Retaining walls are a common feature on many WisDOT projects. They can be constructed from a variety of materials and may range in height from as little as 4 feet, to more than 30 feet. Retaining walls are used in many different applications including addressing right-of-way restrictions, protecting existing structures, acting as grade separations, allowing new highway embankment construction or widening of roadways, addressing stabilization of slopes, protecting environmentally sensitive areas, providing temporary support for staging, etc. Normally retaining walls are designed as a long term installation with a 75-year design life, unless a specific wall is designed for a temporary installation. Extensive background information on retaining walls can be found in Chapter 14 of the WisDOT Bridge Design Manual and Section 11 of the AASHTO Specifications.

There are two aspects to the design of retaining walls. The first is the internal stability of the wall. Here the various components of the wall must be designed so that the wall will maintain its shape and integrity for its design life. The second aspect is the external stability of the wall. Here the soil and surcharge pressures acting on the wall must be analyzed to determine if the wall has an adequate Capacity-to-Demand Ratio (CDR) [safety factor] against failure by the five classic modes of sliding, bearing, eccentricity, settlement, and overall global stability.

Retaining walls on WisDOT projects may be separated into two general categories based on the internal design process of the wall. The first category is generic (or non-proprietary) walls. These are walls where the internal design follows well-established engineering practices and principles available to all engineering practitioners. The second category is proprietary walls. These are walls where the wall components, as well as the internal design of the wall, are marketed as a package by a commercial vendor. Some, or all, parts of the wall and its design procedure may be patented.

It is important to clearly understand this distinction between wall types. For non-proprietary walls, WisDOT is responsible for both the internal and external stability of the selected wall. The external stability of a wall is an application of soil mechanics and is the responsibility of the geotechnical engineer. The responsibility for internal stability may fall either to the structural engineer or to the geotechnical engineer depending on the type of wall selected. Gravity walls and gabion walls are usually designed by the geotechnical engineer, while cantilevered reinforced concrete walls are the province of the structural engineer. Sheet pile walls along with post and panel walls may be designed by either the geotechnical engineer or the structural engineer. For proprietary walls, the internal design is always the responsibility of the contractor, but usually completed by the wall vendor/supplier. However, in all cases, the external stability of the proposed wall remains the responsibility of WisDOT (or their designated design consultant), to be carried out by the geotechnical engineer.

Another method of distinguishing walls is the way in which they are constructed. There are ‘cut walls’ that are built from the existing ground surface downward (i.e. top-down construction), as opposed to fill walls, that are built from the base upward (i.e. bottom-up construction). The particular project needs will determine which construction method is necessary for the wall being investigated, and which of the various wall types are applicable to the individual site.

7-6.1 Typical Wall Types

Wall types used on WisDOT projects include the following:

<u>Gravity Walls.</u> Generic walls formed by a mass of concrete or rock. Stability is achieved by the weight and dimensions of the wall. These are normally less than 8 feet in height.

<u>Bin and Crib Walls.</u> Proprietary walls formed by stacking preformed or precast metal or concrete components that are filled with soil.

<u>Gabion Walls.</u> Generic walls formed by filling large wire baskets with a select stone material that is generally 4-8” in diameter. The filled baskets are then anchored together to form a solid mass. These are a specialized type of gravity wall and can reach heights of 12 feet or more. However, the required wall mass will disproportionally increase as the wall height increases.

<u>Sheet Pile Walls.</u> Generic walls developed by driving interlocking structural steel sections to a specified depth. Walls of this type may be designed as a cantilevered installation, or as a tieback installation. The steel section is determined by the height of the wall, site geometry, subsurface conditions, external loads, and method of design. There are various sizes/shapes of structural sheet pile, and these walls can reach heights of more than 20 feet. Tie-backs are generally required for exposed heights greater than 15 feet.

<u>Post and Panel Walls.</u> Generic walls somewhat similar to a sheet pile wall. Walls of this type consist of a series

of posts consisting of heavy steel H-sections embedded in CIP concrete shafts. Panels inserted between the posts transmit the soil pressure loads to the posts. Posts are typically spaced between 6-12 feet apart. These walls may be designed either as a cantilever or as a tieback installation. Exposed wall heights in excess of 15 feet typically require the use of tiebacks.

Mechanically Stabilized Earth (MSE) Walls. These are proprietary walls composed of a number of layers of steel or polymer geogrids or strips which distribute earth pressures back into the soil mass beyond the failure plane. Walls of this type have a facing of precast concrete panels, interlocking concrete blocks, wire-facing (with some type of protection), or are cast-in-place, to retain the soil between the strips or grids. Granular backfill is necessary to develop the necessary internal friction for the geogrids or strips. Some walls of this type can reach heights of 30 feet.

Cantilevered Reinforced Concrete Walls. A generic CIP reinforced concrete wall consisting of a vertical stem with a horizontal footing shaped as an “L” or inverted “T”. The wall develops stability by distributing soil pressure to the underlying soil through the footing by direct bearing pressure, or by the inclusion of piles. Walls of this type can be designed for heights of 30 feet or more.

Specialty Walls. Walls of this type include a number of methods including slurry walls, deep soil mix walls, secant/tangent drilled shaft walls, and soil nail walls. These are systems that have been developed and designed specifically for top-down construction. Top-down construction generally occurs in locations that require a cut/excavation. The process starts at the existing ground surface, then the wall system is installed, and then the earth in front of the wall is excavated until the planed cross section is achieved. All of these specialty wall systems require specialized design procedures, along with specialized construction equipment. These tend to be more expensive installations that are best suited to unique situations.

Table 1 presents basic information on these various types of walls.

Table 1 – Retaining Wall Properties

Wall Category	Wall Sub-Category	Wall Type	Typical Construction Concept	Proprietary
Gravity	Mass Gravity	CIP Concrete Gravity	Bottom Up (Fill)	No
	Semi-Gravity	CIP Concrete Cantilever	Bottom Up (Fill)	No
	Reinforced Earth	MSE Walls: • Precast Panels • Modular Blocks • Geogrid/ Geo-textile/Wire-Faced	Bottom Up (Fill)	Yes
	Modular Gravity	Modular Blocks, Gabion, Bin, Crib	Bottom Up (Fill)	Yes
	In-situ Reinforced	Soil Nailing	Top Down (Cut)	No
Non-Gravity	Cantilever	Sheet Pile, Soldier Pile, Tangent/Secant	Top Down (Cut) /Bottom Up (Fill)	No
	Anchored	Anchored Sheet Pile, Soldier Pile, Tangent/Secant	Top Down (Cut)	No

Generally each retaining wall site is analyzed for single wall type. The objective of selecting a wall type is to determine an appropriate wall system that is practical to construct, structurally sound, economic, has minimal maintenance problems and meets the needs of the project and subsurface conditions.

Factors affecting the proper wall system selection include cut vs. fill wall, site characteristics (subsurface conditions, corrosion, settlement and lateral movement limitations, groundwater), wall heights and geometry, underground/overhead utility obstructions, right-of-way constraints, scour, water retention/drainage needs, constructability considerations, environmental concerns, availability of materials, cost, public requests/desires, railing/traffic barrier placement, aesthetics, etc.

7-6.2 Subsurface Investigations

A subsurface investigation is necessary for all types of retaining walls. This investigation will allow a full analysis of the external stability of the wall, and will also provide information for the internal wall design.

Before planning a subsurface wall investigation, available subsurface information such as geological studies/maps, groundwater studies, existing/adjacent structure geotechnical reports, etc. should be collected and reviewed to optimize the investigation program.

Generally, the subsurface investigation should comply with AASHTO specifications presented in Section 10.4 and Chapter 10 of the WisDOT Bridge Design Manual and generally following these guidelines:

1. All borings should generally provide continuous sampling to a depth of twice the height of the wall, beginning at the proposed base of the wall. If the proposed wall is a 'cut' wall, any borings advanced behind the face should also collect backfill soil characteristics to use in the wall design analyses. Borings should be conducted and reported using similar procedures as previously described for a bridge boring.
2. If a pile foundation is anticipated, the investigation and subsequent reporting should be the same as that for a bridge investigation.
3. For walls not supported on piles, borings are generally continued to a depth equal to twice the exposed height of the wall. The boring may be ended at this depth if at least 5 feet of either firm, or better, granular material, or stiff, or better, cohesive material have been logged. If not, the boring should generally be continued until this occurs. The boring should be advanced and recorded in the same manner as a bridge boring.
4. If bedrock is encountered, the boring may be ended when split spoon refusal is obtained. Coring is usually not necessary unless a relatively high wall is proposed to bear directly on the bedrock surface, or a deep foundation into the shallow bedrock is anticipated (such as for a post-and-panel wal). Borings ending in "possible bedrock or cobbles/boulders" (or similar language), may require additional borings, or coring, to better define the conditions.
5. The minimum number of borings required will be dependent upon the length of the wall. For walls up to 40 feet long, at least one boring is required. For walls of 40 feet up to 100 feet, generally two borings are necessary. For walls in excess of 100 feet, an additional boring should be added for each 100-200 feet, or major portion thereof, of additional wall length.

These guidelines should be considered as the minimum effort necessary. The geotechnical engineer must consider the specific subsurface conditions to determine if more borings are needed. The presence of an irregular rock surface, strata with highly variable blow counts and textures, or evidence of potential compressible soils would be reasons to consider additional boring and sampling. Sometimes it may also be cost effective to complete cone penetrometer testing (CPT) and/or pressure-meter testing (PMT) to help define soil properties more accurately.

7-6.3 Analyses and Recommendations

The geotechnical engineer must conduct appropriate investigation to enable the complete analyses and design of the selected wall type. The following discussion highlights some items to use in this analyses.

When borrow soils are required adjacent to retaining walls, WisDOT generally assumes design properties similar to the local in-situ soils on the project site. This often results in the design assumption of friction angles of 30 degrees, cohesion of zero and unit weight of 120 pcf, for these borrow soils.

For the majority of WisDOT wall applications, active earth pressure is assumed. But, the geotechnical engineer needs to be aware of the wall type and application, to determine if an at-rest active pressure may be more appropriate at an individual wall site.

The equivalent height of soils to account for vehicular loading is 2.0 feet. Assuming a standard 120 pcf unit weight of soil, results in a 240 psf design live load surcharge. Walls without traffic live load should be designed with a 100 psf surcharge live load to account for construction loads.

Cut retaining wall facings in cohesive soils usually have provisions for drainage of the retained soil. Stability analyses for walls in cohesive soils should be conducted for both short-term (undrained) conditions, and long term (drained) conditions. In addition, the potential for consolidation resulting from soil drainage, and the impact this could have on adjacent buildings or other installations, should be considered.

Soil pressures on walls constructed to retain cohesive soils may be reduced by placing a wedge of granular soil immediately behind the effective back face of the wall. This soil wedge should have a minimum horizontal length of one half the wall height and then angle upward at a 1H:1V slope to the retained ground surface.

There are various sources that relate the friction angle of granular soils to texture and blow count. WisDOT experience has shown that natural rounded sands in the state rarely have a friction angle exceeding 30 degrees. This should be considered as the practical limit for friction angles in unprocessed granular sand materials used for MSE wall backfill. Therefore, MSE wall reinforced backfills are designed using 30 degrees, unless there is sufficient laboratory testing to prove a higher value can be used, up to a maximum WisDOT allowed value of 36 degrees. A well-graded processed granular material can generally be considered to have a friction angle of 32-36 degrees. Use of higher design values should be accepted only if confirmed by internal WisDOT laboratory testing.

7-6.4 Site Investigation Report

As a minimum, a retaining wall SIR should include the following items:

- Estimates of the unit weight and shear strength (drained and undrained) values of foundation, retained and backfill materials.
- Location of water table, and its impact on design and construction.
- An estimate of earth pressures on the wall based on site geometry, proposed backfill and known in-place soils.
- An estimate of the nominal bearing resistance of the soil strata at the wall base elevation. If the bearing resistance is insufficient, and shallow foundations are designed, recommendations for site improvement must be developed and provided. This may include proposals such as sub-excavation, backfilling with granular materials, or expanding the base of the wall.
- A determination of the potential for consolidation in the underlying soil strata from wall and/or retained embankment loads. If such potential exists, the consolidation properties and magnitude and time rate must be determined. Recommendations to address this situation should be developed.
- If piles are proposed, a discussion on viable pile types, and the most appropriate type(s) and size(s), including the appropriate factors for skin friction and/or end bearing. This includes estimated pile lengths, design loads, drivability analyses, and construction installation monitoring method. (modified Gates, PDA)
- A full analysis of the external stability of the proposed wall system. This would include stability determinations for bearing, sliding, eccentricity, settlement, and global stability conditions when appropriate. The required Capacity-to-Demand Ratio (CDR) under the various loading conditions and appropriate load resistance factors should be used. Any deficiencies must be addressed and recommendations for methods of improvement must be developed and presented. This could include, but is not limited to, approaches such as lengthening the wall base, sub-excavating and backfilling with improved materials, increasing the embedment of the wall base, developing reinforced soil platforms, using pile foundations, changing backfill materials, etc.
- Discussion on any geotechnical design and/or construction issues that may affect the wall.

The Structure Site Investigation Report should document/summarize the subsurface investigation, findings, analyses, conclusions and recommendations for the proposed retaining wall system. Chapter 14 of the WisDOT Bridge Design Manual fully discusses the design/analysis methods of the various types of retaining walls, and associated Departmental policies concerning walls.