crossing: Judicial Ditch #33		County: Redwood	
Structure Type: Concrete Box Culvert Replacement			
New Structure Number: 64X07		Existing Structure Number:	
Number of Barrels: 1	Opening Width: 10 ft.	Opening Height: 8 ft.	Spa btwn Precast Barrels: NA
Range of Cover ⁽²⁾ : MAX . 6.8 ft MIN xx ft.		Skew Angle: 0°	End Sections: Square
Inlet Elevation (new structure): 1037.34		Outlet Elevation (new structure): 1036.60	
Inlet Elevation (inplace structure): 1037.34		Outlet Elevation (inplace structure): 1036.60	
Extension Distances from end of inplace: NA			
Plans Requested: Precast			

(1) T.H. over _____, ___ Mi. ___ of Jct. T.H. _____ & T.H. _____, ___ of _____. (modify as necessary)

(2) Show range of cover (maximum and minimum cover).

Attachments: Sketch of Cross Section
 Sketch of Plan View

Figure 9-3.02A
SAMPLE CULVERT REQUEST FORM

9-3.02.02 Large Circular Pipe

Large circular pipe is usually either concrete or metal. Sizes are normally limited to the standard sizes shown in the MnDOT Standard Plates Manual and MnDOT Drainage Manual, although additional special designs can be provided by the Bridge Office.

1. Concrete Pipe

Most concrete pipe is precast and can be provided in standard sizes, up to 2700 mm (**108 in.**) (inside dimension), in increments of approximately 150 mm (**6 in.**). Manufacturers can make larger sizes, but they are considered special designs. The basis for the design of all reinforced concrete circular pipes shall be AASHTO M170. Five classes of concrete pipe are specified, based on strength requirements in terms of D-load.

The MnDOT Standard Plates 3000 series gives detailed information pertaining to pipe dimensions, strength test requirements, and laying length. The MnDOT Drainage Manual provides values to be used for maximum overflow heights based upon type of bedding and loading conditions. When reinforced concrete pipe with a gasket joint is required, refer to the MnDOT Standard Plates 3000 series. When pipe with rubber gasket seals are required, the tongue and groove design shall be indicated in the plans. Two types of joints are shown in the MnDOT Standard Plates 3000 series for this purpose.

2. Metal Pipe

Metal pipe is fabricated in a variety of diameters and corrugations. Metal pipe can also be made from field assembled structural plates. Structural details are available in the MnDOT Standard Plates 3000 series and in the MnDOT Drainage Manual. Maximum fill heights for corrugated steel and aluminum pipe can be found in Chapter 2 of the MnDOT Drainage Manual.

9-3.02.03 Pipe Arches

Pipe arches can be either metal or concrete. Details for reinforced concrete arch pipe are available in the MnDOT Standard Plates 3000 series. Metal pipe arches are fabricated in a variety of spans and corrugations. Metal pipe arches can also be made from field assembled structural plates. Details for fabricated corrugated steel pipe arches or structural plate pipe arches are available in the Standard Plates 3000 series, Chapter 2 of the MnDOT Drainage Manual, and the AISI Handbook of Steel Drainage and Highway Construction Products.

9-3.02.04 MnDOT Precast Concrete Arch

The MnDOT precast concrete arch is available in five sizes. This structure can be placed either on spread footings or on footings with piling. The footing design will depend on the type and allowable bearing capacity of the soil, the height of overflow, and proximity of bedrock. Scour protection for the footings will depend on velocities through the structure. Guidelines for the use of the MnDOT precast concrete arch are provided in Section 12 of the MnDOT LRFD Bridge Design Manual.

9-3.02.05 Three-Sided Bridge Structures

Three-sided precast concrete bridge structures offer an alternative for short span bridges. There are two types of three-sided bridge structures: arch top and flat top. These structures can be constructed rapidly, thus minimizing road closure time and they allow for a natural stream bottom. Potential applications include pedestrian underpasses and stream crossings where the waterway opening requirements are on the low end of a conventional bridge but are at the high end of box culvert capabilities. They are generally not as economical as cast-in-place (CIP) structures or multiple precast concrete box culverts. In general, precast three-sided structures may be used where:

1. Design span is less than or equal to 12.8 m (**42 ft**). Span is measured from inside face of sidewalls along the longitudinal axis of the unit.
2. Rise is less than or equal to 4 m (**13 ft**). Rise is measured from top of footing/pedestal wall to bottom of top slab.
3. Fill height is less than or equal to 3 m (**10 ft**) but is greater than or equal to 0.9 m (**3 ft**).
4. Skew is less than 30 degrees.
5. No foundation limitations exist, such as unusually weak soil.
6. No site access limitations exist for transporting and erecting the three-sided structures.

Since these are vendor supplied structures, their final structural design occurs after the award of the construction contract. The time required for final design and the subsequent review/approval period affect the total contract length. A list of pre-qualified three-sided bridge structure vendors is posted on the Bridge Office website.

9-3.02.06 Metal Long Span Structures

Long span structures are special shapes of any size which involve a relatively large radius of curvature in the crown and side portions. Structure types include the horizontal ellipse, low profile arc, and high profile arc. The span length of any of these shapes shall be limited to a maximum of 4.8 m (**16 ft**). Metal box culverts are also included in as metal long span structures. Contact the Bridge Office for more details.

9-3.03 End Treatments

Culvert end structures, prebuilt or constructed in place, are attached to the ends of a culvert barrel to reduce erosion, inhibit seepage, retain the fill, improve the aesthetics and hydraulic characteristics, and make the ends structurally stable. Pipe end sections, sometimes called flared end sections or aprons, are prefabricated metal or precast concrete sections, placed onto the ends of the culverts. See MnDOT Standard Plates 3000 series. Cast-in-place end sections are also shown in Standard Plates and are to be used on large structural plate culverts. Special design end sections are necessary for long span culverts and will be the responsibility of the Bridge Office. Dropwalls should be included to prevent undermining of pipe end sections and the area beneath the pipe itself.

Culvert ends located within the clear zone may need to be protected for traffic safety considerations. See Chapter 8 of this manual for guidance.

9-3.04 Energy Dissipaters

The use of energy dissipaters at the outlets of culverts may be necessary to prevent damage to the roadway embankment and/or culvert from erosion along with preventing erosion of the downstream channel due to high outlet velocities. Information regarding energy dissipaters is available in Chapter 6 of the MnDOT Drainage Manual. Energy dissipaters along the roadside require the same considerations as culvert ends.

THIS PAGE LEFT INTENTIONALLY BLANK

9-4.0 WALLS

When a vertical drop in ground elevation has to be accommodated, retaining walls are built to withstand lateral earth pressure. Conventional cantilever reinforced concrete walls are detailed in the 620 section of the Standard Plans Manual. Many other types of retaining wall systems may be used as they become available and are approved by the New Retaining Wall Committee.

Mechanically stabilized earth (MSE) retaining walls are another type of retaining wall which uses extensible (polymer) or nonextensible (steel) soil reinforcement in conjunction with various types of facings to retain the earth. In most situations, they have established significant cost advantages along with an excellent performance record. MSE retaining wall systems may be considered as an alternative to conventional reinforced concrete retaining walls.

MSE slopes or steepened slopes are another proven cost effective retaining option. Steepened slopes use similar technology to MSE walls, except the facia covering consists of vegetation instead of concrete units. Slopes up to 67 percent (1:1.5) and 60 ft in heights have been successfully used by the MNDOT Foundations Unit. Cost savings of up to 75 percent compared to conventional reinforced concrete walls may be achieved. Steepened slopes are minimally maintained and often blend in well with the rural type environment.

The design procedure for reinforced soil retention systems, or mechanically stabilized earth (MSE) walls, for use in MnDOT projects is taken from the FHWA publication Reinforced Soil Structures, Volume I, Design and Construction Guidelines, as published by the Federal Highway Administration. In addition, all retaining walls used on MnDOT projects must incorporate certain MnDOT requirements into their design based on AASHTO Standard Specifications for Highway Bridges. These requirements, such as type of backfill and depth of cover, are discussed in the following sections of this manual.

If an additional live load is placed on top of a fill retained by a wall, the design procedure is to replace the live load with an equivalent weight of earth. This additional weight is represented by an additional uniformly distributed load on the original surface and is known as the equivalent surcharge. In general, there are four cases of surcharge loads:

1. Point loads such as a truck wheel on backfill surface.
2. Line loads or narrow-strip loads of finite length.
3. Area loads of finite length.
4. Area loads of infinite length.

The MnDOT Standard Plans Manual 600 series provides details for a retaining wall with a 2 ft earthload (250 pounds per square foot), live load surcharge.

9-4.01 Design Responsibility

The Office of Bridges and Structures shall have responsibility for all special designs of conventional retaining walls not contained in Standard Retaining Wall designs found in the Standard Plans. For proprietary walls, the Office of Bridges and Structures shall have responsibility of reviewing the structural aspects of the design and construction plans provided to the District Designers by the wall company. The Foundations Unit shall be responsible for global stability and soil related concerns. The Office of Technical Support, Site Development Unit, should be contacted for aesthetic and/or rustication treatments for retaining walls. See Section 9-4.03.07 for acceptance procedures.

9-4.02 Design Types (Conventional)

There are a number of types of conventional retaining walls which can be designed for containing unstable material or providing a steeper slope at locations close to the roadway. The basic types used by the Department are cantilever walls, crib walls, precast walls and, on occasion, counterfort walls. The following sections are a brief description of the major types of conventional walls.

9-4.02.01 Cantilever Walls

A cantilever wall consists of a base slab from which a vertical wall or stem extends upward. Reinforcement is provided in both members to supply resistance to bending and shear. Standard designs call for

positioning the stem at about the forward third point on the base of the slab. The maximum height of cantilever walls is 30 ft without obtaining a special design from the Office of Bridges and Structures. Cantilever walls can be founded on spread footings or, in some cases, piling when the Foundations Unit indicates that the insitu soils will not support a spread footing. Piling can be timber, cast-in-place concrete, or steel-H. Standard designs for reinforced concrete retaining walls can be found in the Standard Plans Manual 600 series.

Geotechnical aspects of conventional retaining wall design and construction are detailed on Figure 9-4.02A. The Foundations Unit has the drilling equipment and laboratory testing equipment necessary for obtaining "undisturbed samples" and determining design parameters for the soils found at each site. The District Soils Engineers contact the Foundations Unit whenever a retaining wall is of sufficient size to justify undisturbed samples and laboratory testing. Specific recommendations suitable for the specific soils found at each site are provided to the District Designer and Soils Engineer by the Foundations Unit. Design parameters for walls less than 5 ft tall are generally determined by the District Soils Engineer without involving the Foundations Unit.

9-4.02.02 Counterfort and Buttress Walls

Cantilever type walls with heights in excess of those shown in the Standard Plans are more economically constructed when provided with brackets to assist strengthening the junction of the stem and base slab. When the brackets are behind the stem, they act in tension and are called "counterforts". When the brackets are in front of the stem, they act in compression and are called "buttresses". The Office of Bridges and Structures should be consulted for the design of these wall types.

9-4.02.03 Precast Panels Walls

In many situations, precast retaining wall panels can be used where the height-of-fill is 10 ft or less. The Standard Plans for precast retaining wall panels provide for up to a 2 ft live load surcharge. Panels can be either reinforced or prestressed concrete. See Standard Plan 5-297.625 for details of panel construction and placement.

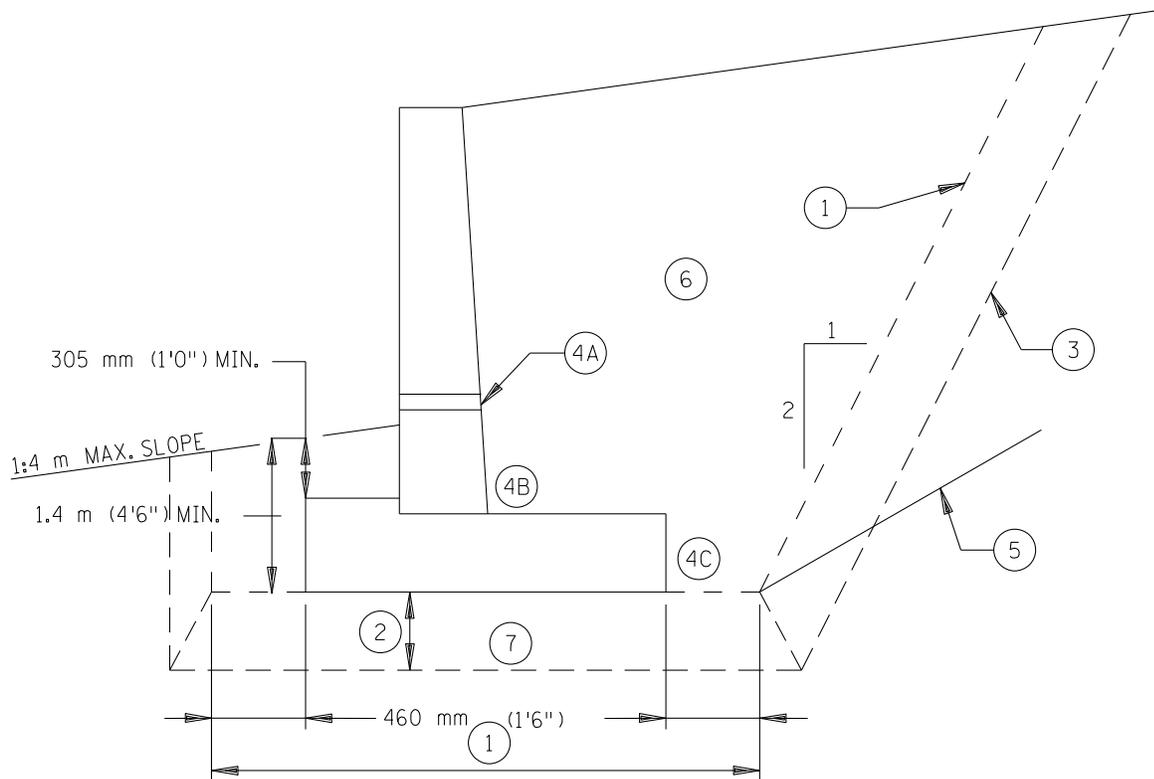
9-4.03 Design Types (Alternate)

9-4.03.01 General

Figure 9-4.03A shows a typical section of MnDOT's mechanically stabilized earth retaining wall. A considerable number of alternate, proprietary retaining wall systems are available. Table 9-4.03A provides general information on some of the different types of alternate walls.

The FHWA classifies walls as either "small" walls (5000 ft² or less), or "large" walls (over 5000 ft²). They are promoting the use of alternate designs for all new walls. Correspondence from the FHWA states: "We believe the most cost-effective contracting method is to propose a complete design by alternate bids. For large walls, the additional preliminary engineering costs are easily justified due to the resulting increased bid competition (and associated savings). For smaller walls, the specifications should allow Value Engineering proposals limited to acceptable site-specific alternates. Designers should, therefore, consider alternate walls for all projects."

When alternate walls are considered, it is necessary for the designer to provide site specifics to the alternate wall company. Site specifics would include items such as: profiles; wall heights; loading conditions; i.e., live loads, etc., results of foundation investigations; water conditions; utility locations; site restrictions; and desirable wall face treatments. A flowchart of the coordination required for inclusion of alternative walls into MnDOT projects is included for the designer's reference in Figure 9-4.03B. The designer must allow adequate time for checking of the plans for alternate walls. (See timeline on flowchart.) Alternatively, in-house generic designs may be done.



NOTES:

PARAPET OR RAILING WITH FENCING MAY BE REQUIRED AT TOP OF WALL. WHEN THE LONGITUDINAL SLOPE OF THE FOOTING BECOMES GREATER THAN 10%, THE FOOTING MUST BE STEPPED.

- ① PAY LIMITS FOR STRUCTURAL EXCAVATION WHEN NO SUBCUT IS REQUIRED.
- ② SUBCUT AS DETERMINED FROM FOUNDATION RECOMMENDATIONS REPORT.
- ③ PAY LIMITS FOR STRUCTURAL EXCAVATION WHEN A SUBCUT IS SPECIFIED.
- ④ ALTERNATE POSITIONS FOR DRAINAGE SYSTEM INCLUDE WEEP-HOLES, POSITION 4A, OR POSITIONS 4B OR 4C THAT REQUIRE PERFORATED 100 mm (4 IN.) T.P. PIPE, MnDOT 3245, WRAP WITH A TYPE I GEOTEXTILE, MnDOT 3733. RUN PERFORATED PIPE TO DAYLIGHT OR CONNECT TO A STORM SEWER. ALTERNATE 4C CONNECTED TO STORM SEWER IS THE PREFERRED DRAINAGE SYSTEM.
- ⑤ ACTUAL EXCAVATION SLOPE IS DETERMINED BY OSHA REGULATIONS AND IN-SITU SOILS.
- ⑥ BACKFILL TO MEET MnDOT 3149.2B2, MODIFIED TO 10 PERCENT OR LESS PASSING THE 75 um (#200 SIEVE). COMPACTION PER MnDOT 2105.3F1.
- ⑦ BACKFILL AND COMPACTION PER FOUNDATIONS RECOMMENDATIONS.

**Typical Section
MnDOT Standard Cantilever Walls
Figure 9-4.02A (Dual Unit)**

Table 9-4.03A

Wall Type	Surface Texture	General Comments	Typical Suppliers
Modular Concrete Gravity	Rough sawn random width planks; random vertical rustication; exposed aggregate; raised surface; fractured fin; smooth	Walls over 30 ft in height, walls supporting bridge abutments, and locations where substantial settlement is anticipated are experimental and must be coordinated with the New Retaining Wall Committee.	Doublewal Corporation, Hilfilker Retaining Walls
Precast Concrete Facing panels	Rough sawn random width planks; random vertical rustication; exposed aggregate; raised surface; fractured fin; carved panels; glenwood panels; smooth.	Walls which support bridge abutments, retain more than 6 ft of earth, or with surcharge loadings are experimental and must be coordinated with the New Retaining Wall Committee. Walls requiring earth reinforcement must be coordinated with the New Retaining Wall Committee.	VSL Corporation, Reinforced Earth Company
Segmental Concrete Masonry Units	Split face; broken face; smooth face; raked face; brick face; all textures are available in various colors.	Not allowed for walls which support bridge abutments, except on an experimental basis when specifically approved by the Office of Bridges and Structures. Height is limited by FHWA criteria as discussed in the publication, "Reinforced Soil Structures, Volume 1 – Design and Construction Guidelines," and MnDOT criteria as presented in this section of the Road Design Manual.	See Section 9-4.03.08 Diamond, Keystone, Loffelstein, Rockwood, Anchor, Risi Stone, Versa-lok, Allan Block
Crib Wall using Precast Concrete or Timber Units	Smooth; exposed aggregate; conducive to the use of various vegetative plantings.	Walls which support bridge abutments, retain more than 6 ft of earth, or with surcharge loadings are experimental and must be coordinated with the New Retaining Wall Committee. Shorter walls which do not exceed these conditions may be used per the proprietary standards as supplied by the manufacturer.	Timber Railroad ties, Geo-concrete Systems
Large Precast Proprietary Units	Smooth; exposed aggregate; typical formlines allow a variety of surface textures.	Walls over 30 ft in height, walls supporting bridge abutments, and locations where substantial settlement is anticipated are experimental and must be coordinated with the New Retaining Wall Committee.	Tech Wall, Cretex Wall
Steepened Slopes	Vegetated with crownvetch or native grasses.	No embedment for frost required. Blends into surrounding vegetation. Large amounts of settlement are ok. By far the least cost system, and no maintenance.	Mirafi, Contech, Presto Products, MnDOT Foundations Unit

9-4.03.02 Site Restrictions**1. Foundation Investigation**

The foundation recommendations shall be determined based on sound geotechnical information, since both internal and external stability requirements must be met. The requirements for the foundations of mechanically stabilized earth (MSE) and many other proprietary walls may be less stringent than those for conventional retaining walls since they generally spread their load over a larger area. Also, many of these walls are more flexible and tolerant of settlement than a rigid reinforced concrete wall.

The design of all retaining walls should be based on soil conditions found at the site. The District Soils Engineer generally will provide recommendations for walls less than 5 ft tall and, the Foundations Unit will provide recommendations for taller walls.

The Foundations Unit takes undisturbed samples and uses laboratory testing to determine the in-situ soil properties. These properties will be used to check deep-seated shear failure, global stability, local stability, including local bearing capacity, sliding, and overturning. Figure 9-4.03D illustrates these geotechnical design conditions. Recommendations related to local and global stability will be provided to the designer in the "Foundations Report."

In areas where suitable backfill is scarce or expensive, it may be possible to use native soil. The Foundations Laboratory has a large scale direct shear box for testing a variety of soils or recycled materials. Three months advance notice and 1 ft³ of material sample is required for testing.

The amount of differential settlement expected along the wall due to soil conditions is a major factor which determines the type of wall that can be used at each site. Each type of wall should be evaluated for its unique ability to deform without experiencing structural damage, such as excessive stress on bolts or spalling of concrete corners due to the deformation of joints or twisting of members. Even if differential settlement would not result in significant structural distress, aesthetic considerations due to a settlement problem may eliminate some walls. A maximum deviation from plan dimensions during construction of 1 in. in 10 ft is permitted.

An estimate of differential settlement should be supplied by the District's Soil Unit or an investigation made by the Foundations Unit. The settlement estimate should be made while the designer is considering various wall types because settlement tolerance may influence the Designer's decision as to what type of wall to use at the site. The key conditions governing differential settlement would include the presence of compressible soils, the uniformity of these soils along the site, the proposed height of additional fill to be placed on these soils, the ground water level at the site and proposed dewatering systems that will be installed in the area. If the above conditions are uniform or only change gradually along the length of the wall, then it is probable that differential settlement along the wall will only be slight. However, if portions of a wall will bear upon firm soils and other portions bear upon highly compressible soils (with very little transition distance), then a high amount of differential settlement could be expected and only walls that can tolerate such deformation should be considered. A better approach is to remove poor soils.

2. Construction Limits

Construction limits for all walls are dependent upon whether the wall is retaining a highway embankment or a cut slope. The construction limits for alternate retaining walls are somewhat different than those required for conventional concrete cantilever retaining walls. In urban construction, special consideration may be necessary when buildings and/or underground utilities are in close proximity to the construction limits of retaining walls. Mechanically stabilized earth (MSE) retaining walls utilize reinforcing strips or geosynthetic reinforcing that are embedded in the backfill to a distance of approximately 70 percent of the wall height. Therefore, the construction limits must be established to include the reinforcement embedment depth plus the normal setback for the construction excavation slope. See Figure 9-4.03A. A proprietary crib wall type such as the Doublewal product functions as a mass retaining wall. The required

excavation and corresponding construction limits are similar to those required for standard crib wall construction.

3. Utilities

Placement of utilities behind MSE retaining walls should not be considered in the backfill area that contains the wall reinforcement. Some proprietary wall manufacturers advise that utilities can be placed in the reinforcement zone and that reinforcing can be cut and spliced, but this is not allowed on MnDOT walls because of possible damage to such reinforcement during future utility maintenance operations. However, utilities which are aligned normal to the retaining wall can usually be spanned without any difficulty.

9-4.03.03 Design Parameters

1. General

The following requirements shall apply to all designs of alternate retaining walls. In many cases, these requirements are more restrictive than those promulgated by some proprietary wall companies. However, alternate walls designed for MnDOT projects must meet these requirements. Uniform adherence to these requirements will ensure that no company receives an unfair bid advantage and alternate walls will provide a minimum design life of 75 years. Figures 9-4.02A and 9-4.03A detail these requirements. Some independent testing is required to establish the allowable design parameters of various combinations of facings and reinforcements for MSE walls. Plans of alternate walls should be coordinated for checking according to the flowchart found on Figure 9-4.03B. Special conditions such as those detailed in Figure 9-4.03C require special consideration by the Office of Bridges and Structures and the Foundations Unit. Tiered walls cannot replace one large wall without special analysis and changes to yield the same external safety factors.

2. Allowable Design Reinforcement Strength

Allowable design reinforcement strength is to be determined according to the methods contained in the FHWA publication, "Reinforced Soil Structures, Volume I, Design and Construction Guidelines," and pull-out testing of the reinforcement and facing combination. The facing to reinforcement connection shall develop at least two times the full allowable design strength of the reinforcement at an ultimate limit condition and shall develop 1.5 times the full allowable design strength with no more than 0.75 in. deformation. The facing-to-connection strength shall be determined by pull-out testing performed by an independent laboratory in accordance with procedures in appendix A of the Design Manual for Segmented Retaining Walls, by Simac, et. al. The testing is to be performed at the manufacturer's expense.

3. Design Earth Pressures

Design earth pressures are related to the type of backfill, elasticity of the reinforcement, and both magnitude and location of the compaction energy applied during construction. Modeling of earth pressures for design of MSE walls is detailed in the FHWA Guidelines. Note that the passive earth pressure from the fill in front of the wall is not normally considered in designs for any MnDOT retaining wall. This is a conservative design philosophy which allows some excavation in front of the wall in the future while preserving an adequate safety factor, especially for soil shear. The minimum safety factors used in the design of MnDOT conventional and alternate retaining walls are shown in Figure 9-4.03D.

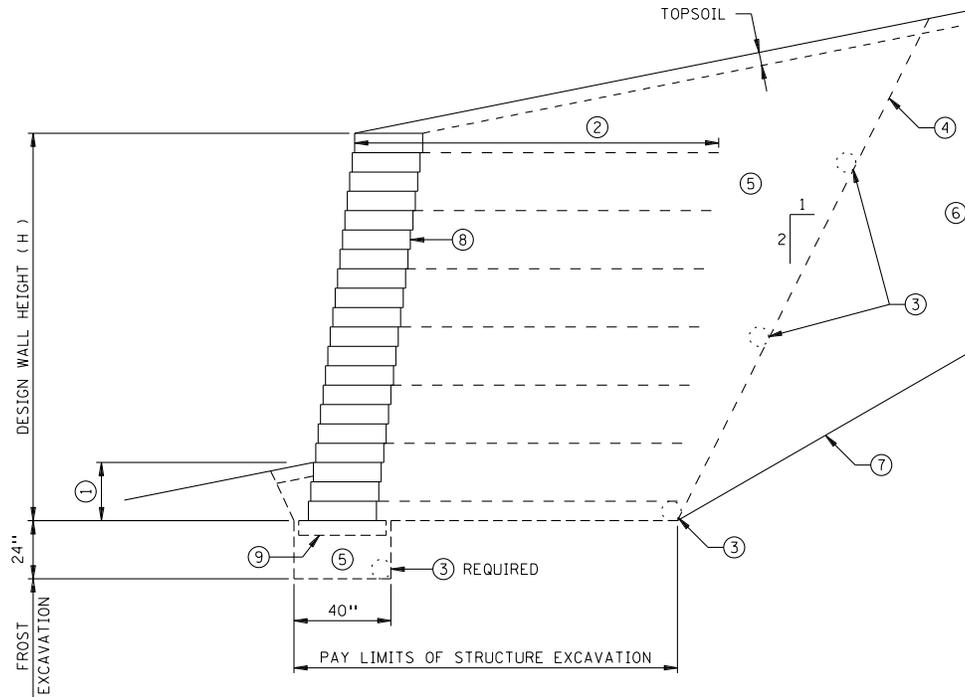
4. Drainage Considerations

In addition to the clean granular fill specified for all MnDOT retaining walls, provisions for removal of the water from the fill behind the wall is also required. Walls with a sealed face require a drainage system located near the bottom of the footing behind the wall. This drain system should be designed to carry any water which it collects out from behind the wall. Mechanically stabilized earth walls with open faces generally have their drain located at the base of the fill behind the reinforced zone to ensure that the fill does not become saturated. As shown on Figure 9-4.03A, additional drains may be required to intercept drainage from water-bearing soil seams to prevent the soil in the reinforced zone of MSE walls from becoming saturated. Water-bearing seams are usually apparent only after a cut slope has been excavated for

construction of the wall. The joints of walls with open faces need to be backed with a Type I geotextile designed to allow the passage of water while retaining the backfill. MnDOT's experience with MSE walls indicates that an additional layer of coarse backfill adjacent to the back of the facing is not necessary and, in some cases, hinders construction of the wall. Therefore, only the Type I geotextile is required behind and against the facing.

5. Backfill Design Parameters

Design parameters of the backfill are related to the soil type, drainage conditions, and degree of compaction. MnDOT requires that compaction be in accordance with Section 2105.3F1 of the MnDOT Specifications, which requires 95 or 100 percent maximum density depending upon the location behind the wall. Section 7.3C of the Federal publication, Reinforced Soil Structures - Design and Construction Guidelines should be followed for additional details on compaction control. Note that only light compaction equipment is to be used within 3 ft of the wall and that no sheepsfoot rollers are allowed anywhere behind the wall. The backfill for retaining walls must meet the requirements given in Figures 9-4.02A and 9-4.03A. An angle of internal friction of 35-degrees may be used to model the MnDOT select granular modified backfill. Contact the MnDOT Foundations Unit for large scale direct shear testing of proposed soils.

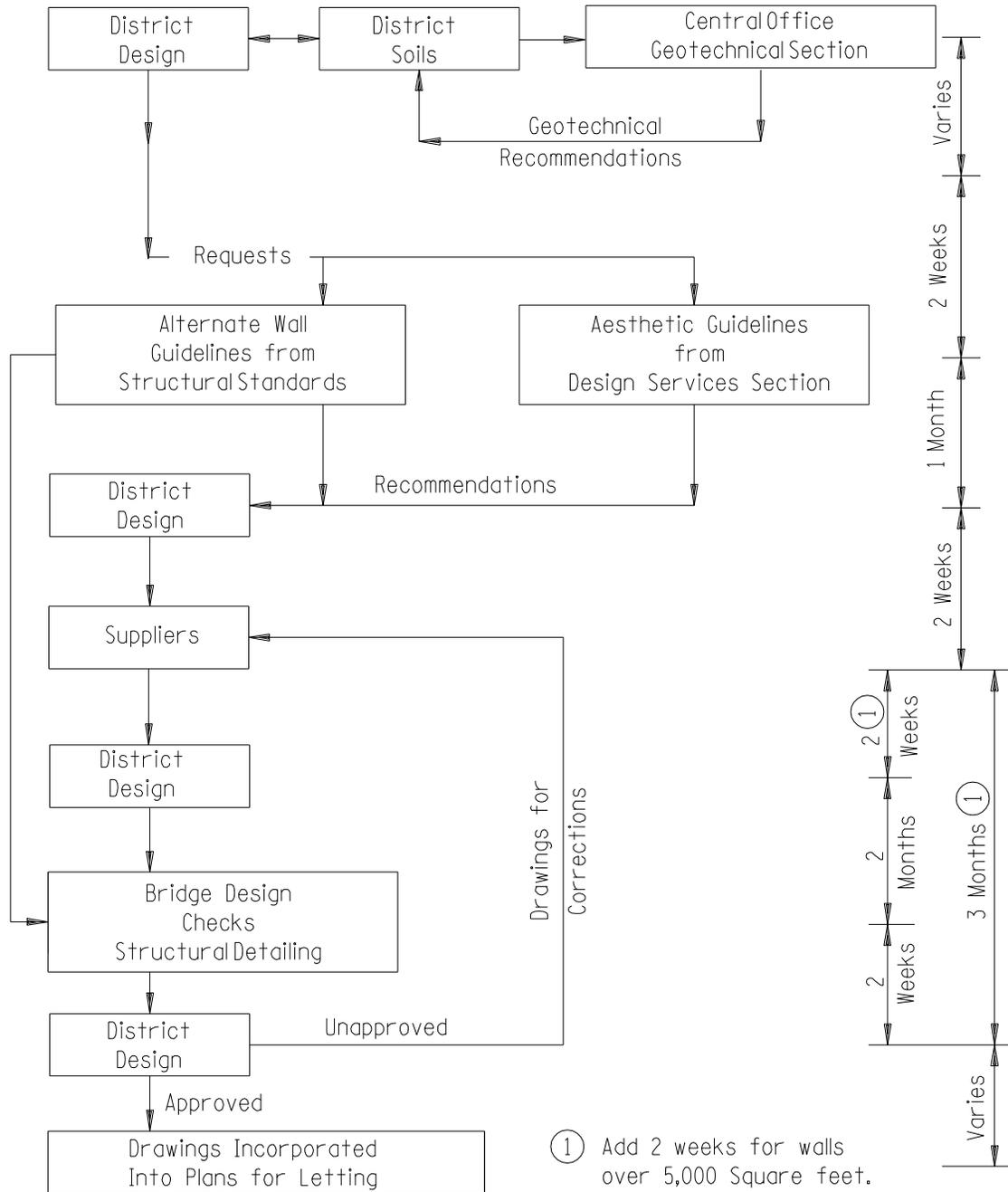


NOTES:

- ① MINIMUM DEPTH OF BLOCK EMBEDMENTS IS 2 FT.
- ② MINIMUM REINFORCEMENT LENGTH IS $0.7H$ OR AS REQUIRED BY ANALYSIS. ALL REINFORCEMENT TO BE THE SAME LENGTH.
- ③ 4 IN. T.P. DRAIN, MnDOT 3245, WITH A TYPE I GEOTEXTILE, MnDOT 3733. PROJECT ENGINEER SHOULD HAVE ADDITIONAL DRIANS PLACED TO INTERCEPT ANY WATER-BEARING SOIL STRATA DISCOVERED DURING CONSTRUCTION.
- ④ PAY LIMITS OF STRUCTURAL EXCAVATION.
- ⑤ BACKFILL TO MEET 3149.2B2 MODIFIED TO 10 PERCENT OR LESS PASSING THE #200 SIEVE. 100 PERCENT MUST PASS THE 2 IN. SIEVE. BOTTOM OF FROST PAD TO BE 4.5 FT BELOW GROUND SURFACE.
- ⑥ ANY SUITABLE BACKFILL.
- ⑦ ACTUAL EXCAVATION SLOPE IS DETERMINED BY OSHA REGULATIONS AND IN-SITU SOILS; EXCAVATION BEYOND "LIMITS OF STRUCTURE EXCAVATION" AT CONTRACTOR'S EXPENSE.
- ⑧ TYPE I GEOTEXTILE TO BE PLACED ON BACK SIDE OF FACING BLOCKS.
- ⑨ OPTIONAL UNREINFORCED, 6 IN. LEAN CONCRETE LEVELING PAD IN LIEU OF AGGREGATE LEVELING PAD.

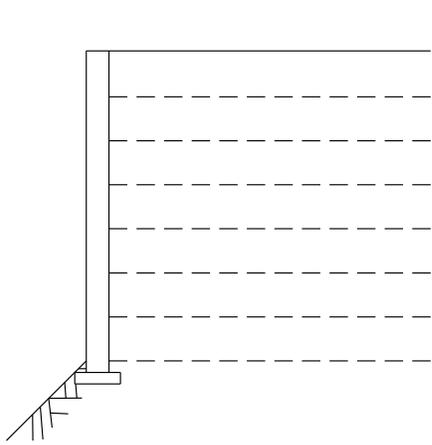
PARAPET OR RAILING WITH FENCE MAY BE REQUIRED AT THE TOP.

TYPICAL SECTION
MnDOT MECHANICALLY STABILIZED EARTH RETAINING WALL
Figure 9-4.03A

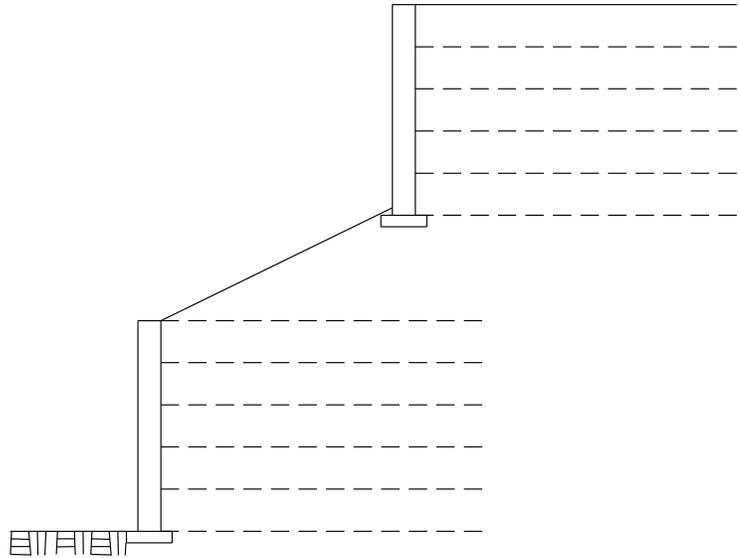


ALTERNATE WALL APPROVAL FLOW CHART

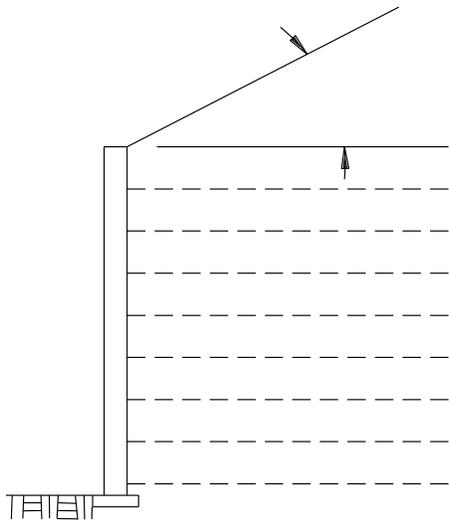
Figure 9-4.03B



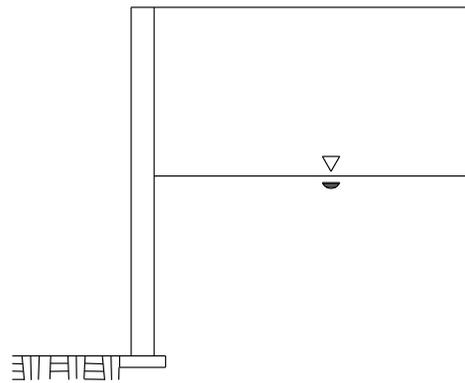
A. SLOPING FILL AT TOE



B. TIERED WALLS



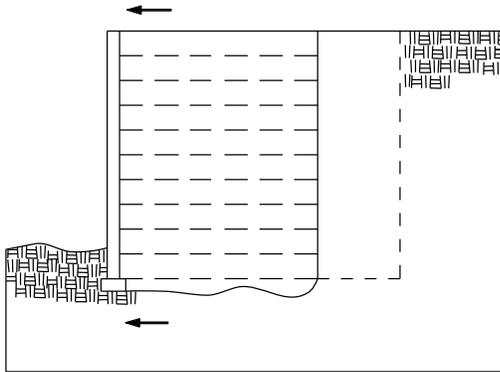
C. SLOPING ANGLE $> \phi_r / \phi_b$



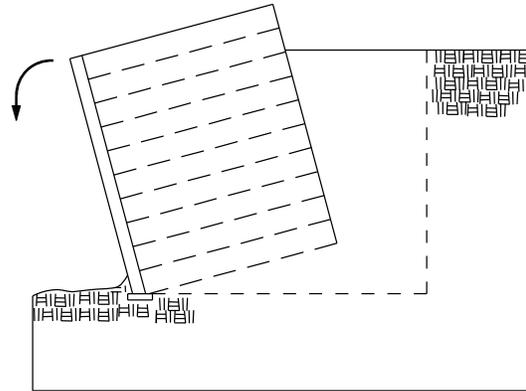
D. HIGH PHREATIC SURFACES

EXAMPLES OF WALLS WHICH REQUIRE ADDITIONAL ANALYSIS

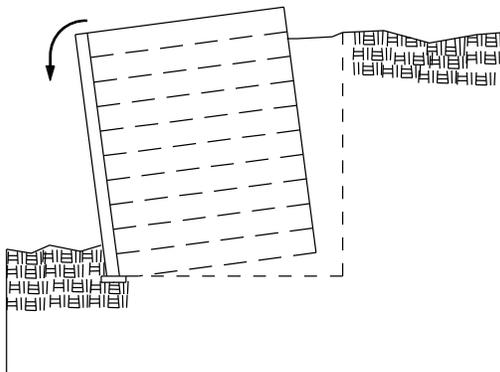
Figure 9-4.03C



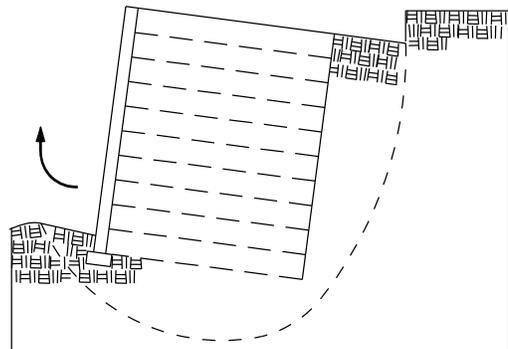
a. SLIDING FAILURE
F.S. ≥ 1.5



b. OVERTURNING FAILURE
F.S. ≥ 2.0



c. TILTING / BEARING FAILURE
F.S. ≥ 3.0



d. OVERALL FAILURE
F.S. ≥ 1.5

MSE WALL EXTERNAL SAFETY FACTORS
Figure 9-4.03D

9-4.03.04 Material Properties

For alternate retaining walls, the following specifications will govern the materials used in the construction of the walls. These specifications are established as MnDOT requirements and may be more restrictive than those required by the wall companies. However, as stated above, applying these requirements for all alternate walls is in the best interest of MnDOT.

1. **Concrete and Minimum Cover**
The minimum concrete cover over reinforcing steel shall be 2 in. on the exposed face and 1.5 in. on other faces, except for faces cast against earth where the minimum cover is 3 in. The concrete mix used for concrete footing shall be 1A43 or equivalent. The mix for all exposed concrete shall be 3Y43 or equivalent.
2. **Wall Backfill**
The backfill for conventional retaining walls shall meet the requirements of Spec. 3149.2B2, granular backfill modified so that not more than 10 percent, by weight, of the portion passing the 1 in. sieve will pass the number #200 sieve. Salvaged bituminous material or crushed concrete shall not be allowed in the backfill. An additional requirement is placed upon the backfill for MSE walls; i.e., MnDOT Specification 3149.2B2 modified so that 100 percent passes the 2 in. sieve and not more than 10 percent, by weight, of the portion passing the 1 in. sieve shall pass the #200 sieve. Compaction shall be per Specification 2105.3F1. All MSE walls shall have at least 3.5 ft of cover above the bottom of the subcut for frost protection. Unreinforced segmental block walls less than 6 in. in height without live load surcharge used for landscape applications shall have at least 4.5 ft of cover above the base course. Other types of retaining walls, such as reinforced concrete retaining walls, shall have at least 4 ft of cover. Specific design details for MSE walls are shown in Figure 9-4.03A.
3. **Steel Strap or Bar Stock (Reinforcing Strips)**
Steel strap or bar stock shall meet the requirements of Grade 300, ASTM A36 or Grade 50, ASTM A588 or Grade 65, ASTM A572.
4. **Wire Fabric**
Wire fabric shall meet the requirements of ASTM A82 and ASTM 185.
5. **Deformed Bars**
Deformed bars shall meet the requirements of ASTM A615 and ASTM A185, Grade 420.
6. **Threaded Fasteners**
All threaded fasteners shall meet the requirements of ASTM A276 Type 304 stainless steel or as approved by the Engineer.
7. **Coil Embed Steel Wire**
Coil embed cold drawn steel wire shall meet the requirements of ANSI C1035. The wire shall be galvanized per ASTM B633.
8. **Coil Bolts**
Coil bolts shall be 80-55-06 ductile iron per ASTM A536. They shall be galvanized per ASTM B633.
9. **Galvanizing**
All metal materials shall be galvanized per ASTM A123, unless noted otherwise in the above requirement.
10. **Joint Materials**
Type 1 geotextiles, MnDOT 3733, shall be used to cover all joints on the rear face of panels and applied using pressure sensitive tape. As an alternate, 2 in. x 2 in. foam may be placed in the panel joints.

11. Polymer
Polymer reinforcements for reinforcing the soil behind MSE walls shall be reviewed and approved by the New Retaining Wall Committee (NRC) on a case by case basis. Allowable design strength shall be established according to the FHWA publication, Reinforced Soil Structures, Volume I. - Design and Construction Guidelines, and upon pull-out testing to check the facing to reinforcement connection strength, which shall have a safety factor of 1.5. Only reinforcements approved by the NRC may be used in MnDOT retaining walls. Discontinuous geosynthetic sheets (reinforcement coverage ratio $R_C < 1.0$) are not allowed without special approval from the Foundations Unit, and then only for justifiable reasons and with detailed field inspection.
12. Concrete Masonry Retaining Wall Units
Units shall meet ASTM C 90 Load-Bearing Concrete Masonry Units, Type I modified such that the minimum required compressive strength shall be 3000 psi for the average of 3 units and 2500 psi for an individual unit. The maximum absorption shall be 6 percent by weight.

9-4.03.05 Retaining Wall Aesthetics

1. General

Retaining walls are one of the key road design elements which provide corridor continuity by linking together land forms and other highway structures. Therefore, the designer must be aware of the total impact of retaining walls within the roadway corridor and determine how to treat them aesthetically so that they blend into their surrounding environment. In addition, the designer should be conscious of the traveler's view of the walls and the view by those adjacent to the corridor.

To achieve a visually pleasing transportation corridor, each highway design element should be coordinated in a complimentary manner. Retaining walls should be designed to reflect good proportion and balance, paying particular attention to the surrounding environment. Material selection, color, texture and detailing of wall caps, parapets and railings can enhance retaining walls. Architectural texturing of surfaces available to the designer range from custom and standard form liners to individual block units and concrete panels of various shapes and colors, including entirely vegetated faces. Once designed, the wall system should be uniformly repeated throughout the highway corridor to establish a strong sense of continuity and balance.

The Site Development Unit of the Office of Technical Support, should be contacted to provide design recommendations for aesthetic treatments of retaining wall structures.

2. Design

The design of retaining walls should reflect the public inputs and concerns which are generated from public meetings during the preliminary design and environmental documentation process.

Retaining wall design or the selection of a retaining wall system should consider the following design criteria:

- a. Corridor continuity

A specific retaining wall system which will physically, visually and aesthetically address the requirements of a project or design should be identified for each corridor and then be repeated uniformly throughout the corridor.

- b. Engineering

The retaining wall design, or the selection of a proprietary wall system, should be aligned and structured so that engineering principles are not compromised. Material selection and surface treatments should be considered to enhance the aesthetic quality of the structure. Cost, while important in the overall context of a project, should not prohibit or minimize aesthetic treatments.

- c. Proportion

To achieve a strong sense of three dimensional beauty, good proportions between various parts of a wall are necessary. Height, width and length dimensions should exhibit a balanced relationship. Textured surfaces and resulting light and dark patterns should reflect visual

harmony. Surface treatments should convey an impression of balance throughout the corridor.

d. Color

A very important aesthetic consideration in the design of retaining walls is color, which lends a sense of cohesiveness throughout the corridor and stimulates driver and viewer interest. Color can also be used to relieve monotony, provide contrast and soften harsh looking structures. Color selection should be based upon color coordination of various design elements within the highway corridor. It should also allow the wall structures to subtly blend into the surrounding environment.

The critical factor each designer should be aware of is that from the viewpoint of the traveling public, retaining walls are often the dominant design feature of a highway corridor. This is particularly true in high density, urban areas. Retaining wall placement and their aesthetic treatment is a significant design relationship which the designer must consider if the highway is to be visually pleasing.

9-4.03.06 Traffic Safety Aspects

Although retaining walls are constructed with a primary function to retain earth slopes, thereby reducing right of way requirements, traffic safety must also be considered. A number of factors should be considered when designing retaining walls to provide for the safety of the motorist. Factors to be considered are:

- Location of the wall along the roadway
- Wall terminals
 - a. Along mainline and ramps
 - b. In gore areas
- Wall facings
- Earth slopes in front of walls
- Guardrail
- Plantings

1. Location of Wall Along the Roadway

Since retaining walls are located to retain earth slopes in areas of restricted right-of-way, they generally are located within the clear zone of the roadway. Clear zone is defined as the roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. Clear zones are discussed in Section 4-6.04. Because the walls are generally located within the clear zone, care should be taken not to place walls in potentially hazardous conditions.

When steps in the horizontal alignment are used in the wall design, the steps should face away from traffic. This will avoid protruding angles or pockets facing approaching traffic. If these obstructions cannot be avoided within the clear zone or where they can be reached by an out-of-control vehicle, guardrail or other impact attenuators are necessary.

The face of the wall should be capable of deflecting vehicles. If this is not possible, traffic barriers should be provided. See Item 3 below for a further discussion of wall facings.

2. Wall Terminals

The end of a retaining wall can be a hazard to approaching traffic. To reduce the hazard of the end of a wall, the designer should consider the following:

- a. Along the mainline
When the end of a wall is exposed to approaching traffic within the clear zone area, it should be considered as another fixed object and protection provided. The protection may be either in the form of guardrail or a crash cushion.
- b. Gore Area
When the end of a wall is located in a gore area, a crash cushion will generally be required. Since the recovery area is very limited, guardrail is generally not appropriate.

Refer to Chapter 10 for guidance.

3. Wall Facing

A smooth surface along a low retaining wall may not be considered a hazard. However, a tall wall or rough or irregular surface can be a hazard. When it is necessary to provide this type of surface, protection should be provided in the form of a concrete safety shape (incorporated into the bottom of the wall) or guardrail should be installed. Wide and deep vertical rustication schemes should be avoided in the lower 3 ft of the wall. Horizontal stepping that creates corners and protrusions of 3 in. or more are considered hazards.

4. Earth Slopes and Curbs in Front of Walls

Slopes in front of retaining walls should be as flat as possible. A 1:4 slope will provide a slope that can be readily maintained and provide a traversable slope to a wayward motorist. A 1:3 slope should be considered as the steepest slope that should be used. See Section 4-6.0 for a further discussion of roadside slopes.

The use of curbs is discussed in Section 4-4.04. Curbs in front of retaining walls should be avoided whenever possible. As discussed in Section 4-4.04, vehicles striking a curb may vault and become unstable prior to impacting the wall.

5. Guardrail

When a guardrail is to be installed in front of a retaining wall, the designer should consider the design deflection of the guardrail and provide enough distance between the guardrail and wall to absorb the design deflection. Also, if curbs are located in front of the wall, the guardrail should be placed flush with the face of curb.

When transitioning from a guardrail to the end of a retaining wall, the same type of problem as transitioning to a bridge rail occurs. The same transition treatment used at a bridge should be used at the retaining wall. See Chapter Ten for further details on guardrail installations.

6. Plantings

Although plantings in connection with a retaining wall may be desirable to improve the aesthetic effect of the wall, safety must also be considered. Large plantings, i.e., trees which may become a hazard to traffic, should either be avoided or located where an errant vehicle cannot reach them. Sight distance restrictions also apply to plantings. Plantings should not be located in critical areas such as sight distance corners and gores. Planting receptacles should also be located away from traffic (outside of the clear zone). Plantings requiring considerable maintenance should be avoided since the maintenance crew and their vehicles may become a hazard to traffic.

9-4.03.07 Acceptance Procedure

1. Wall Selection Procedure for Specific Projects

- a. The flowchart in Figure 9-4.03B delineates the procedure for inclusion of alternate retaining walls into MnDOT projects. The intent of this procedure is to use the principles of Total Quality Management by empowering the District Designers to control the selection of retaining walls for their projects. The Office of Bridges and Structures, the Site Development Unit of the Office of Technical Support, and the Foundations Unit of the Office of Materials and Road Research will serve as resources to support the District Designers. When the District Designers determine that an alternate retaining wall is desirable on a project, the District should assemble specific project information into a packet to be supplied to the retaining wall companies and to the personnel within MnDOT who will be providing review services to the District. This packet should include site considerations such as: (1) proposed wall height, (2) soil conditions, (3) ground water levels, (4) wall alignment, (5) plan views of location of walls on project, (6) slopes, (7) anticipated loading conditions, (8) utilities behind and under walls, (9) aesthetic requirements, and (10) any other criteria pertinent to the design of the walls. The District should clearly indicate their design criteria.
- b. The retaining wall companies may then submit designs for alternate walls to the Districts. The retaining wall companies must prepare their plans in accordance with the design criteria established in this section of the manual. The Districts should forward designs which meet

their design criteria to the Office of Bridges and Structures for structural checking. The packet of information supplied to the manufacturers should accompany the design submittals to the Office of Bridges and Structures. The Office of Bridges and Structures needs complete plans and shop drawings to check the designs. The designs will be checked in accordance with the FHWA Guidelines for Reinforced Soil Structures and other appropriate design standards such as the AASHTO Manual and MnDOT design criteria shown on Figures 9-4.02A and 9-4.03A.

- c. After the plans and shop drawings have been checked for structural adequacy, the plans for alternate retaining structures can be incorporated into the project plans by the District prior to the letting.
- d. Note that inclusion of plans for alternate walls into project plans requires at least 6 months prior to the letting. The District and manufacturers of alternate retaining wall systems are encouraged to make the required plan submittals and necessary changes in a timely manner.
- e. The NRC in cooperation with the District personnel will follow-up after completion of the project with performance reviews to monitor the long-term performance of the alternate retaining wall designs.
- f. In the case where MnDOT is designing an alternate style of wall for a special situation, the District should submit the packet of project information directly to the Office of Bridges and Structures.

2. New Types of Walls

In order to provide a uniform, structured approach to the Department's evaluation of new retaining wall products, a New Retaining Wall Committee (NRC) has been established to recommend actions to be taken regarding the use of proprietary retaining walls. The NRC is charged with the responsibility of providing a general and fair evaluation of any new proprietary retaining wall product that is brought to the attention of the Department. The composition of the NRC and its general operating procedures are described as follows:

- a. Composition of Committee
 - 1) Structural Standards Engineer, Chairman
 - 2) Foundations Engineer
 - 3) Bridge Design Engineer
 - 4) Design Standards Engineer
 - 5) Site Development Landscape Architect
 - 6) District Design Engineer
 - 7) Bridge Design Unit Engineer
- b. Technical Assistance for NRC

The technical expertise that exists in any of the offices in the Department is available to the NRC on an as-needed basis and may be called upon by the Chairman of the NRC to participate in a review and/or investigation.
- c. General Operating Procedures
 - 1) Information received from any source (whether internal or external) concerning a new retaining wall product shall be referred to the Chairman of the NRC.
 - 2) The Committee shall meet on a periodic basis as appropriate to hear presentations by vendors regarding new retaining wall products and systems.
 - 3) The Chairman shall decide on the need for a task force review, office review or other type of review, and will take the necessary steps to initiate the appropriate review of the retaining wall products.
 - 4) After hearing presentations by vendors and receiving recommendations from appropriate Department experts, the Committee shall determine the appropriate use and limitations, if any, for use of the retaining wall system on MnDOT projects.
 - 5) The NRC will develop design assumptions and guidelines for use of the acceptable proprietary walls.
 - 6) The NRC shall make its findings known by reporting to the Final Design Advisory Committee, Bridge Research & Development Committee and publish findings in the Design Scene and, if appropriate, in this manual.

9-4.03.08 Approved MSE Retaining Wall Systems

Presently, a considerable amount of testing has been performed for the manufacturers of segmental retaining wall blocks and earth reinforcements. These tests have been submitted to the NRC for review. Most tests meet the criteria set by the NRC; these retaining wall systems are included in the list of approved systems maintained by the Assistant Foundation Engineer. Other MSE retaining wall systems will be approved on a case-by-case basis. The same tests will be required for approval on a case-by-case basis. All tests are to be performed at the manufacturer's expense by an independent laboratory or University approved by the NRC.

Designers are encouraged to select alternate retaining wall systems from the approved list because the checking and approval process will be much simpler for all parties. Designers are also encouraged to include at least three alternate MSE systems in their plans when they choose to allow the use of alternate walls on MnDOT projects.

THIS PAGE LEFT INTENTIONALLY BLANK

9-5.0 MISCELLANEOUS STRUCTURES

Certain other structures which are designed by the Office of Bridges and Structures include foundations, tunnels, utility bridges, vaults and other underpass structures. Discussion here is limited to those subjects which are used with regularity. Other subjects which are designed by the Office of Bridges and Structures are discussed in Chapter Eleven, "Special Designs."

9-5.01 Foundations for Signs, Signals, and Illumination Poles

The steel structures for major signs, luminaires, and traffic signals are usually standard items, designed by the manufacturers and approved for use by the FHWA and the appropriate Department offices. Most foundations for these appurtenances and standard designs are approved for the usual conditions. These are shown in the Standard Plates Manual in the 8000 series.

Foundation structures for high-mast lighting, large signs or other heavy steel supports are usually designed by the Office of Bridges and Structures. The designer should be aware of the dimensions to avoid conflicts with new or existing underground installations and the potential hazards for vehicles if the foundation is within the clear zone.

9-5.02 Utility Bridges and Vaults

A bridge or underground conduit is occasionally required for a utility crossing the roadway. These structures should conform in appearance, location, excavation and markings to the bridge and culvert practice of MnDOT. If there is a possibility that several utility crossings will be required, the cost of a bridge or tunnel may be less than for several untrenched or separately encased pipelines.

If a tunnel or bridge is constructed to provide a crossing for more than one type of utility, provisions shall be made to isolate mutually hazardous utilities, such as fuel and electric lines, by compartmentalizing or by auxiliary encasement of incompatible carriers.

To the extent possible, utility line crossings of the highway should cross on a line normal to the highway alignment. Bridges should be designed to conform with the clear zone policies applicable for the system, type of highway, and specific conditions for the particular highway section involved. Minimal vertical clearance requirements shall be the same as for other overhead crossings based upon the type of highway involved.

Utility vaults may be required within the right of way for underground connections, valving and monitoring equipment. Vaults are underground enclosures which contain utility equipment which must have ready access. When these facilities are required, the utility company will design the vaults in accordance with their needs and meeting the design criteria of the Department. When these vaults are located underneath or in close proximity to the roadway, they must be designed to withstand the design loading for the roadway.

General requirements and policies governing utility coordination and design are found in Section 11-7.0.

9-5.03 Tunnels**9-5.03.01 General**

The development of a highway may require the design of segments in tunnels to carry the highway under or through a natural obstacle or to minimize the impact on the immediate area. Areas which warrant the consideration of tunnels include:

1. Long, narrow ridges where a cut section may be costly because of the difference in elevation.
2. Limited rights of way where most of the surface area is required for other purposes.
3. Large intersection areas or a series of adjoining intersections on an irregular or diagonal street pattern.
4. Railroad yards, airport runways, ship channels or similar facilities.
5. Parks or major buildings, either existing or planned.

Two types of tunnels can be constructed. Tunnels constructed by mining methods do not remove the overlying rock or soil and can be classified according to the character of material to be excavated (e.g., hard rock or soft ground). The second type of tunnel is constructed using either the cut-and-cover method or the trenching

method. The most common type of tunnel construction in urban areas is the cut-and-cover method because it is generally the most economical for shallow depths.

9-5.03.02 Design Considerations

Tunnels are very expensive structures to build and maintain. Because of their cost, they should be designed to be as short as possible. Keeping the tunnel on a direct alignment will minimize its length and improve operating efficiency.

Grades in tunnels should be determined on the basis of driver comfort. If the grade is too steep, the driver will feel uneasy and drive at a slower speed. However, in most cases grade will also determine the total length of the tunnel. Because cost varies directly with length, an economic balance must be established.

The designer should try to eliminate conditions within the tunnel which distract the driver. For example, guide signs within a tunnel should be avoided. Exit ramps should be located a sufficient distance downstream from the tunnel exit portal to permit any required signs to be placed between the exit portal and the exit ramp. There should be no merging, divergence or weaving in a tunnel. Forks and exit and entrance ramps should be avoided within any tunnel.

Tunnels which carry divided highways should be provided with median crossings. These crossings should be spaced at appropriate intervals, depending on the length of the tunnel, to allow emergency vehicles access from the opposite lane. Other emergency services should also be provided in the tunnel as well as at the entrances. Such facilities should include fire hydrants, fire alarms, emergency lighting, and 2-way communication systems.

In terms of clearances, tunnels are similar to grade separation structures. The same standards for alignment and profile should be followed wherever practical. However, tunnel construction is so infrequent and costly that the width of pavement and horizontal clearance should be considered on an individual basis. Normally, the minimum horizontal clearance on high-volume multi-lane roadways in urban areas shall be the full approach width plus a 2.5 ft safety walk. Consideration should be given to providing additional lateral space for emergency or disabled vehicles. The minimum vertical clearance shall be 16 ft-4 in. at any point over the traveled way.

9-5.04 Underpass Structures

There are two types of underpass structures besides tunnels which may be required to provide crossing of the roadway. Livestock underpasses are provided at locations where the roadway divides contiguous agricultural areas. Pedestrian underpasses are constructed in urban or rural areas where pedestrian/roadway grade separations are required and pedestrian overpasses are not possible.

9-5.04.01 Livestock Underpasses

In rural areas where the roadway has divided farms or pasture areas, cattle and horse passes will be designed to provide farm access in accordance with the right of way agreement. The standard design for a cattle pass should consist of either a reinforced precast concrete culvert with an opening 4 ft wide by 5 ft or 6 ft high or a deformed metal culvert 4.5 ft wide by 6 ft high. The standard design for a horse pass should be a deformed metal culvert approximately 5 ft wide by 6.5 ft high. However, the designs should be in accordance with the 3000 series of the Standard Plates.

If unusual conditions clearly indicate the need for a larger cattle or horse pass, full details concerning the proposed clearance requirements, right of way considerations, drainage conditions, comparative costs and any other pertinent data shall be submitted to the Office of Bridges and Structures for their design. No design effort should be expended for any size cattle pass greater than the standard without approval of the Office of Bridges and Structures.

9-5.04.02 Pedestrian Underpasses

A pedestrian underpass may provide thoroughfare for walkers, bikers, skaters, and/or snowmobilers. The standard design should consist of a 14 ft wide by 12 ft high precast concrete box culvert.