21. Miscellaneous Structural Elements

In general, the Bridge Section is responsible for all structural design elements for DOT&PF projects. Although the majority of the Section's work is for highway bridges, the transportation system includes a wide variety of other structural elements.

Sections 11 and 12 of the AASHTO *LRFD Specifications* discuss design and detailing requirements for retaining walls and buried structures.

This chapter presents DOT&PF policies, practices, and criteria for the structural design of these miscellaneous structural elements.

21.1. Retaining Walls

See Section 1120.4 in the *Alaska Highway Preconstruction Manual* for more discussion on retaining walls.

21.1.1. Applications

DOT&PF uses retaining walls 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
- surcharge loads from adjacent buildings, highways, and other structures that must remain in place
- slope stabilization
- protection of environmentally sensitive areas
- excavation support

21.1.2. DOT&PF Classifications

Retaining walls are classified as follows:

1. **State-Designed Structures**. These walls are designed entirely by the DOT&PF or a consultant without the use of proprietary systems. Examples of this type of structure are cast-in-place concrete cantilever retaining walls, soldier-pile lagging walls, and steel sheet pile walls.

2. **Pre-Approved Proprietary Structures**. These walls are patented structures. The special provisions of the contract documents may list pre-approved proprietary structures as an alternative wall system based upon the recommendation of the Statewide Materials Section. Typically, these are Mechanically Stabilized Earth (MSE) retaining walls. For the use of proprietary walls on federal-aid projects, the DOT&PF must adhere to the Code of Federal Regulations, Title 23, Section 635.411 "Material or Product Selection."

21.1.3. Retaining Wall Selection and Design Process

Foundation Investigation and Report

The project manager will notify the foundation engineer of the need to conduct the foundation investigation for the wall and to prepare the Structural Foundation Engineering Report (SFER).

This report should describe soil conditions, make foundation engineering design recommendations, and identify and recommend feasible wall systems. Section 17.2 discusses the SFER in detail.

For retaining walls, the foundation engineer:

- performs the geotechnical investigations;
- provides recommendations for feasible wall types;
- recommends the nominal soil bearing and lateral earth design coefficients for gravity, surcharge, and seismic loading;
- performs the global and external stability checks; and
- determines if there is a need for special drainage features due to the selected wall type, site conditions, or both.

The foundation engineer will also provide the following information to the bridge engineer:

- earth pressure coefficients (e.g., k_a, k_o, k_p) and an estimate of the amount of deformation to develop the active and passive earth pressures
- unit weight of the backfill material
- allowable interface friction between cast-in-place and precast concrete footings and soil

- allowable bearing capacity
- expected settlement
- requirements for drainage control
- special construction requirements

Retaining Wall Type Selection

The selection of a wall type depends on several performance variables:

1. **Material Availability and Cost**. These are important considerations for every site. Mechanically Stabilized Earth walls usually require a select backfill material. These materials are not locally available in certain areas of the state.

   At remote sites (see Chapter 20), concrete may not be practical, and the necessary aggregate may not be available locally. Therefore, at remote sites, transportation costs for construction equipment and materials are a major consideration.

2. **Ease of Construction**. Evaluate the equipment requirements to construct a wall. Determine if the required equipment can be mobilized to the construction site and will have sufficient maneuvering room.

   Generally, a contractor can construct MSE and anchored walls with smaller tools and lifting equipment.

   For all wall types, some earth-moving equipment is required, but a tie-back wall minimizes the need.

3. **Cut vs. Fill Walls**. Some wall construction types are better suited in earth cuts and some in fills. For example, MSE walls perform well in new embankment but may require extra excavation, backfill, and right-of-way when used to retain soils adjacent to a depressed roadway.

4. **Drainage**. Retaining wall design forces typically assume fully drained conditions. All retaining wall designs shall address drainage and prevent the build-up of hydrostatic pressure.

5. **Settlement**. Potential settlement is also a consideration. Rigid walls do not tolerate settlement well. If significant settlement is anticipated, the most favorable walls are MSE walls.

   With limited construction space, a sheet pile wall or a tie-back soldier-pile wall may be ideal. The bridge engineer can use piling to resist settlement on cast-in-place concrete walls, but this solution is usually costly.

6. **Service Life**. Use of metal products in corrosive environments (e.g., marine, acidic soils) requires special attention. Always treat timber products with a preservative for ground contact and minimize the number of field cuts. Provide corrosion protection systems for the steel reinforcing bars in concrete exposed to salt.

7. **Surcharge**. Surcharge loading (loads along the top of the retained embankment) may require walls with additional strength and stiffness. Most structures built on top of retained embankments are sensitive to settlement.

8. **Aesthetics**. The aesthetic value of wall facings are important where visual exposure will be high, such as in urban settings.

9. **Railings**. All walls with an exposed face height exceeding 3 feet need a cable safety railing if they do not already have another type of railing or barrier.

Structural Design of CIP Concrete Retaining Walls

Standard Drawings are available for CIP concrete cantilever retaining walls. For non-standard walls, the Bridge Section, or a consultant experienced in wall design, will design all cast-in-place walls over 4 feet in height. Design the structural aspects of a wall using this *Manual* and Section 11 of the *LRFD Specifications*. The following summarizes the objectives:

1. **Design**. The bridge engineer will perform the internal stability design for the wall (e.g., wall dimensions and reinforcing configurations) and perform the overturning, sliding and bearing checks, using the geotechnical parameters provided by the foundation engineer.

2. **Contract Plans**. The bridge engineer and highway design engineer will coordinate to provide all construction details for the wall, including:

a. beginning and end of wall stations

b. horizontal wall alignment

c. elevation on top of wall at the beginning and end of wall, all profile break points, and roadway profile data at wall line

d. original and proposed profiles in front of and behind the retaining wall, including the ground line at wall ends

e. typical sections

f. elevation of highest permissible level for foundation construction (place the top of footings at least 2 feet below the frost line), location, depth, and extent of any unsuitable material to be removed and replaced

g. right-of-way limits shown on the plans

h. design high water and normal water levels at stream locations

i. quantities table showing estimated square feet of wall area and quantity of appurtenances and traffic barriers

j. the location of new or existing utilities in proximity of the retaining wall

k. reinforcing details and cross sectional dimensions

l. construction sequence requirements if applicable, including traffic control, access, and stage construction sequences

m. boring logs (provide the SFER as supplemental information to the contract bidding documents)

n. details of wall appurtenances (e.g., traffic barrier, coping, handrail, noise barrier, drainage outlets, location, configuration of signs and lighting including conduit location)

Design of Proprietary Retaining Walls

Provide sufficient geometric controls in the contract plans so that a vendor may prepare a system structural design. Typically, this is a line in the contract plans that provide the lateral offset and termini of the wall. The contract documents will identify those vendors that are qualified, either through a reference to the Qualified Products List or in the special provisions.

21.1.4. Retaining Wall Types

Walls are classified according to their construction method and the mechanism used to develop lateral support:

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.

Lateral Load Support

The basic mechanism of lateral load support may be either "externally stabilized" or "internally stabilized."

Externally stabilized wall systems, such as a CIP concrete cantilever wall, use an external structural wall, against which stabilizing forces are mobilized.

Internally stabilized wall systems, such as an MSE wall, employ reinforcement that extends within and beyond the potential failure mass.

21.1.5. Fill Walls

MSE Walls

MSE walls are constructed using reinforced layers of earth fill with non-extensible (metallic) reinforcing. The facing for the walls shall be concrete panels. 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.

MSE walls are not allowed along bodies of water. See Section 21.2 for more information on MSE walls.

CIP Concrete Cantilever Walls

CIP concrete cantilever walls are best suited for sites characterized by good bearing material where minimal long-term settlement is anticipated. In some cases, weaker surface soils can be excavated and replaced with 5 feet of compacted gravel backfill to economically improve the bearing capacity.

In particularly, soft soils or when settlement may be a problem, walls can be pile supported. Piles add to the cost, especially relative to a MSE wall; however, for short wall lengths, the pile-supported CIP concrete cantilever wall may be a cost-effective option.

An important advantage of CIP walls is that they do not require special construction equipment, wall components, or specialty contractors. They can be up to 30 feet in height, although most are less than 20 feet in height. The footing width for these walls is normally ½ to ⅔ 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. Do not use excavation slopes steeper than 1.5H:1V, which would result in significant excavations in sloped areas. In this case, a shored excavation may be required, or alternative wall types (e.g., soldier-pile walls) may be more suitable.

21.1.6. Cut Walls

Soldier-Pile Walls

Soldier pile walls involve installing H-piles every 6 to 10 feet 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 drilling is that this avoids vibrations and the potential for driving refusal.

The embedded depth of the soldier pile is approximately two times the exposed height. The exposed height is typically up to 15 feet. Lagging can be either treated timber or concrete panels.

A concrete facing may be cast in front of the soldier piles and lagging after the wall is at full height to improve aesthetics.

Anchored Walls

Ground-anchored wall systems (also called tie-back walls) typically consist of tensioned ground anchors connected to a concrete wall facing. Use ground anchors 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. Anchors are typically laid out at 8-feet to 10-feet horizontal and vertical spacing, depending on the required anchor capacity. Each anchor is proof tested to confirm its capacity.

Anchored walls require specialized equipment to install and test, resulting in a higher cost relative to conventional walls. Consider the subsurface easement requirements for the anchoring system. The upper row of anchors can extend a distance behind the wall equal to the wall height plus up to 40 feet.

Soil-Nail Walls

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

- a vertical cut of approximately 4 feet;
- drill, insert, and grout soil nails;
- shotcrete exposed cut surface;
- repeat operation until total height of wall is complete; and
- for permanent applications, cast a reinforced concrete wall 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-feet to 6-feet 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.

Soil-nail walls require specialty contractors. They 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.

Sheet-Pile Walls

Sheet-piles 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, the bridge engineer must perform a driveability analysis. The SFER should address drivability when sheet-pile walls are considered. Sites with shallow rock or consisting of significant amounts of cobbles, boulders, or permafrost are not suitable for sheet-pile driving.

Generally, the sheet pile must be driven to a depth of two times the exposed height to meet stability requirements. Most sheet-pile walls are 10 feet to 15 feet 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 waler beam installed across the face of the sheet piles.

21.1.7. References

Further guidance on walls:

- *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

21.2. Mechanically Stabilized Earth (MSE) Walls

21.2.1. Responsibilities

DOT&PF

DOT&PF will conduct the global stability analysis and the external stability analyses with respect to sliding, overturning, slope stability, and bearing pressure failures. The contract documents identify the following typical information and details:

- location and elevation of leveling pad;
- total height of wall from top of leveling pad to top of coping/bottom of barrier rail;
- minimum 4-foot 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, MSE backfill, and retained backfill; and
- surcharges.

Wall Supplier

The approved wall supplier will check the external stability with respect to sliding, overturning, and bearing pressure. The Department will determine the need for any changes indicated by the wall supplier's external stability analysis.

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

21.2.2. External Stability and Internal Stability

The external stability calculation should include a check for sliding, overturning, rotational failure, and bearing pressure. Establish the wall geometry (including the width of reinforcement and height) 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.

The foundation engineer verifies increases over that required for external stability to ensure that the increase is justified.

21.2.3. Loads from Other Structures

Design MSE walls that support structures for the lateral and vertical loads imposed on the MSE wall. These loads can be substantial. The contract documents should identify the magnitude of the force and where the force is applied on the MSE wall in the "Footing Data Table." See Table 17.2-3.

21.2.4. Barrier Rails

MSE walls that incorporate a barrier rail at the top of the wall require special attention. The top of MSE walls are not strong enough to resist traffic impacts.

Design the wall to transfer traffic impacts from the barrier rail into a reinforced concrete slab that is located just below the roadway pavement. The concrete slab needs to be sufficiently massive to keep vehicular impact forces from being transferred into the MSE wall.

Size the concrete slab to resist sliding and overturning forces due to vehicular impacts, wind, or seismic loading as appropriate. Provide a minimum of 2 inches of separation between the bottom of the slab and the top layer of reinforcement.

21.2.5. Copings

Use CIP concrete copings at the top of all MSE walls. The top of the walls generally project 1 foot to 2 feet above the top layer of soil reinforcement. The coping holds together this unbraced section. Reinforcing steel from the top wall panels should extend into the coping.

21.2.6. Shop Drawings

The wall supplier prepares the shop drawings and supporting calculations. The bridge engineer reviews and approves the wall geometry and facing panel details. The calculation package is sent to the foundation engineer for review and approval.

21.3. Other Structures

21.3.1. Buried Structures

Use Section 12 of the *LRFD Specifications* for the structural design of buried structures or culverts. DOT&PF has developed standard designs that apply in most cases. See the DOT&PF *Standard Drawings*. A special design may be required when:

- the culvert geometry or height of soil above the culvert exceeds the values in the DOT&PF standard designs;
- loads are imposed on the culvert from other structures;
- the sequence of backfilling the sides of the culvert will not allow equal loading, or;
- special inlet, outlet, confluence, or other special hydraulic structures are needed for which a standard does not exist.

21.3.2. Signs, Signals, and Luminaire Structures

For these structures, including their foundation design, DOT&PF has adopted the AASHTO *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals.*

Observed problems with these structures include welded connections and anchor bolts. The AASHTO *LFRD Specifications* discuss the design and detailing of welded connections and anchor bolts. See the AASHTO/AWS *Structural Welding Code - Steel, D1.1* for additional discussion on welding issues.

DOT&PF has developed standard designs that apply in most cases. Occasionally, the Bridge Section will design structural supports for these roadside appurtenances. The Engineer-of-Record is also responsible for approving shop drawings on these structures.

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