

Chapter 23

MISCELLANEOUS STRUCTURAL ELEMENTS

NDOT STRUCTURES MANUAL

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Chapter 23

MISCELLANEOUS STRUCTURAL ELEMENTS

In general, the Structures Division is responsible for all structural design for NDOT projects. Although the vast majority of the Division's work is for highway bridges, the transportation system includes a wide variety of other structural elements. Chapter 23 presents NDOT policies, practices and criteria for the structural design of these miscellaneous structural elements.

23.1 EARTH RETAINING SYSTEMS

23.1.1 General

NDOT uses earth retaining systems to provide lateral support for a variety of applications:

- cuts in slopes for roadway alignments;
- roadway widening where right-of-way is limited;
- grade separations;
- proximate live-load surcharge from buildings, highways, etc., that must remain in place;
- stabilization of slopes where instabilities have occurred;
- protection of environmentally sensitive areas; and
- excavation support.

Earth retaining systems are classified according to their construction method and the mechanism used to develop lateral support:

1. Construction Method. This may be either a “fill-wall” construction or “cut-wall” construction. Fill-wall construction is where the wall is constructed from the base of the wall to the top (i.e., “bottom-up” construction). Cut-wall construction is where the wall is constructed from the top of the wall to the base (i.e., “top-down” construction). Note that the “cut” and “fill” designations refer to how the wall is constructed, not the nature of the earthwork (i.e., cut or fill) associated with the project.
2. Lateral Load Support. The basic mechanism of lateral load support may be either “externally stabilized” or “internally stabilized.” Externally stabilized wall systems use an external structural wall, against which stabilizing forces are mobilized. Internally stabilized wall systems employ reinforcement that extends within and beyond the potential failure mass.

Note that, because of their special nature and frequent use by NDOT, [Section 23.2](#) discusses MSE walls separately from other earth retaining systems, which are discussed in Section 23.1.

23.1.2 Responsibilities

The type selection for an earth retaining system is a collaborative effort between the Structures Division and Geotechnical Section. The following identifies the basic responsibilities of the respective NDOT Units for the design of earth retaining systems, except MSE walls. See [Section 23.2](#) for a discussion on the division of responsibilities for MSE walls.

23.1.2.1 Structures Division

The following summarizes the role of the Structures Division in the design of earth retaining systems:

1. Design. For CIP concrete cantilever walls, non-gravity cantilever (sheetpile) walls and anchored walls, the Structures Division will perform the internal stability design for the wall (e.g., wall dimensions and reinforcing configurations). For these walls, the Structures Division also performs the overturning, sliding and bearing checks using the geotechnical parameters provided by the Geotechnical Section. For soil nail and tie-back anchor walls, the Structures Division will design the reinforcing for the structural facing of the wall.
2. Detailing. The Structures Division provides all the construction details for the earth retaining system, including:
 - Plan views are provided to indicate the layout of the walls. The station and offset to the wall layout line (usually the front face) is provided at all locations needed for locating the wall.
 - Elevation views are provided to show the length and design height of wall segments, and top and bottom elevations of the wall. Top-of-wall elevations are provided at intervals necessary to build the walls. Provide elevations every 25 ft when the top of wall is not on a straight line. Footings are almost always level with the bottom and top of footing elevation shown for each step.
 - Typical sections are provided to show all additional information on the wall. This can include the dimensions of the footing and wall, approximate original ground line, finished ground line at the bottom and top of wall, bench at bottom of wall, slopes at the bottom and top of wall, drainage requirements and reinforcing steel.
 - Special details are used to show specialty items specific to a wall type and location, treatments at the top and bottom of wall and drainage details.

23.1.2.2 Geotechnical Section

For permanent earth retaining systems, the Geotechnical Section:

- performs the geotechnical investigations;
- provides recommendations for wall type;
- recommends the allowable soil bearing and lateral earth design coefficients for gravity, surcharge and seismic loading;
- performs the global and external stability checks;
- determines if there is a need for special drainage features due to the selected wall type and/or site conditions; and
- determines the size and spacing of soil nails and tie-back anchors.

The Geotechnical Section will also provide the following information to the Structures Division:

- earth pressure coefficients (k_a , k_o , k_p) and an estimate of the amount of deformation to develop the active and passive earth pressures and any recommendations on factors of safety;
- unit weight of the backfill material;
- allowable interface friction between cast-in-place concrete footing and soil;
- allowable bearing capacity;
- expected settlement;
- requirements for drainage control;
- testing requirements for anchored and soil nail walls; and
- special construction requirements for all walls.

23.1.2.3 Roadway Design Division

The Roadway Design Division identifies the need for an earth retaining system and provides the Geotechnical Section and the Structures Division with the alignment file and/or cross sections.

23.1.2.4 Other NDOT Units

Depending on the site, other NDOT Units may participate in the design and selection process for earth retaining systems. These include:

- Hydraulics Section, if the wall is located near flowing water or if it could be inundated during floods and the scour potential at the base of the wall.
- Environmental Services Division, if the wall will be located in or adjacent to wetlands or other environmentally sensitive areas or if the wall requires excavations in contaminated soils.

23.1.3 References

For further guidance on earth retaining systems, see:

- *NDOT Geotechnical Policy and Procedures Manual*
- *Foundations and Earth Structures*, Department of the Navy, Naval Facilities Engineering, NAVFAC DM 7.2, May 1982
- *Geotechnical Engineering Circular No. 2 – Earth Retaining Systems*, FHWA-SA-96-038
- *Geotechnical Engineering Circular No. 4 – Ground Anchors and Anchored Systems*, FHWA-IF-99-015

- *Geotechnical Engineering Circular No. 7 – Soil Nail Walls*, FHWA-IF-03-017
- *Training Course in Earth Retaining Structures*, FHWA-NHI-132036
- *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines*, FHWA-SA-96-071

23.1.4 Types of Earth Retaining Systems

23.1.4.1 Fill Walls

23.1.4.1.1 MSE Walls

MSE walls are constructed using reinforced layers of earth fill with non-extensible (metallic) reinforcing. Extensible (polymeric) reinforcing may be used when approved by the Chief Structures Engineer. The facing for the walls can be concrete panels, geotextile fabrics or exposed welded wire. The heights of these walls can extend to over 100 ft. Advantages of MSE walls include:

- They tolerate larger settlements than a CIP concrete cantilever wall.
- They are relatively fast to build.
- They are relatively low in cost.

See [Section 23.2](#) for detailed information on MSE walls.

23.1.4.1.2 CIP Concrete Cantilever Walls

CIP concrete cantilever walls are best-suited for sites characterized by good bearing material and small long-term settlement. In soft soils or when settlement may be a problem, the semi-gravity walls can be pile supported. This adds to the cost, especially relative to a MSE wall. However, for short wall lengths, the CIP concrete cantilever wall may be the most cost-effective selection.

An important advantage of these walls is that they do not require special construction equipment, wall components or specialty contractors. They can be up to 30 ft in height, although most are less than 20 ft in height. The footing width for these walls is normally $\frac{1}{2}$ to $\frac{2}{3}$ the wall height.

CIP concrete cantilever walls can be used in cut slope locations. In this case, the slope behind the face of the wall requires excavation to provide clearance for the construction of the wall footing. Typically, excavation slopes should not be steeper than 1.5H:1V, which can result in significant excavations in sloped areas. In this case, a shored excavation may be required, or alternative wall types may be more suitable.

23.1.4.1.3 Prefabricated Modular Walls

Prefabricated modular walls include concrete and metal bin walls and concrete crib walls. These types of walls may occasionally be advantageous. For example, because the components are prefabricated before delivery to the field, prefabricated modular walls may be desirable where the time to build the wall is limited.

23.1.4.2 Cut Walls

23.1.4.2.1 *Soldier Pile Walls*

Soldier pile walls involve installing H-piles every 8 ft to 10 ft and spanning the space between the H-piles with lagging. The H-piles are usually installed by grouting the H-pile into a drilled hole; however, they can also be installed by driving. The advantage of installing the H-pile by drilling is that vibrations, and the potential for driving refusal, are usually avoided. The depth of the soldier pile is similar to the sheetpile wall; i.e., approximately two times the exposed height. Lagging can be either timber or concrete panels.

For most soldier pile walls, a concrete facing is cast in front of the soldier piles and lagging after the wall is at full height. Various architectural finishes can be used for the facing.

23.1.4.2.2 *Anchored Walls*

Ground-anchored wall systems (often called tie-back walls) typically consist of tensioned ground anchors connected to a concrete wall facing. Ground anchors may also be used to construct soldier pile walls of a taller height. Ground anchors consist of a high-strength steel bar or prestressing strand that is grouted into an inclined borehole and then tensioned to provide a reaction force at the wall face. These anchors are typically located at 8-ft to 10-ft horizontal and vertical spacing, depending on the required anchor capacity. Each anchor is proof tested to confirm its capacity.

Specialized equipment is required to install and test the anchors, resulting in a higher cost relative to conventional walls. An important consideration for this wall type can be the subsurface easement requirements for the anchoring system. The upper row of anchors can extend a distance equal to the wall height plus up to 40 ft behind the face of the wall.

23.1.4.2.3 *Soil Nail Walls*

A soil nail wall uses top-down construction. The typical construction methodology includes:

- a vertical cut of approximately 4 ft;
- drill, insert and grout soil nails;
- shotcrete exposed cut surface;
- repeat operation until total height of wall is complete; and
- for permanent applications, a reinforced concrete wall is cast over the entire surface.

A soil nail wall involves grouting large diameter rebar (e.g., #10 or larger) or strand into the soil at 4-ft to 6-ft spacing vertically and horizontally. The length of the rebar or strand will typically range from 0.7 times the wall height to 1.0 times the wall height, or more.

Specialty contractors are required when constructing this wall type. Soil nail walls can be difficult to construct in certain soil and groundwater conditions. For example, where seeps occur within the wall profile or in relatively clean sands and gravels, the soil may not stand at an exposed height for a sufficient time to install nails and apply shotcrete.

23.1.4.2.4 *Nongravity Cantilever (Sheet Pile) Walls*

Sheet pile walls are normally driven or vibrated into the ground with a pile driving hammer and are most suitable at sites where driving conditions are amenable to pile driving. Therefore, part of the design process requires performing a driveability analysis. Sites with shallow rock or consisting of significant amounts of cobbles and boulders are not suitable for sheet pile driving.

Generally, the sheet pile must be driven to a depth of 2 times the exposed height to meet stability requirements. Most sheet pile walls are 10 ft to 15 ft or less in height. Although higher walls are possible, the structural design and installation requirements increase significantly. Taller sheet pile walls are possible, but require ground anchors that are typically attached to a horizontal whaler beam installed across the face of the sheet piles.

23.2 MECHANICALLY-STABILIZED EARTH (MSE) WALLS

23.2.1 External Stability and Internal Stability

The Geotechnical Engineer is responsible for the external stability calculation. The approved wall suppliers, shown in the NDOT Qualified Products List (QPL), are responsible for the internal stability of the wall.

The external stability calculation should include a check for sliding, overturning, rotational failure and bearing pressure. The wall geometry (including the width of reinforcement and height) will be established based on these items for each height of wall. If the wall supplier must increase the reinforcement width or height of the backfill due to internal stability requirements, the contractor is not paid for quantity increases. Increases over that required for external stability must be verified by the Geotechnical Engineer to ensure that the increase is justified.

23.2.2 Spread Footings

Spread footings supported by MSE walls pose a special problem during construction. The *Standard Specifications* are not specific on how construction of the wall will occur when a spread footing will be supported. The *Specifications* require that the mechanically stabilized earth backfill be compacted to 95% of maximum density. It is almost impossible, however, to compact the material adjacent to the wall panel, particularly with bar mat systems. Therefore, a note on the plans or in the Special Provisions is needed. The following statement is suggested:

Special consideration shall be given the mechanically stabilized earth backfill placed adjacent to the back face of wall panel. The methods of placement and the materials used to meet the minimum compaction density specified in the Standard Specifications shall be approved by the Engineer.

NDOT does not allow the placement of spread footings for bridges on embankments retained by MSE walls.

23.2.3 Piles Within MSE Walls

Piles placed within the mechanically stabilized earth backfill require special consideration. The piles must be placed prior to the construction of the wall. As the wall is constructed, the subsoils beneath the wall and the MSE wall itself may compress. The piles, however, are rigid. The compression of the soils will induce a load into the piles due to friction. Depending on site materials, these downdrag forces can be substantial. To reduce the friction on the piles and to mitigate the downdrag forces, a material such as "Yellowjacket" sleeves can be placed on the piles, or a slightly larger corrugated pipe can be placed over the pile prior to backfilling.

The soil reinforcement must be modified when piles are located within the wall. The soil reinforcement cannot be bent around the piles; they must remain linear to develop their strength. Also, the soil reinforcement cannot be attached to the piles. A skew of up to 15° from a line perpendicular to the wall face may be allowed provided that the design accounts for this.

Bar mats can be cut and skewed, but they must conform to the following:

- Do not allow single longitudinal wires.
- Bar mats develop their strength from the cross wires. At least two longitudinal wires are needed to make the cross wire effective.
- Cut segments must meet minimum pull-out capacity factors of safety. Testing of cut segments is required to show that their full strength is developed.

All cutting of reinforcement shall be done prior to the application of corrosion protection. Bridging frames for soil reinforcing may be required around the piling if cutting and skewing cannot resolve all conflicts. The bridging frames are designed to transfer all forces within the soil reinforcement and shall be corrosion protected. The bridging frame shall be designed by the wall supplier and verified by the bridge designer. Detail all bridging frames on the shop drawings.

23.2.4 Loads From Other Structures

MSE walls that support structures, such as soundwalls, must be designed for the lateral and vertical loads imposed on the MSE wall. These loads can be substantial. The magnitude of the force and where the force is applied on the MSE wall must be noted in the contract documents or a drawing provided.

23.2.5 Barrier Rails

MSE walls that incorporate a barrier rail at the top of wall require special attention. The top of MSE walls are not strong enough to resist traffic impacts. Traffic impacts must be transferred from the barrier rail into a reinforced concrete slab that is part of or located just below the roadway pavement. The concrete slab is sufficiently massive to keep vehicle impact forces from being transferred into the MSE wall. Size the concrete slab to resist sliding and overturning forces due to vehicle impacts, wind or seismic loading as appropriate.

23.2.6 Copings

All copings at the top of MSE walls shall be cast-in-place. The top of the walls generally project 1 ft to 2 ft above the top layer of soil reinforcement. The coping must be sufficiently large to hold together this unbraced section. Reinforcing steel from the top wall panels should extend into the coping.

23.2.7 Shop Drawings

The wall supplier prepares the shop drawings and supportive calculations. NDOT or the design consultant approves the shop drawings. See [Appendix 25A](#) for an MSE wall checklist.

23.2.8 Responsibilities

23.2.8.1 Geotechnical Section

The Geotechnical Engineer will conduct global stability analyses and provide design recommendations including depth of embedment and width of reinforcement. The Geotechnical

Engineer will conduct external stability analyses with respect to sliding, overturning, slope stability and bearing pressure failures.

The Geotechnical Engineer uses publication No. FHWA-NHI-00-043 *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines* and/or the latest edition of the *LRFD Specifications* to design and determine the minimum reinforcement lengths of the wall. Typical information and details to be provided by the Geotechnical Section to the Structures Division include the following:

- depth of embedment of leveling pad;
- total height of wall from top of leveling pad to top of coping/bottom of barrier rail;
- minimum 4-ft wide bench in front of walls located on top of slopes;
- no steeper than 2H:1V slopes in front of or on top of walls;
- strength properties of soils supporting the wall (i.e., foundation soils), MSE backfill and retained backfill;
- magnitude of anticipated total and differential settlement;
- recommended waiting period prior to the construction of barrier rails, copings, concrete anchor slabs and roadway surface;
- the minimum required reinforcement lengths for the entire length of the wall; and
- surcharges.

23.2.8.2 Wall Supplier

The approved wall supplier will check the external stability with respect to sliding, overturning and bearing pressure to confirm NDOT's proposed minimum reinforcement lengths. The Geotechnical Engineer will determine the need for any changes indicated by the contractor's external stability analysis. NDOT is responsible for all costs associated with changes to the wall due to external stability.

The wall supplier is responsible for internal stability. The wall supplier is responsible for all costs associated with modifications to the overall wall geometry due to internal stability design or construction convenience.

23.2.8.3 Structures Division

The Structures Division will estimate the quantities and prepare the contract documents for MSE walls. See Chapter 5 for a discussion on MSE contract documents.

23.2.8.4 Roadway Design Division

The discussion in [Section 23.1.2.3](#) also applies to MSE walls.

23.3 BURIED STRUCTURES

23.3.1 Reinforced Concrete Boxes

The structural design of reinforced concrete boxes is based on Section 12 of the *LRFD Specifications*. The Hydraulics Section is primarily responsible for these drainage appurtenances, and NDOT has developed standard designs that will apply in most cases. See the *NDOT Standard Plans*. Occasionally, the Hydraulics Section may request that the Structures Division verify the structural adequacy of a proposed or existing reinforced concrete box. A special design is required when:

- The box geometry or height of soil above the reinforced concrete box exceeds the values in the *Standard Plans*.
- Loads are imposed on the reinforced concrete box from other structures.
- The sequence of backfilling the sides of the reinforced concrete box will not allow equal loading.
- Special inlet, outlet, confluence or other special hydraulic structure is needed for which a standard does not exist.

23.3.2 Concrete Arch Culverts

The use of concrete arch culverts is only permitted when approved by the Chief Structures Engineer, the Chief Hydraulic Engineer and the applicable District Engineer. The following will apply:

1. The design must meet the requirements of Section 12 of the *LRFD Specifications*.
2. The arch must be doubly reinforced meeting AASHTO LRFD requirements for minimum reinforcing and service limit state (crack control) criteria.
3. The arch must be poured in-place using Class A (AA) modified or Class D (DA) modified concrete. Shotcrete construction is not permitted.
4. Design verification using the CANDE computer program is necessary.
5. Provide design verification for a potential future condition that would require excavation of backfill material along one edge of the arch.
6. The arch culvert must be constructed with a concrete invert.
7. The "saddle" area of multiple-cell arch structures must be constructed with a waterproofing system and a suitable drainage system to control ponding and saturation of backfill soils. Provide weepholes in exterior walls at 50-ft maximum spacing. All drains and weepholes shall be a minimum 3-in diameter.
8. A technical representative of the arch culvert supplier shall be on-site and shall supply the necessary technical assistance during the initial completion of major work activities including, but not limited to, the placement of reinforcing, forming, concrete placement, form removal, waterproofing and backfilling.

9. Upon completion of the culvert, provide certification from the Engineer of record that the arch was constructed with materials and procedures consistent with what was used for the arch design.
10. Only rigid formwork and falsework conforming to Section 502 of the *Standard Specifications* shall be used.

23.4 SOUND BARRIERS

The Environmental Services Division will determine the warrants for, locations of and minimum heights for sound barrier walls. The following discusses the basic NDOT requirements for conventional concrete (precast or cast-in-place) or masonry sound barrier walls. Proprietary wall systems and/or walls composed of other materials are subject to evaluation and approval under NDOT's Product Evaluation Program before they may be used. Refer to the NDOT "Soundwall System Evaluation Manual" for requirements for alternative wall systems.

23.4.1 Design Criteria

NDOT's practices for the structural design of sound barriers are:

- The design standards are the current editions of the AASHTO *Standard Specifications for Highway Bridges* and *Guide Specifications for Structural Design of Sound Barriers*.
- Wind pressure as determined by the AASHTO *Guide Specifications* using a minimum wind velocity of 80 mph and minimum B-2 exposure (20 psf minimum wind pressure).
- Seismic load as determined by the AASHTO *Guide Specifications* using the appropriate site acceleration coefficient but, in no case, shall the coefficient be less than 0.15.
- Ice load where applicable as determined by the AASHTO *Guide Specifications*.
- 10-kip vehicular impact load when the sound wall is constructed within the roadway clear zone (as defined by the current edition of the AASHTO *Roadside Design Guide*) and is not otherwise protected by a traffic barrier. Walls constructed within this clear zone should incorporate a suitable safety barrier.
- A Nevada-registered professional civil or structural engineer shall stamp the structural calculations and plan sheets.
- Foundation design should be based on the recommendations of a Nevada-registered civil or structural engineer. A copy of the geotechnical investigation report should be included with the project documents.
- Masonry design shall be based on a specified 28-day compressive strength (f'_m) of 1.5 ksi without special inspection (use one-half reduction). Grout all cells and provide minimum reinforcing consisting of #4 bars at 16-in vertical and 20-in horizontal spacings.

23.4.2 Material Requirements

The following applies:

- Minimum concrete 28-day compressive strength shall be 4 ksi. Concrete used at locations subject to roadway salting shall be Class EA with a minimum 28-day compressive strength of 4.5 ksi for those elements located within the salt-affected area, defined as 12-in below or 48-in above the adjacent roadway surface.

- All reinforcing steel shall conform to AASHTO M31 Grade 60. Welded wire reinforcement may also be used; see [Section 14.3.2](#). Reinforcing in concrete elements within the salt-affected area shall be epoxy coated.
- Structural steel shall conform to AASHTO M270 Grade 36 or 50 and shall be galvanized unless embedded in concrete.
- Masonry units shall conform to ASTM C90, Type I. Construct masonry walls level using running bond and provide cap blocks of 2-in minimum thickness.

23.5 SIGN, SIGNAL AND LIGHTING STRUCTURES

For these structures, NDOT has adopted the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*. The NDOT Traffic Engineering Section is primarily responsible for these structures, and NDOT has developed standard designs that will apply in most cases. Occasionally, the Structures Division will become involved in the design of structural supports for these roadside appurtenances.

The Structures Division is responsible for the design of all structures in the *NDOT Standard Plans* and for developing the designs for special installations. The Structures Division is also responsible for approving shop drawings on these structures. See [Appendix 25A](#).

23.6 PEDESTRIAN/BICYCLE BRIDGES

23.6.1 Preliminary Design

The preliminary design for a pedestrian or bicycle bridge is intended to determine the most appropriate structure type and configuration for a given site. The Preliminary Design Report must be approved before initiating final design. The Report should address the following.

23.6.1.1 Geometrics

The geometrics of the bridge and the approach transitions shall meet the requirements of the AASHTO *Guide Specifications for Design of Pedestrian Bridges*. A minimum vertical clearance of 18'-0" is required over NDOT highway facilities. Clearances over other facilities will be determined on a project-by-project basis. For pedestrian/bicycle bridges over waterways, the Hydraulics Section will determine the necessary hydraulic opening.

23.6.1.2 Structure Type

Generally accepted structure types for pedestrian and bicycle bridges include:

- cast-in-place, post-tensioned box girders;
- precast, prestressed concrete girders with a cast-in-place concrete deck;
- CIP concrete slabs;
- steel girders with a cast-in-place concrete deck; and
- tubular steel pony trusses.

Additional structure types may be considered as deemed appropriate for the given site. An evaluation of structure types must include a consideration of constructibility, aesthetics, use of falsework, construction costs, etc.

23.6.2 Final Design

The design shall conform to the latest edition of the AASHTO *Standard Specifications for Highway Bridges*, except as modified by the AASHTO *Guide Specifications for Design of Pedestrian Bridges* and as noted herein.

23.6.2.1 Seismic

AASHTO seismic provisions shall apply to pedestrian and bicycle bridges, as modified by the *NDOT Structures Manual*. See [Section 13.3](#).

23.6.2.2 Fatigue

All tension members shall meet minimum V-notch toughness requirements for Zone 2.

23.6.2.3 Tubular Steel Pony Trusses

Tubular steel pony trusses are generally designed and fabricated by a company specializing in this type of pedestrian/bicycle bridge. A generic detail of the pony truss shall be shown in the contract documents. All applicable design standards also need to be shown in the documents.

The contract documents shall include provisions for the design, detailing and submittal of shop drawings. A Nevada Professional Engineer registered in civil or structural engineering must perform the design. Stamped calculations and design drawings must be submitted for review and approval prior to the start of fabrication. Shop drawings must also be submitted for review and approval. If the design drawings and shop drawings are combined in one submittal, they must also be stamped by the Registered Professional Engineer.