Training Manual

Excavation Protection System
Planning & Design

Syracuse, New York
5 November 2014
BIO

Ernest Holmberg, PE

Ernest Holmberg is a Design Squad supervisor for the Geotechnical Engineering Bureau of the New York State DOT, in Albany, New York. Mr. Holmberg is part of the Structures Foundation Section, which provides geotechnical design, support, and quality assurance for bridge, wall, and support structures foundations. The section analyzes soil structure interaction, provides foundation design and review for any DOT structure, provides design and review of temporary and permanent retaining walls, and provides quality assurance of all of the previously mentioned foundations during construction.

Mr. Holmberg is a graduate of Rensselaer Polytechnic Institute, and holds a Bachelor’s and Master’s Degree in Civil Engineering. He is a licensed professional engineer in New York, and has worked for the Geotechnical Engineering Bureau for 20 years. In addition to his design squad duties, he is in charge of the Structures Foundation Training Manual and has trained new bureau engineers since 1998.

ABSTRACT

This course describes the planning and design of Excavation Protection Systems for bridges and structures following NYSDOT policies and procedures. The course begins with brief introduction and overview of soil properties and parameters, safe slope layback, theory of earth pressure, pore water pressures, effective stress principle, groundwater effect, Rankine active & passive pressure and common types of excavation protections systems i.e. sheeting used for highway & bridge construction.

The course covers typical applications of Cantilevered Sheeting, Anchored Sheeting, Soldier Pile & Lagging Walls, and Braced Walls for earthwork and excavation protection commonly used in bridge construction. The advantages and disadvantages of different earthwork protection systems, detailed earth pressure distribution for these sheeting systems, design, and detailing of various components are briefly explained with construction pictures emphasizing different site conditions for the applicable sheeting for protection of earthwork and excavation while supporting the design loads and stage construction to maintain and protect vehicular traffic during construction.

1.  Course Introduction and Excavation Protection System Basics 40 min
2.  Cantilevered Sheeting 35 min
3.  Anchored Sheeting 35 min
4.  Soldier Pile and Lagging Walls 35 min
5.  Braced Walls 35 min
Excavation Protection System Planning & Design

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course Introduction and Excavation Protection System Basics</td>
<td>1</td>
</tr>
<tr>
<td>Cantilevered Sheeting</td>
<td>8</td>
</tr>
<tr>
<td>Anchored Sheeting</td>
<td>16</td>
</tr>
<tr>
<td>Soldier Pile and Lagging Walls</td>
<td>25</td>
</tr>
<tr>
<td>Braced Walls (35 minutes)</td>
<td>36</td>
</tr>
<tr>
<td>Geotechnical Design Procedure for Flexible Wall Systems</td>
<td>46</td>
</tr>
<tr>
<td>NYSDOT Bridge Manual - Section 4</td>
<td>95</td>
</tr>
</tbody>
</table>
Introduction

- The majority of our projects will be rehabilitation or reconstruction of existing structures.
- The high traffic volumes on most of our roads preclude complete closure of the structure.
- Staged construction techniques are used on the majority of our projects.
- Excavation support is therefore an essential and integral component of most our projects.

Course Objectives

- Describe the common types of excavation protection systems used on NYSDOT projects.
- Cover the basic theory behind the NYSDOT design of excavation protection systems.
- Describe the typical applications and limitations of said systems.
- Discuss how we plan and layout these systems.
- Discuss how these systems are detailed in our contract plans.

Common Excavation Support Systems

- Cantilever Sheeting Wall
- Anchored Sheeting Wall
- Cantilever H-pile or Soldier Pile Wall with Lagging
- Anchored H-pile or Soldier Pile Wall with Lagging
- Braced Sheeting/H-pile Wall or Cofferdam

Course References

- GDP-11 Geotechnical Design Procedures for Flexible Wall Systems, Revision #3, April 2007
- NAVEAC DM-7.2 Foundation and Earth Structures.

NYSDOT Bridge Manual

Chapter 4:

- The department’s responsibility in designing excavations is to provide support of the roadway and adjacent structures and utilities. The contractor’s responsibility in performing excavations is to provide protection for the workers from cave-ins.
NYSDOT Bridge Manual

Protection for employees working in an excavation shall be provided except when:

- The excavation is made entirely in stable rock; or
- The excavation is less than 5 feet deep and an examination of the ground by a competent person gives no indication of a potential cave-in.

For excavation depths from 5 to 20 feet, one of the following shall be used:

1. If there are no encumbrance with elements which would require support (traffic lane, utilities, structures, etc.), a safe slope (typically 1V on 1.5H) should be detailed.

2. If there is interference within a safe slope but vibrations are minor and repairable subsidence is not considered a problem, and there is no interference at least 10 ft. from edge of excavation, then a steeper slope up to 1V on 1H may be used, if approved by the Regional Geotechnical Engineer or the Geotechnical Engineering Bureau.

3. If 1 or 2 cannot be satisfied, an appropriate support system is required and shall be designed and detailed on the contract drawings.

For excavations greater than 20 feet, a support system or slope lay back must be site specifically designed and detailed on the contract plans.
Soil Parameter Determination

• Subsurface Exploration
  - Borings
  - Test Pits
  - In-situ Testing (Cone Penetrometer, Field Vane Shear, etc.)

• Regional Geotechnical Engineer

• Geotechnical Engineering Bureau
  (Foundation Design Report)
**Typical Values for Common Soil Types**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>( \phi ) Friction Angle (Degrees)</th>
<th>( \gamma ) Unit Weight (pcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SILT</td>
<td>28 - 30</td>
<td>110 - 130</td>
</tr>
<tr>
<td>SAND</td>
<td>30 - 32</td>
<td>110 - 130</td>
</tr>
<tr>
<td>GRAVEL</td>
<td>32 - 34</td>
<td>120 - 140</td>
</tr>
<tr>
<td>CLAY (drained condition)</td>
<td>22 - 26</td>
<td>110 - 120</td>
</tr>
<tr>
<td>ORGANIC</td>
<td>Consult GEB</td>
<td>Consult GEB</td>
</tr>
</tbody>
</table>

**Groundwater**

- Groundwater elevation determination
  - Hydrostatic Force
  - Submerged Unit Weights

- Based on groundwater elevations on drill logs or nearby bodies of water

**Soil Parameters in Plans**

NYSDOT typically recommends using:

Wall Friction \( = 0 \)

Cohesion \( = 0 \) (Drained Condition)

Using wall friction or cohesion in the design of excavation support systems results in un-conservative designs.

**Total Vertical Pressure**

\[
\sigma_V = \gamma z
\]

\( \gamma = \text{Soil Unit Weight} \)

\( z = \text{depth} \)

Total Vertical Pressure at Point \( O = \sigma_V = z \gamma \)
Pore Water Pressure (Neutral Pressure)

Neutral Pressure at Point O = \( u = u_H = u_V = z_W \gamma_W \)

Effective Stress Principle

Effective Vertical Stress:

\[
\bar{\sigma}_V = \sigma_V - u
\]

Where:

\( \sigma_V = z \gamma \)
\( u = z_W \gamma_W \)

So:

\[
\bar{\sigma}_V = z \gamma - z_W \gamma_W
\]

Effective Stress Principle 2

Effective Stress at Point O = \( \bar{\sigma}_V = z \gamma - z_W \gamma_W \)

Effective Stress Principle - Example

Given:

\( \gamma = 120 \text{ pcf} \)
\( \gamma_w = 62.4 \text{ pcf} \)

Find: Effective Stress at Point O

Rankine Earth Pressures

Assumes:

- The wall is smooth (no wall friction)
- Vertical wall
- Failure occurs in the form of a sliding wedge along an assumed failure plane defined as a function of the soil’s \( \phi \) angle
Rankine’s Active State

$K_A = \tan^2(45° - \phi/2)$, $F_A = \frac{1}{2} K_A \gamma H^2$

Rankine’s Passive State

$K_p = \tan^2(45° + \phi/2)$, $F_p = \frac{1}{2} K_p \gamma H^2$

Coefficient of Active Earth Pressure

$$K_A = \cos \beta \frac{\cos \beta - \sqrt{(\cos^2 \beta - \cos^2 \phi)}}{\cos \beta + \sqrt{(\cos^2 \beta - \cos^2 \phi)}}$$

Where:
- $\beta = $ Backfill slope angle
- $\phi = $ Soil angle of internal friction

Coefficient of Passive Earth Pressure

$$K_p = \cos \beta \frac{\cos \beta + \sqrt{(\cos^2 \beta - \cos^2 \phi)}}{\cos \beta - \sqrt{(\cos^2 \beta - \cos^2 \phi)}}$$

Where:
- $\beta = $ Backfill slope angle
- $\phi = $ Soil angle of internal friction

Earth Pressure Coefficients – Level Backfill

If the backfill surface is level, angle $\beta$ is 0 and $K_A$ and $K_p$ revert to:

$$K_A = (1 - \sin \phi) / (1 + \sin \phi) = \tan^2(45° - \phi/2)$$

$$K_p = (1 + \sin \phi) / (1 - \sin \phi) = \tan^2(45° + \phi/2)$$

Submerged Level Backfill
Submerged Backfill – Active Forces

\[ \frac{1}{2} K_A \gamma' H^2 + \frac{1}{2} \gamma_w H^2 = F_A \]

Active Earth + Hydrostatic = Total Active Force

Where \( \gamma' = \text{Submerged soil unit weight} = \gamma - \gamma_w \)

Submerged Backfill – Passive Forces

\[ \frac{1}{2} K_P \gamma' H^2 + \frac{1}{2} \gamma_w H^2 = F_P \]

Passive Earth + Hydrostatic = Total Passive Force

Where \( \gamma' = \text{Submerged soil unit weight} = \gamma - \gamma_w \)

Question

\[ H = 20 \text{ ft} \]

\[ \gamma = 120 \text{ pcf} \]

\[ \gamma' = 120 - 62.4 = 57.6 \text{ pcf} \]

\[ \phi = 30^\circ \]

\[ K_A = 0.33 \]

\[ K_P = 3.0 \]

Calculate active and passive forces with and without water in the backfill.

Example - Solution

Active forces without water:

\[ F_A = \]

Active forces with water:

\[ F_A = \]

\[ = \]

Passive forces without water:

\[ F_P = \]

Passive forces with water:

\[ F_P = \]

\[ = \]

\[ = \]

Rankine Theory vs. Coulomb

- Developed nearly a century before Rankine

Assumes:
- Failure occurs in the form of a wedge
- Friction occurs between the wall and the soil (\( \delta \))
- Wall does not have to be vertical (\( \alpha \))

In the case of a smooth (\( \delta = 0 \)), vertical wall (\( \alpha = 90^\circ \)) with level backfill (\( \beta = 0 \)), Coulomb reduces to Rankine
NYSDOT LRFD Wall Policy

NYSDOT current policy for flexible walls is to continue to design temporary walls using ASD methods and to design permanent walls using LRFD methods.

Questions

1. A typical friction angle for a silty sand would be:
   a. 15 degrees
   b. 30 degrees
   c. 45 degrees
   d. 60 degrees

2. The effective vertical stress at a depth of 10 ft with the water table at the ground surface and a total unit weight of 120 pcf is about:
   a. 100 psf
   b. 200 psf
   c. 600 psf
   d. 1200 psf

Cantilevered Sheeting

• Steel is the most common sheeting material.

• Sheets are driven to a depth sufficient for the passive pressure exerted on the embedded portion to resist the lateral active earth pressures acting on the cantilevered section.
### Cantilevered Sheeting - Continued

* In order to achieve the required resistance from the passive earth pressure, embedment depths can be quite high (rule of thumb is 2 to 1 embedment vs. exposed height ratio).
* Usually restricted to a maximum height of 15 ft.

### Cantilevered Sheeting - Advantages

* Quick, 1 Step installation process
* Readily available installation equipment – typically a vibratory hammer
* Minimal footprint - width of sheeting
* Fairly impervious to water
* Sheet ing can be pulled and re-used when excavation is backfilled

### Cantilevered Sheeting - Disadvantages

* Since sheeting is installed in full length pieces, a high overhead clearance is necessary
* Will not penetrate compact soil layers (over 50 SPT blows)
* Sheet ing will “hang up” or be crushed by boulders

### Disadvantages - continued

* Medium compact (SPT blows between 30 and 50) soil layers can impede or halt installation depending on soil type
* Deflection at the top of cantilevered sheeting can be substantial (inches), which can be a concern when supporting sensitive structures
Cantilevered Sheeting
The Simplified Method

- The simplified method assumes that a concentrated load is applied at the bottom of the sheeting replacing the passive resistance developed on the back of the sheeting.

- Not as accurate as the Conventional Method, but saves greatly in computations.
The Simplified Method

The design of sheet pile retaining walls requires the determination of:

- a) the lateral pressures that act on the wall
- b) the depth of pile embedment
- c) the maximum bending moment
- d) the section modulus required of the sheeting

See GDP-11 for a Simplified Analysis example.

Steps 1 and 2

Step 1 - Determine the Soil Profile and Soil Parameters.

Step 2 - Calculate the lateral earth pressure coefficients using either the Rankine or Coulomb Theory. In most cases, the wall friction (δ) is assumed to be zero. For the conditions of this example (vertical wall, level backfill, no wall friction), the Rankine and Coulomb active and passive pressure coefficients will be equal.

Step 3

Step 3 - Develop Lateral Earth Pressure Diagram (see Fig. 1)

A. Lateral pressure due to uniform surcharge:
   The lateral pressure (p_s) due to the uniform surcharge (q) is given by the uniform surcharge (q) times the coefficient of lateral earth pressure (K)
   \[ p_s = K q \]

B. Lateral earth pressures due to overburden:
   Lateral earth pressure due to the soil at any depth is obtained by multiplying the vertical soil pressure (p_v or p_o) at that depth by the coefficient of lateral earth pressure (K)
   \[ p_h = K p_v \]

C. Lateral pressure due to water (Hydrostatic Pressure):
   The hydrostatic pressure is given by multiplying the unit weight of the water (γ_w) times the water head (h_w).
   \[ p_w = \gamma_w h_w \]

Figure 1

Steps 4 and 5

Step 4 - Calculate the resultant forces, acting on one lineal foot of the wall, are shown in Figure 2.

Step 5 - Calculate the depth of embedment (d) by summing moments about the point of rotation (0) (assumed bottom of sheeting). (See Figure 2).

Solve for d.
Figure 2

Step 6

Step 6 - Determine the final depth of embedment (D) as follows:

\[ D = 1.2d \]

20\% of the calculated embedment (d) is added onto account for differences between the simplified and the conventional methods of analysis. This is not a factor of safety.

Steps 7 and 8

Step 7 - Determine the point of zero shear (s) by summing all the horizontal forces to the depth which satisfies \( \Sigma F_H = 0 \). (See Figure 3).

Solve for s.

Step 8 - Calculate the maximum moment by summing the moments at the point of zero shear. Since the sheeting is assumed to be pinned at the base, only the moments due to the forces above the point of zero shear should be used in determining the maximum moments.

Figure 3

Step 9

Step 9 - The minimum section modulus of the sheeting can then be determined using:

\[ S_{\text{MIN}} = \frac{M_{\text{MAX}}}{\sigma_{\text{ALL}}} \]

Where: \( M_{\text{MAX}} = \) maximum moment (from Step 9)

\( \sigma_{\text{ALL}} = \) allowable bending stress of the sheeting material, is typically taken as 25 ksi for carbon steel type ASTM - Designation A328
Step 10

Step 10 - Select a piling with a section modulus (per lin. ft. of wall) equal to or greater than the section modulus calculated in Step 9.

NOTE: The above analysis has no factor of safety. To provide for a factor of safety the passive pressure may be reduced by an appropriate factor, i.e.

\[ K_p/1.25 \] for temporary walls  
\[ K_p/1.50 \] for permanent walls

Item Numbers

Item 552.13 - Temporary Sheeting  
Sheeting is removed when the excavation is backfilled.

Item 552.15 - Interim Sheeting  
Sheeting is cut off and left in place when the excavation is backfilled.

Temporary vs. Interim Sheeting

Reasons to leave sheeting in place include:

- Pulling the sheeting may leave voids (usually in a clayey soil, where the soil will adhere to the sheeting).
- Sheet ing is adjacent to a structure and pulling may cause structural damage. Typically this occurs when the adjacent structure is founded on spread footings and pulling sheeting with a vibratory hammer could densify the soil causing settlement.

Detailing

As per the NYSDOT Bridge Manual, the following information should be shown on the contract plans:

- Plan location of the sheeting placement
- Typical section(s) showing:
  - Top and toe sheeting elevations
  - Bottom of excavation elevation
  - Minimum sheeting embedment below bottom of excavation
  - Payment lines
- Minimum sheeting section modulus
- Table showing the soil parameters used in the design

BD-EE15E

BD-EE16E
Questions

1. Sheeting cannot be driven when the following are present:
   a. Shallow rock
   b. Boulders
   c. Buried substructures
   d. All of the above

2. When designing flexible cantilevered retaining walls, using the simplified method, a factor of 1.2 is generally applied to the pile embedment length to:
   a. Equate the results with the conventional design method
   b. Provide a safety factor
   c. Support the steel industry
   d. Equate ASD and LRFD design methods

Questions

3. To determine the required length of sheeting in a cantilevered sheet pile wall, sum moments about:
   a. The pile top
   b. The anchor
   c. The pile tip
   d. The dredge line

Anchored Sheeting

The anchored sheet pile walls derive their support by two means:

1. Passive pressure on the front of the embedded portion of the wall and;
2. Anchor tie rod near the top of the piling.

- These walls are suitable for heights up to about 30 ft.
Anchored Sheeting - Advantages

- Can support much higher excavations than cantilevered sheeting with much less embedment
- Readily available installation equipment – typically a vibratory hammer and trenching equipment (unless anchors are used)
- Fairly impervious to water

Advantages - Continued

- Sheet can be pulled and re-used when excavation is backfilled
- Deflections at the top of anchored sheeting are generally small

Anchored Sheeting - Disadvantages

- Will not penetrate compact soil layers (over 50 SPT blows)
- Sheet will often “hang up” or be crushed by boulders
- Wider footprint than cantilevered sheeting because of wale/tieback assembly

Disadvantages - continued

- Tiebacks/wale assembly will need to be “flipped” for stage 2 excavation
- More ROW required for placement of anchors or deadman
Anchored Sheeting

Anchorage Types

- Continuous Sheeting Deadman
- Concrete Block
- Steel Plate Deadman
- Earth/Rock Anchors

Free Earth Support Method

- The Free Earth method assumes that the wall is rigid and rotates about the anchor level.

Free Earth Support Method

- The design of an anchored sheet pile retaining wall includes calculation of the following:
  a) the required depth of embedment
  b) the anchor load
  c) the section modulus of the sheet piles
  d) the deadman or earth or rock anchor

See GDP-11 for a Free Earth Support Method example.

Steps 1 through 4

Steps 1 - 4 - Are the same as for cantilevered walls in the previous section and as shown in Figures 5 and 6.
**Step 5**

Step 5 - Calculate the resultant of the active forces \( R_A \) and the point of application \( z \) from the top of the wall (See Figure 6).

Determine the moment arm length \( 'z' \) by summing moments about the pile top.

**Step 6**

Step 6 - Determine the depth of embedment \( d \), and the final total embedment \( D \) by summing the moments about the anchor and solving for \( d \).

There is no correction for using a simplified form of the analysis (unlike in the cantilever design), so \( d = D \).

A safety factor is provided by reducing the passive pressure by an appropriate factor, i.e.

\[
K_p/1.25 \quad \text{for temporary wall} \\
K_p/1.5 \quad \text{for permanent wall}
\]

**Step 7**

Step 7 - Calculate the anchor load by setting all the horizontal forces equal to zero.

Solve for \( A_L \).

The final design anchor load \( A_{DL} \) is obtained by:

\[
A_{DL} = 1.5A_L
\]

Remember, \( A_{DL} \) is per lineal foot of wall. To finalize the type and the size of the anchor, this load has to be multiplied by the anchor spacing.

**Step 8**

Step 8 - Calculate the depth of zero shear \( s \) and the maximum moment on the sheeting (see Fig. 7).

Solve for \( s \). In Figure 7, \( s \) is assumed above the bottom of excavation.

If \( s \) occurs beneath the bottom of excavation, the above equation for \( \Sigma F_H = 0 \) must be expanded accordingly to include lower shear forces.

The maximum moment is then obtained by summing moments about the point of zero shear from the top of the pile to depth \( s \).
Step 9 - The minimum required section modulus (SMIN) of the sheeting can then be determined by the following:

$$SMIN = \frac{MAX}{\sigma_{ALL}}$$

Where:
- $MAX$ = maximum moment (from Step 9)
- $\sigma_{ALL}$ = allowable bending stress of the sheeting material, typically taken as 25 ksi for carbon steel type ASTM - Designation A328

Select a piling with a section modulus (per lineal foot of wall) equal to or greater than the section modulus calculated.

Note: The above analysis has no factor of safety. To provide for a factor of safety the passive pressure may be reduced by an appropriate factor, i.e.

- $K_P/1.25$ for temporary wall
- $K_P/1.50$ for permanent wall.

Step 10 - Deadman Design

A deadman may consist of driven H-piles, large masses of concrete or a continuous sheet pile wall. The following procedure is for the design of a continuous sheet pile wall as deadman. No surcharge loads are assumed to act on the deadman.

Determine the active and passive pressures and forces per lineal foot of wall. (See Figure 8).

Step 11 - Determine the required depth of embedment ($y$) by summing moments about the bottom of the deadman. For the moment due to the anchor load, use the final design anchor load.

Solve for $y$.

If $y$ is excessive, repeat the above procedure assuming a lower anchor point of attachment.

Step 11 - Continued

If $A_1$ is used instead of $A_{DL}$, to provide a safety factor, the passive pressure should be reduced by an appropriate factor, i.e.

- $K_P/1.25$ for temporary wall
- $K_P/1.5$ for permanent wall

A comparison between the two methods described above and the confidence of the designer in his analysis may help in finalizing the required depth of embedment for the deadman. If $A_{DL}$ is used, no other safety factors should be applied to the deadman embedment.
Step 12

Step 12 - Determine the required section modulus of the deadman sheeting by finding the depth of zero shear ($s_d$) where the sum of all the horizontal forces are equal to zero (see Figure 9).

The maximum moment is found by summing the moments about the zero shear point considering forces between the top of the deadman and depth $s_d$.

Figure 9

Step 12 - Continued

The minimum required section modulus ($S$) is given by:

$$S_{MIN} = \frac{M_{MAX}}{\sigma_{ALL}}$$

$M_{MAX}$ = the maximum moment

$\sigma_{ALL}$ = the allowable bending stress of the sheeting material

Select a piling with a section modulus (per lineal foot of wall) equal to or greater than the section modulus calculated.

Step 13

Step 13 - A minimum distance is required between the wall and the deadman to fully mobilize the available deadman resistance outside the active zone of the wall. This distance can be found graphically and analytically as shown in Figs. 10 and 10a.

Figure 10 – Location Requirements for a Deadman

Single Soil Layer

A—— B—— C

$\alpha = 45^\circ - \phi/2$  $AB = L_W \tan \alpha$

$\beta = 45^\circ + \phi/2$  $BC = L_D \tan \beta$

$L_W$ = Wall Length

$L_D$ = Deadman Length

Minimum Distance Between Wall and Deadman

= $L_W \tan (45^\circ - \phi/2) + L_D \tan (45^\circ + \phi/2)$

Figure 10a – Location Requirements for an Earth Anchor

Single Soil Layer

A—— B

$\alpha = \tan (45^\circ - \phi/2)$  $L_W$ = Sheeting Length

$\beta$ = Anchor Inclination (typically 15° to 30° in soil)

= $L_W$  $\beta$ = 15 ft min.

= $5$ ft

= Free Length  |  Bond Length
**Item Numbers**

- Item 552.13 - Temporary Sheeting
- Item 552.15 - Interim Sheeting
- Item 211.10 – Grouted Tiebacks (Temporary)
- Item 211.11 – Grouted Tiebacks (Permanent)
- Item 203.1756 – Steel Ties (Temporary)
- Item 203.1757 – Steel Ties (Permanent)

Wales and braces are typically paid for under the sheeting items.

**Detailing**

As per the NYSDOT Bridge Manual, the following information should be shown on the contract plans:

- Plan location of the sheeting placement
- Typical section(s) showing:
  - Top and toe sheeting elevations
  - Bottom of excavation elevation
  - Minimum sheeting embedment below bottom of excavation
  - Payment lines
  - Location of wales or bracing
  - Location of tiebacks or deadman

**Detailing - Continued**

- Minimum sheeting section modulus
- Minimum section modulus of wales and/or size of bracing
- Minimum section modulus of deadman, if applicable
- Table showing the soil parameters used in the design

**Example**

BD-EE12E

Example
Questions

1. NYSDOT’s preferred anchored wall design method is:
   a. Equivalent beam method
   b. Finite element analysis
   c. Fixed earth support method
   d. Free earth support method

2. An anchored sheeting wall derives its support:
   a. From passive earth pressure only
   b. From the active earth pressure
   c. From hydrostatic forces
   d. From passive earth pressure and the anchor

3. To determine the required length of sheeting in an anchored sheeting wall, sum moments about:
   a. The pile top
   b. The anchor
   c. The pile tip
   d. The dredge line
Soldier Pile and Lagging Walls

Soldier Pile and Lagging

- This method of support involves the driving of steel H-piles or sections into the ground and placing lagging between the pile's flanges.
- Wood lagging is most common but steel or concrete lagging may also be used.
- If obstructions or rock is present, the piles are installed in pre-augered holes and can be concreted or backfilled with granular material to dredge line elevation.

Cantilevered Soldier Pile and Lagging

- This type of wall is designed so that the passive resistance on the embedded portion of the pile, counteracts the active pressure acting on the cantilevered section of the wall.
- Cantilevered soldier pile walls are usually practical for excavations up to 20 feet in height.

Anchored Soldier Pile and Lagging

- Same installation techniques as cantilevered soldier pile and lagging walls.
- Anchored soldier pile walls derive their support by two means:
  1. Passive resistance in front of the embedded section of the piles.
  2. Anchor forces near the top of the wall.
- Can be used to support walls up to 40 feet.

Soldier Pile and Lagging - Advantages

- Can support higher excavations than driven sheeting
- When pre-augered holes are used, soldier pile walls can be installed in very compact soils, bouldery soils, and in rock

Soldier Pile and Lagging - Disadvantages

- Much more expensive than sheeting
- Installation requires multiple steps (drilling, placing piles, concreting, placing lagging)
- Soldier pile walls are not impervious to water
Anchored Wall – Disadvantages

- Wider footprint than cantilevered walls because of wale/tieback assembly
- Tiebacks/wale assembly will need to be “flipped” for stage 2 excavation
- More ROW required for placement of anchors or deadman
Soldier Pile and Lagging Walls
Typical Soldier Pile Sections

Driven vs. Preaugered Piles

- Boulders/Obstructions (shallow rock)
- Noise
- Vibration Control
- Alignment (permanent walls)
- Preaugered piles will require a little less embedment
- Preaugered piles are generally more expensive than driven piles

Design Methods

- Cantilevered Soldier Pile Walls
  - Simplified Method
- Anchored Soldier Pile Walls
  - Free Earth Support Method

Brom’s Theory

- Failure was defined in two ways: the development of a plastic hinge in the pile; or for a short pile, an unlimited deflection.
- Pile head is assumed to be either fixed or free to rotate.
- Brom’s assumed that the ultimate lateral resistance is equal to three times the Rankine passive pressure.

Graphical Representation of the Passive Resistance Wedge

Soldier Pile Wall Design Schematic
Warning

The pile flange width (W) or the diameter of the preaugered hole for the installation of the H-piles cannot be greater than one-third of the pile spacing (S) in the design calculations, i.e.:

\[ W \leq S/3 \]

Soldier Pile and Lagging Walls

Soldier Pile Wall Design

• The design of a soldier pile and lagging wall involves determination of:

  1) depth of embedment of the soldier pile
  2) the minimum required section modulus of the soldier piles
  3) thickness of wooden lagging, section modulus of steel lagging or moment distribution for concrete lagging

Soldier Pile Wall Design - Continued

• For anchored walls, the following additional items need to be determined:

  4) the wales
  5) the deadman or earth and rock anchor
  6) the location of the deadman with respect to the wall it supports

Timber Lagging Design

Deadman Design

A deadman may consist of soldier piles, large masses of concrete or a continuous sheet pile wall.

Location Requirements for a Deadman

\[ \begin{align*}
\alpha &= 45^\circ + \phi/2 \\
\beta &= 45^\circ - \phi/2 \\
L_D &= \text{Deadman Length} \\
L_W &= \text{Wall Length (in case of soldier pile walls, equal to exposed height H + 0.1H)} \\
L_{\text{min}} &= \text{Minimum Distance Between Wall and Deadman} \\
\text{Minimum Distance Between } ABC &= \frac{L_W}{2} \tan \alpha + L_D \tan \beta \\
\end{align*} \]
Location Requirements for an Earth Anchor

<table>
<thead>
<tr>
<th>Single Soil Layer</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15 ft min.</td>
<td>5 ft</td>
</tr>
</tbody>
</table>

\[
\alpha = \tan (45° - \frac{\phi}{2}) \\
\beta = \text{Anchor Inclination (typically 15° to 30° in soil)} \\
L_W = 1.1 \times H \text{ (exposed wall height)}
\]

Rock Socketed Soldier Pile Wall Design

- Pressures and forces are determined as normal for the type of wall
- The design moment at the top of rock surface is determined from moment diagram, with the variability of rock surface being taken into account
- A geologist evaluates the rock cores and determines a socket depth based on rock quality, design moment, pre-auger hole diameter, and soldier pile spacing

Item Numbers

- Item 552.20nn – Holes in Earth for Soldier Pile and Lagging Wall
- Item 552.21nn – Rock Sockets for Soldier Pile and Lagging Wall
- Item 552.22nn – Soldier Piles for Soldier Pile and Lagging Wall
- Item 552.2302nn – Untreated Wood Lagging for Soldier Pile and Lagging Wall
- Item 211.10 – Grouted Tiebacks (Temporary)
- Item 211.11 – Grouted Tiebacks (Permanent)
- Item 203.1756 – Steel Ties (Temporary)
- Item 203.1757 – Steel Ties (Permanent)

Wales and braces are typically paid for under the lagging item.

Detailing

The following information should be shown on the contract plans:
- Plan location of the soldier pile wall placement
- Table showing:
  - Pile station and offset (or coordinates)
  - Top and toe soldier pile elevations
  - Estimated pile length
  - Depth of excavation
  - Assumed rock elevation (if applicable)
  - Minimum rock socket (if applicable)
  - Minimum soldier pile section modulus
  - Recommended soldier pile shape
  - Minimum pre-auger hole diameter

Detailing - Continued

- Typical section(s) showing:
  - Payment lines
  - Location of wales or bracing (if applicable)
  - Location of tiebacks or deadman (if applicable)
  - Minimum section modulus of wales and/or size of bracing (if applicable)
  - Minimum section modulus of deadman (if applicable)
  - Table showing the soil parameters used in the design
Questions

3. Active earth force on sheeting is calculated per foot. Active force on a soldier pile wall above the dredge line is calculated per:
   a. Foot
   b. Pile width
   c. Pile width times Brom’s factor
   d. Pile spacing

4. The pile flange width or diameter of the preauger hole cannot be greater than the following for design purposes:
   a. 1/10th the pile spacing
   b. 1/3rd the pile spacing
   c. The pile spacing
   d. Three times the pile spacing
Braced Walls

- A braced wall is a retaining structure (usually temporary in nature) which is used to support the sides of deep excavations.
- A wall with more than one anchor or strut level is considered a braced wall.
- Virtually any wall height can be supported with a braced wall as long as you have something to brace against.

Braced Walls Continued

Braced Walls- Advantages

- Can support virtually any height excavation
- Can be designed with little to no penetration below bottom of excavation

Both walls are considered braced walls for design purposes.

Braced Walls- Disadvantages

- Usually a more expensive option than cantilevered or anchored walls
- Internal struts can get in the way of construction equipment or the structure being constructed
Braced Wall Design

- Trapezoidal earth pressure distribution is used.
- Results in less active force than traditional distributions (Rankine or Coulomb).
- Passive pressure forces are not used to support braced walls, braces take all loads.
Braced Wall Design

The design of braced walls requires the determination of:

- a) The lateral pressures that act on the wall
- b) The maximum bending moment in the wall
- d) The section modulus required of the wall
- e) The strut loads
- f) The wale loads

Steps 1 and 2

Step 1 - Determine the Soil Profile and Soil Parameters.

Step 2 - Plot lateral earth pressures.

Lateral Earth Pressures for Braced Walls

a. Earth pressure distributions:

Hydrostatic/Surcharge Pressures

b. If groundwater is present, add its pressure to the trapezoidal soil pressure (see (b) below):

c. If surcharge load is present, add the lateral component of the surcharge load to the soil pressure distribution (see (c) below):

Structural Analysis

The wall may be designed either as a continuous beam supported at the strut levels, or by assuming that pins exist at each strut, (except the top and bottom struts), thereby making each span statically determinate. Although it is slightly more conservative, in order to simplify the analysis, the following procedure assumes that the wall acts as a simply supported beam with pins at each strut.

Structural Analysis Continued

[Diagram of moment diagram]
Structural Analysis Continued

If the sheeting/piles are embedded at least 4 feet below the bottom of excavation, it is customary to assume a support at the bottom of the excavation.

Step 3 – Wall Design

Step 3

a. Determine the maximum bending moment and required embedment depth of the sheeting/piles for each stage of excavation using cantilevered and anchored analyses methods for Stage I and II and by braced wall design methods for Stage III to the final stage.

4 ft min.

b. Determine the maximum bending moment in sheeting/piles between wales for the final stage. The maximum bending moment per foot of width along the sheeting may be computed using:

\[ M_{\text{MAX}} = \frac{1}{8} wL^2 \] (between struts)
\[ = \frac{1}{2} wL_1^2 \] (about top and bottom strut)

- \( w \) = average lateral pressure on the wall over the longest span
- \( L \) = distance between wales
- \( L_1 \) = distance between top of excavation and first strut
- \( L_2 \) = distance between bottom strut and excavation line

The vertical spacing between the struts may be reduced if the moments in the wall are too large.

c. The minimum required section modulus of the sheeting/piles can then be determined using:

\[ S_{\text{MIN}} = \frac{M_{\text{MAX}}}{\sigma_{\text{ALL}}} \]

- \( M_{\text{MAX}} \) = maximum moment calculated from either step 3(a) or 3(b)
- \( \sigma_{\text{ALL}} \) = allowable bending stress of sheeting material
  - 25 KSI for A328 Steel Sheet Piling
  - 30 KSI for Steel H-Pile (A50)
  - 1.2 KSI for Wood

The section modulus may be reduced if the moments in the wall are too large.

d. Select a sheeting/pile section with a section modulus equal to or greater than the section modulus calculated in Step 3(c).

e. Check for bottom heave or piping conditions using Figures 1 and 2. If bottom heave or piping conditions exist, consideration should be given for alternative methods of excavations.

Note that soldier piles will not affect piping conditions and should not be used if there is potential for piping.

Figure 1

Stability Against Heave in Cohesive Soils
(After NAVFAC DM-7, 1971)
**Step 4 Continued**

c. Multiply the axial strut load per linear foot of wall by the horizontal strut spacing and a factor of safety of 1.5 to get the design strut loads.

d. If the axial loads per strut are not within acceptable limits, adjust the strut spacing and re-analyze the system.

**Step 5**

Step 5 - Determine the maximum bending moment generated within the wale as follows:

\[ M_{\text{MAX}} = \frac{1}{8} \cdot w \cdot L^2 \]

where:
- \( w \) = axial strut load per lin. ft. (from Step 4b)
- \( L \) = horizontal distance between struts

**Item Numbers**

- Item 552.13 - Temporary Sheeting
- Item 552.15 - Interim Sheeting
- Item 552.20mn – Holes in Earth for Soldier Pile and Lagging Wall
- Item 552.21nn – Rock Sockets for Soldier Pile and Lagging Wall
- Item 552.22nn – Soldier Piles for Soldier Pile and Lagging Wall
- Item 552.2302nn – Untreated Wood Lagging for Soldier Pile and Lagging Wall
- Item 211.10 – Grouted Tiebacks (Temporary)
- Item 211.11 – Grouted Tiebacks (Permanent)
- Item 203.1756 – Steel Ties (Temporary)
- Item 203.1757 – Steel Ties (Permanent)

Wales and braces are typically paid for under the lagging item.
**Braced Walls**

**Detailing**
Show the appropriate information on the contract plans as described in the anchored sheeting/anchored soldier pile sections.

Refer to the following BD sheets:
- BD-EE10E – Excavation and Embankment Braced Excavation Details
- BD-EE11E – Excavation and Embankment Soldier Pile and Lagging Wall Sample Details
- BD-EE12E – Excavation and Embankment Tieback Wall Details
- BD-EE15E – Excavation and Embankment Sample Drawing of Stage Construction (1 of 2)
- BD-EE16E – Excavation and Embankment Sample Drawing of Stage Construction (2 of 2)

**Questions**

1. A braced wall must always:
   a. Have one level of bracing/anchors
   b. Have 2 or more levels of bracing/anchors
   c. Have a minimum of 3 levels of bracing/anchors
   d. Be braced against a wall on the opposite side of the excavation

2. Braced walls may utilize:
   a. Steel struts
   b. Timber struts
   c. Grouted soil anchors
   d. All of the above

3. Since braced sheeting walls have generally small embeddings, additional design concerns are:
   a. Piping and heaving
   b. Bearing and rotating
   c. Sliding and eccentricity
   d. All of the above

4. In design of a braced wall, lateral active earth forces are calculated with:
   a. Triangular pressure distributions
   b. Circular pressure distributions
   c. Trapezoidal or rectangular pressure distributions
   d. None of the above
GEOTECHNICAL DESIGN PROCEDURE
FOR FLEXIBLE WALL SYSTEMS

NEW YORK STATE DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL DESIGN PROCEDURE:
GEOTECHNICAL DESIGN PROCEDURE FOR FLEXIBLE WALL SYSTEMS

GDP-11
Revision #3

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL ENGINEERING BUREAU

APRIL 2007
# TABLE OF CONTENTS

I. INTRODUCTION ......................................................................................................................4  
   A. Purpose ...........................................................................................................................4  
   B. General Discussion ........................................................................................................4  
   C. Soil Parameters ..............................................................................................................4  

II. DESIGN PREMISE ...................................................................................................................5  
   A. Lateral Earth Pressures ...................................................................................................5  
   B. Factor of Safety ..............................................................................................................8  

III. FLEXIBLE CANTILEVERED WALLS ...................................................................................9  
   A. General ...........................................................................................................................9  
   B. Analysis ..........................................................................................................................9  
   C. Constructionability .......................................................................................................10  

IV. FLEXIBLE ANCHORED WALLS .........................................................................................11  
   A. General .........................................................................................................................11  
   B. Analysis ........................................................................................................................11  
      1. Single Row of Anchors ....................................................................................11  
      2. Multiple Rows of Anchors ...............................................................................12  
   C. Anchor Types ...............................................................................................................12  
   D. Constructability ............................................................................................................13  

V. REVIEW REQUIREMENTS ..................................................................................................16  
   A. General .........................................................................................................................16  
   B. Flexible Cantilevered Walls .........................................................................................16  
   C. Flexible Anchored Walls .............................................................................................16  

REFERENCES ..............................................................................................................................18  

APPENDICIES ..............................................................................................................................19  
   A. Earth Pressures ..............................................................................................................A-1  
      Surcharge Loads ...........................................................................................................A-1  
      Hydrostatic Loads ....................................................................................................A-1  
      Inclined Backfill .........................................................................................................A-2  
      Inclined Foreslope ....................................................................................................A-3  
      Railroad Embankment Zones and Excavation Limits ............................................A-4  
   B. Recommended Thickness of Wood Lagging .............................................................B-1  
   C. Earth Pressures for Braced Excavation .................................................................C-1  
      Deadman Pressure Distribution & Location Requirements ............................C-2
D. Design Guidelines ................................................................................................................................. D-1
   For Use of the Soldier Pile and Lagging Wall Specifications ............................................................. D-1
   For Selecting a Soldier Pile Section for a Soldier Pile and Lagging Wall with Rock Sockets .......................................................................................................................... D-5
   For Use of the Sheeting and Excavation Protection System Specifications ....................................... D-11
   For Use of the Grouted Tieback Specifications ....................................................................................... D-11
   For Use of the Steel Ties Specifications ................................................................................................. D-12
E. Example Problems ................................................................................................................................. E-1
   Cantilevered Sheeting Wall (US Customary Units) ............................................................................... E-1
   Anchored Sheeting Wall (US Customary Units) ..................................................................................... E-3
F. Example Problems ................................................................................................................................. F-1
   Cantilevered Sheeting Wall (International System of Units) ............................................................... F-1
   Anchored Sheeting Wall (International System of Units) ................................................................. F-3
I. INTRODUCTION

A. Purpose
The purpose of this document is to provide an acceptable design method and theory for the
groundtechnical design of flexible cantilevered or anchored retaining walls to be constructed on New
York State Department of Transportation projects.

The following text provides a general discussion and design guidelines for these flexible wall
systems. This document provides any designer with a framework for progressing a design and an
understanding of the criteria which can be used during a geotechnical review. All structural
aspects of these wall systems shall be performed in accordance with the Department’s accepted
procedures.

B. General Discussion
Flexible cantilevered or anchored retaining walls are defined in this document to include
temporary or permanent flexible wall systems, or shoring systems, comprised of sheeting or
soldier piles and lagging. An anchored system may include the aforementioned shoring systems
supported by grouted tieback anchors, anchors to a deadman, rakers to a foundation block or
braces or struts to an equivalent or existing wall system or structural element.

Sheeting members of a shoring system are structural units which, when connected one to another,
will form a continuous wall. The wall continuity is usually obtained by interlocking devices
formed as part of the manufactured product. In New York State, the majority of the sheeting used
is made of steel, with timber, vinyl, and concrete used less often.

Soldier piles used as part of a shoring system are structural units, or members, which are spaced
at set intervals. A lagging material is placed between the soldier piles to complete the shoring
system. In New York State, the majority of the soldier piles used are made of steel, with concrete
and timber used less often. The lagging material is usually dependent upon the design life of the
wall. A temporary wall will usually incorporate timber lagging, with steel sheeting as lagging
used less often. A permanent wall will usually incorporate concrete lagging with an architectural
finish.

C. Soil Parameters
Soil parameters are the design assumptions which characterize the soil type. Typically, designs
are progressed using effective stress parameters to account for long-term stability of the flexible
wall system. For projects in design, the wall designer will be provided the soil parameters to use
in the design of the flexible wall system. For projects in construction, the soil and loading
parameters for the design of the detailed wall are as indicated in the contract plans. If a flexible
wall system is proposed in an area which soil parameters are not listed, the Contractor shall
contact the Engineer, who shall relay the request to the D.C.E.S.
II. DESIGN PREMISE

A. Lateral Earth Pressures

A flexible wall system design is required to resist the anticipated lateral pressures without undergoing significant or excessive lateral deflections. The following list provides an acceptable geotechnical theory for the development of the lateral earth pressures and potential external loads and soil backfill configurations which must be accounted for in design:

1. Earth Pressure Theory:

   Use the Rankine Theory for the development of earth pressures on a flexible wall system. This theory assumes that wall friction ($\delta$) equals zero.

2. Surcharge Loads:

   The term “surcharge” refers to an additional loading on the proposed wall system. This term usually refers to traffic loading that is in proximity to the wall system. Use the Spangler Method of analysis (area load of finite length) or Boussinesq Method of analysis to determine the lateral pressure caused by the surcharge loading. The uniform surcharge is usually given a value of 250 psf (12 kPa) or an equivalent height of fill. If the designer knows that heavier construction equipment will be in the vicinity of the wall, the surcharge loading shall be increased accordingly. A uniform surcharge of at least 250 psf (12 kPa) is always assumed at the top of a wall that has a level backfill. See Appendix Page A-1.

   For analysis of railroad loadings, refer to “6. Railroad Loading” of this Section.

3. Hydrostatic Pressure:

   The identification of the existing groundwater table is necessary to design for sufficient support against all possible loadings. Since the locks of sheeting are more or less watertight when installed and become more watertight as soil is drawn in, water can be trapped behind the wall causing a head imbalance and greatly increasing the total load. Therefore, the elevation, or head difference, shall be accounted for in design of the wall system. The hydrostatic head is the difference between the groundwater elevation and the bottom of dewatered excavation. See Appendix Page A-1.

4. Inclined Backfill:

   An inclined backfill will induce an additional load on the wall. See Appendix Page A-2. This situation shall be analyzed by the following:
Infinite Slope

If the backfill slope remains inclined beyond the limits of the active wedge, the backfill slope shall be assumed to extend infinitely away from the wall at an angle $\beta$. Using this condition, the Rankine earth pressure is a function of the angle $\beta$. To compute horizontal earth pressures, the resulting earth pressure must be adjusted by the backslope angle. Subsequent active earth forces are found using these adjusted earth pressures.

Finite Slope

If the backfill slope changes to horizontal within the limits of the active wedge of failure, the slope may be analyzed in two ways:

A The broken back slope design (A.R.E.A.) method may be used. This method is described in Section 5: Retaining Walls in the Standard Specifications for Highway Bridges, Adopted by the American Association of State Highway and Transportation Officials (A.A.S.H.T.O.), Seventeenth Edition.

B The sloping backfill may be assumed to be equivalent to a horizontal surcharge loading, located an offset of one-half the distance from the wall to the slope break. The surcharge loading shall be equivalent to the full height of the slope.

5. Inclined Foreslope:

An inclined foreslope, or slope in front of the wall system, will reduce the amount of passive resistance available to resist loadings. See Appendix Page A-3. This situation shall be analyzed by the following:

Infinite Slope

If the foreslope extends beyond the passive wedge, the foreslope shall be assumed to extend infinitely away from the wall at an angle $\beta$. Using this condition, the Rankine earth pressure is a function of the angle $\beta$. To compute horizontal earth pressures, the resulting earth pressure must be adjusted by the foreslope angle. Subsequent passive earth forces are found using these adjusted earth pressures.

Finite Slope

If the foreslope changes to horizontal within the limits of the passive wedge of failure, the slope shall be assumed to be finite. In this case, the slope may be analyzed in two ways:
A. Infinite slope as noted above.

B. An excavation to the bottom of the slope.

Engineering judgment shall then be applied when determining which solution to use.

Note in both the infinite and finite slope cases, if the angle $\beta$ is equal to or greater than the internal angle of friction of the soil, the excavation shall be assumed to extend down to the bottom of the slope.

6. **Railroad Loading:**

When the proposed excavation requires the support of railroad loads, the designer shall follow all current applicable railroad requirements. Embankment Zones and Excavation Restrictions are described in Chapter 23 of the Highway Design Manual. See Appendix Page A-4.

The system shall be designed to carry E-80 live load consisting of 80 kips axles spaced 5 ft. on centers (356 kN axles spaced 1.5 m on centers). A lower value load can be used if the railroad indicates, in writing, that the lower value is acceptable for the specific site. Use the Spangler Method of analysis (area load of infinite length) or the Boussinesq Method of analysis to determine the lateral pressure caused by the railroad loading. The load on the track shall be taken as a strip load with a width equal to the length of the ties (8 ft. 6 in.) (2.6 m). The vertical surcharge caused by each axle shall be equal to the axle weight divided by the tie length and the axle spacing.

7. **Cohesive Soil:**

Due to the variability of the length of time a shoring system is in place, cohesive soils shall be modeled in the drained condition. These soils shall be modeled as cohesiveless soils using the drained internal angle of friction. Typically, drained internal angles of friction for New York State clays range from $22^\circ$ to $26^\circ$ (undrained shear strength=0).
B. **Factor of Safety**

A factor of safety (F.S.) shall be applied to the coefficient of passive earth pressure (Kp). The value for the factor of safety is dependent on the design life of the wall (temporary or permanent). The passive pressure coefficients (Kp”) used in the design calculations shall be reduced as follows:

1. **Temporary Retaining Wall:**

   The factor of safety (F.S.) for a temporary wall is 1.25.
   \[ Kp’’ = \frac{Kp}{1.25}. \]

2. **Permanent Retaining Wall:**

   The factor of safety (F.S.) for a permanent wall is 1.50.
   \[ Kp’’ = \frac{Kp}{1.50}. \]
III. FLEXIBLE CANTILEVERED WALLS

A. **General**

Sheeting is driven to a depth sufficient for the passive pressure exerted on the embedded portion to resist the lateral active earth pressures acting on the cantilevered section. To achieve the required passive earth pressure resistance, embedment depths can often be quite high. Therefore, due to limitations on the availability of certain section modulus and its associated costs, cantilevered sheeting walls are usually practical to a maximum height of approximately 15 ft. (4.6 m).

Soldier piles of a soldier pile and lagging wall system are vertical structural elements spaced at set intervals, typically 6 ft. to 10 ft. (1.8 m to 3.0 m). A soldier pile and lagging wall also derives its resistance from the embedded portion of the wall but, because of the higher available section modulus, greater excavation depths can be supported as compared to those supported by sheeting. Cantilevered soldier piles are usually practical for excavations up to approximately 20 ft. (6 m) in height.

The minimum timber lagging thickness for a soldier pile and lagging wall should be determined from the table in Appendix B, taken from Lateral Support Systems and Underpinning, Vol. 1. Design and Construction, FHWA-RD-75128, April 1976.

Additional design guidance for sheeting and soldier pile and lagging walls is provided and/or referenced in Appendix D.

B. **Analysis**

Use either the Simplified Method or the Conventional Method for the design of a cantilevered sheeting wall. To account for the differences between the two methods, the calculated depth of embedment, obtained using the Simplified Method, shall be increased by 20%. This increase is not a factor of safety. The factor of safety shall be applied to the passive pressure coefficient as stated in “II. Design Premise: B. Factor of Safety”.

Use either the Simplified Method or the Conventional Method of analysis for the development of the lateral pressures on a soldier pile and lagging wall. However, as opposed to a sheeting wall which is analyzed per foot (meter) of wall, the calculations for the design of a soldier pile and lagging wall must account for the spacing of the individual soldier piles. To determine the active pressures above the dredgeline, include a factor equivalent to the spacing in the calculations. To determine the active pressures below the dredgeline, include a factor equivalent to the width of the soldier pile (for driven piles), or diameter of the hole (for piles installed in excavated holes) in the calculations. To determine the passive resistance of a soldier pile embedded in soil, assume that the net passive resistance is mobilized across a maximum of three times the soldier pile width (for driven piles), or three times the diameter of the hole (for piles installed in excavated holes).

C. **Constructability**

Prior to the analysis, the designer shall evaluate the site conditions and subsurface profile to determine which type of flexible wall system is appropriate. Subsurface profiles which include cobbles, boulders and/or very compact material are sites where sheeting is not recommended and the designer should investigate alternate wall systems such as soldier piles and lagging. The designer should also focus on the type and size of equipment that will be needed to install the wall members. The designer should contemplate the limits of the wall with respect to the existing site conditions and include the design of any necessary connections. These considerations are valid for both cantilevered and anchored wall systems.
IV. FLEXIBLE ANCHORED WALLS

A. General

When the height of excavation increases over 15 ft. (4.6 m), or if the embedment depth is limited (for example, the presence of boulders or bedrock), it becomes necessary to investigate the use of additional support for the wall system. An anchored wall derives its support by the passive pressure on the front of the embedded portion of the wall and the anchor tie rod near the top of the wall. Anchored walls are suitable for heights up to approximately 35 ft. (10.5 m).

An additional factor of safety of 1.5 shall be applied to all anchor and brace loads.

Each phase of construction of an anchored wall shall be analyzed. Each phase of construction affects the lateral earth pressures on the sheeting or soldier piles and therefore, the embedment and section modulus requirements. Ex.: Phase I: cantilever analysis (excavation to install first anchor), Phase II: anchored analysis (excavation below first anchor to install second anchor), Phase III: multiple anchor analysis (excavation below second anchor to install third anchor), etc...Final Phase: multiple anchor analysis.

Additional design guidance for grouted tiebacks and steel ties is provided and/or referenced in Appendix D.

B. Analysis

1. Single Row of Anchors:

   Use the Free Earth Support Method for the design of an anchored sheeting or soldier pile and lagging wall. The Free Earth Support Method assumes the wall is rigid and may rotate at the anchor level.

   For the design of an anchored soldier pile and lagging wall system, the design must account for the spacing of the individual soldier piles as stated in “III. Flexible Cantilevered Walls: B. Analysis”.

   The designer shall analyze the effect of any additional vertical or horizontal loads imposed on the soldier piles or sheeting by the angle (orientation with respect to the wall) of the anchor. The embedment of sheeting or H-piles (or other sections used as soldier piles) below the bottom of the excavation should be checked to ensure that it is sufficient to support the weight of the wall and the vertical component of the tieback force. The factor of safety should be at least 1.5 based on the design load, assuming resistance to the vertical load below the bottom of excavation only. Pile and sheeting bearing capacity should be calculated as shown in the manual on Design and Construction of Driven Pile Foundations, FHWA-HI-97-013, Rev. November 1998 with $P_d$ and $P_D$ equal to the values on the excavation side of the wall.
2. **Multiple Row of Anchors:**


When a rectangular or trapezoidal pressure distribution is used, all of this pressure has to be resisted by the anchors and by the bending resistance of the sheeting or H-piles. Do not consider active or passive earth pressure below the bottom of the excavation when calculating the required anchor loads, unless groundwater level is above the bottom of excavation. In that case, passive pressure may be used to help resist active earth pressure and excess hydrostatic pressure. Due consideration should be given to the effect of uplift on the passive pressure and to the amount of movement required to mobilize full passive pressure.

For the design of an anchored soldier pile and lagging wall system, the calculations shall account for the spacing of the individual soldier piles as stated in “III. Flexible Cantilevered Walls: B. Analysis”.

The designer shall analyze the effect of any additional vertical or horizontal loads imposed on the soldier piles or sheeting by the angle (orientation with respect to the wall) of the anchor. The embedment of sheeting or H-piles (or other sections used as soldier piles) below the bottom of the excavation should be checked to ensure that it is sufficient to support the weight of the wall and the vertical component of the tieback force. The factor of safety should be at least 1.5 based on the design load, assuming resistance to the vertical load below the bottom of excavation only. Pile and sheeting bearing capacity should be calculated as shown in the manual on Design and Construction of Driven Pile Foundations, FHWA-HI-97-013, Rev. November 1998 with \( P_d \) and \( P_D \) equal to the values on the excavation side of the wall.

C. **Anchor Types**

The following are possible types of anchor support systems:

1. **Grouted Tiebacks:**

A grouted tieback is a system used to transfer tensile loads from the flexible wall to soil or rock. It consists of all prestressing steel, or tendons, the anchorage, grout, coatings, sheathings, couplers and encapsulation (if applicable).
2. **Deadman:**

A deadman may consist of large masses of precast or cast-in-place concrete, driven soldier piles or a continuous sheeting wall. The required depth of the deadman shall be analyzed based on the active and passive earth pressures exerted on the deadman. See Appendix Page C-2.

Deadman anchors must be located a distance from the anchored wall such that they can fully mobilize their passive pressure resistance outside of the anchored wall’s active zone. This is described in such references as: USS Steel Sheet Piling Manual and Foundation Analysis and Design, Fourth Edition by Joseph E. Bowles. See Appendix Page C-2.

3. **Struts or Braces / Rakers:**

Struts or braces are structural members designed to resist pressure in the direction of their length. Struts are usually installed to extend from the flexible wall to an adjacent parallel structure. Rakers are struts that are positioned at an angle extending from the flexible wall to a foundation block or supporting substructure.

D. **Constructability**

Constructability concerns are outlined in “III. Flexible Cantilevered Walls: C. Constructability”. The following are additional considerations which must be addressed:

1. **General:**

   The mass stability of the earth-tieback-wall system will be checked by the Geotechnical Engineering Bureau unless the consultant agreement states that the consultant will do all the geotechnical design work for the project. The designer will be notified of any special requirements that have to be included in the contract to ensure mass stability.

   **Sheeting Walls:**

   In the case of permanent anchored sheeting walls (not H-pile and lagging walls with drainage zones) without special features that would permit water to drain from behind the wall (weep holes alone are ineffective), the effects of an unanticipated rise in groundwater level during periods of heavy precipitation should be considered. Unless detailed groundwater level analyses indicate otherwise, the final anchor design should be based on a 10 ft. (3 m) rise in the groundwater level compared to the highest groundwater level determined from subsurface explorations. To account for possible perched water conditions, multiply by 1.25 the calculated anchor loads above the groundwater level (after adding the 10 ft. (3 m) rise).
Soldier Pile and Lagging Walls:

H-pile (or other type of soldier pile) and lagging walls should not be used in excavations below groundwater level unless the design includes appropriate positive methods to control seepage.

2. Grouted Tiebacks:

The presence of existing structures and utilities should be taken into account when deciding upon the location and inclination of anchors. The installation of the grouted tieback, location and inclination, should be surveyed against these existing site constraints. The design shall meet the requirements for minimum ground cover for the grouted tieback (Recommendations for Prestressed Rock and Soil Anchors, Post-Tensioning Institute, Fourth Edition: 2004).

The minimum anchor free length is:

a. 15 ft. (4.6 m) or
b. the length of the tieback from the face of the wall to the theoretical failure plane plus H/5, whichever is greater.

The theoretical failure plane is inclined at an angle of 45° - φ/2 with the vertical, where φ is the friction angle of the soil, if the backslope is horizontal. For cases where the backslope is not horizontal, the inclination of the failure plane should be determined from Foundations and Earth Structures, Design Manual 7-2, NAVFAC DM-7.2, May 1982, p. 7.2-65, or by means of a trial wedge analysis. The point of intersection of the theoretical failure plane with the face of the wall for walls in non-plastic soils can be determined as follows:

a. H-pile and lagging wall with single level of anchors: H/10 below the bottom of the excavation, Fig. 1(a).
b. Sheetng wall with single level of anchors: Level below bottom of excavation where moment in sheet pile is zero. Fig. 1(a).
c. H-pile and lagging wall with more than one level of anchors: Bottom of excavation, Fig. 1(b).
d. Sheetng wall with more than one level of anchors and groundwater level below bottom of excavation: Bottom of excavation, Fig. 1(b).
e. Sheetng wall with more than one level of anchors and groundwater level above bottom of excavation: Level below bottom of excavation where moment in sheeting is zero.
### Deadman:

Both the proposed maintenance and protection of traffic scheme and the construction sequencing should be evaluated to ensure that there is no interference with the method and sequence of tie rod installation and its subsequent functioning.

### Struts or Braces / Rakers:

The location and spacing of struts or rakers should be critiqued with respect to the allotted working space and proposed construction. Consideration should be given to access by workers, supplies and equipment.

The installation of the raker block should be evaluated with respect to the support of the wall system. The wall should be analyzed for any additional excavation or other construction impacts necessary to install the raker block.
V. REVIEW REQUIREMENTS

A. General

All designs will be reviewed using the analyses and theories stated in this document. All designs that are part of a construction submittal shall be stamped by a currently registered New York State Professional Engineer and shall follow the methods described or yield comparable results.

All designs shall be detailed in accordance with the current Departmental guidelines for the applicable item(s). Copies of these guidelines are available from the Geotechnical Engineering Bureau.

B. Flexible Cantilevered Walls

For review of the design of a flexible cantilevered wall, the following information is required:

1. All design assumptions.

2. Cite all reference material. Provide copies of relevant pages of any reference material that is used in the design and that is not included in the reference list on page 14.

3. Design elevations, including top and toe of sheeting or soldier pile, bottom of excavation, site specific soil layering and parameters. Cross sections are preferred.

4. Calculations or a computer design for the sheeting or soldier pile and lagging wall design. If a computer program is used, provide documentation of the assumptions used in writing the program.

5. Summary of constructability aspects of the proposed design as described in “III. Flexible Cantilevered Walls: C: Constructability”.

An example design calculation is shown on Appendix Pages E-1 & 2 (US Customary Units) or Pages F-1 & 2 (International System of Units).

C. Flexible Anchored Walls

For review of the design of a flexible anchored wall, the following information is required:

1. All design assumptions.

2. Cite all reference material. Provide copies of relevant pages of any reference material that is used in the design and that is not included in the reference list on page 14.

3. Design elevations, including top and toe of sheeting or soldier pile, bottom of excavation, location of wales or bracing, deadman/raker block location(s), site specific soil layering and parameters. Cross sections are preferred.
4. Calculations or a computer design for the anchored sheeting or soldier pile and lagging wall design. These calculations shall include each phase of construction. If a computer program is used, provide documentation of the assumptions used in writing the program. The design loads for the anchors/braces shall account for the proposed inclination (if applicable).

5. Calculations for the deadman or raker block design (if applicable).

6. Calculations for the waler design(s) showing connections.

7. For grouted tiebacks, specify proposed free length, inclination and corrosion protection (if applicable).

8. Summary of constructability aspects of the proposed design as described in “IV. Flexible Anchored Walls: D. Constructability”.

An example design calculation is shown on Appendix Pages E-3, 4 & 5 (US Customary Units) or Pages F-3, 4, & 5 (International System of Units).
REFERENCES

1. USS Steel Sheet Piling Design Manual, Updated and reprinted by US Department of Transportation / FHWA with permission: July, 1984.


APPENDICIES
Earth Pressures

Foreslope

Passive Earth Pressure Distribution

K_p \gamma D

Soil: \gamma, \phi

Active Earth Pressure Distribution

K_A \gamma H

Where:

K_A = \frac{1 - \sin \phi}{1 + \sin \phi}

K_p = \frac{1 + \sin \phi}{1 - \sin \phi}

K_{p''} = K_p / F.S.

Surcharge Loads

Surcharge Pressure Distribution

K_A q

Hydrostatic Loads

Hydrostatic Pressure Distribution

\gamma_w H_w
**Inclined Backfill**

Plot the anticipated active failure wedge line against the slope line. If the slope line intersects the active failure wedge line, the slope can be considered infinite (Case 1), otherwise the slope can be modeled by using an equivalent surcharge (Case 2).

**Case 1 - Infinite Slope Analysis**

\[ K_{ar} = (\cos \beta) \left[ \cos \beta - (\cos^2 \beta - \cos^2 \phi)^{0.5} \right] \\
\left[ \cos \beta + (\cos^2 \beta - \cos^2 \phi)^{0.5} \right] \]

**Case 2 - Equivalent Surcharge Method**

\[ q = \gamma Y \]

\[ K_{aq} = K_{a} \gamma Y \]
Inclined Foreslope

Plot the anticipated passive failure wedge line against the slope line. If the slope line intersects with the passive failure wedge line, the slope can be considered infinite (Case 1), otherwise the slope can be accounted for by increasing the depth of excavation (Case 2). In the latter case, methods should be analyzed and engineering judgement used to determine the solution.

**Case 1 - Infinite Slope Analysis**

\[ K_{PR}'' \gamma D = K_{PR}'' \gamma D \]  

Where:  
\[ K_{PR}'' = \frac{K_{PR}}{F.S.} \]

**Case 2 - Increase Excavation Depth to Compensate for Slope**

\[ H_2 = H_1 + X \]
Figure 23-4 Embankment Zones and Excavation Restrictions

**NOTE:** Consult Geotechnical Engineering Bureau when consideration is first given to excavating in proximity to railroads.

![Diagram of embankment zones and excavation restrictions]

**NOTES:**

1. Sheet piling for the support of railroad tracks is not permitted closer than 3.05 m (10'-0") from the centerline of the nearest track.
2. Excavations located** outside of the theoretical railroad embankment do not require sheeting for support of railroad tracks.
3. Sheet piling, installed prior to excavation, is required for excavations located** within the theoretical railroad embankment (Zones A & B). The following conditions apply to the design and construction of this sheeting.
   - A Cooper's E-80 live load, applied as a Boussinesq distribution, must be used to account for the railroad surcharge. Contact the Geotechnical Engineering Bureau for assistance with the application and calculation of the railroad surcharge.
   - Sheet piling shall be interlocking steel sheet piles, unless penetration cannot be obtained or dry, non-running, stable material will be encountered, in which case the designer may consider soldier pile and lagging walls subject to railroad approval.
   - During construction, the sheeting shall not extend above the top of rail elevation. After construction, sheeting for excavations located** in Zone A may be removed after the excavation is backfilled. (There are situations where this sheeting should be left in place, such as, to prevent settlement of spread footings, etc. Contact GEB.) Sheet piling for excavations located** in Zone B must be left in place. All sheeting left in place ("Interim Steel Sheetings") must be cut off 0.46 m (1.5") below existing ground line.

*For Norfolk Southern tracks, increase indicated quantities as follows:
  a. Distance from centerline of track to working point: 4.27 m (14'-0")
  b. Top of Rail down to working point: 1.10 m (3'-7.25")
  c. Slope of theoretical Railroad embankment line: 1(V) ON 2(H)

**The excavation location is defined as the point of intersection between the bottom of the excavation and the proposed line of sheeting at its closest offset from the railroad.
<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unified Classification</th>
<th>Depth (ft.)</th>
<th>Recommended Thickness (inches) of Lagging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competent Soils</td>
<td>Silts or fine sand and silt above the water table.</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Sands and gravels (medium dense to dense).</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Clays (stiff to very stiff); non-fissured.</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Clays, medium consistency and ( \gamma_{H/Su} &lt; 5 ).</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Clays, medium consistency and fissured.</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Clays, medium consistency and fissured.</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Difficult Soils</td>
<td>Sands and silty sands (loose).</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Clayey sands (medium dense to dense) below water table.</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Clayey sands (medium dense to dense) below water table.</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Clayey sands (medium dense to dense) below water table.</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Clayey sands (medium dense to dense) below water table.</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Clayey sands (medium dense to dense) below water table.</td>
<td>10</td>
<td>-</td>
</tr>
</tbody>
</table>

**NOTE:** In the category of "Potentially Dangerous Soils," use of lagging is questionable.

Earth Pressures For Braced Excavations

SAND

\[0.65\gamma H \tan^2(45^\circ - \Phi/2)\]

or

\[0.80\gamma H \tan^2(45^\circ - \Phi/2)\]

Dense

0.2H

0.6H

H

0.2H

Loose

0.2H

0.8H

H

0.25H

Soft to Medium

0.25H

0.75H

H

0.25H

Stiff-Fissured

0.25H

0.50H

H

0.25H

CLAY

\[\gamma H[1 - (4C/\gamma H)]\]

0.2\gamma H to 0.4\gamma H
Deadman Pressure Distribution

Location Requirements for a Continuous Deadman

Single Soil Layer

\[ \begin{align*}
\alpha &= 45^\circ - \phi/2 \\
\beta &= 45^\circ + \phi/2 \\
L_w &= \text{Wall Length} \\
L_d &= \text{Deadman Length}
\end{align*} \]

Minimum Distance between Wall and Deadman

\[ = ABC = L_w \tan \alpha + L_d \tan \beta \]

\[ = L_w \tan (45^\circ - \phi/2) + L_d (\tan 45^\circ + \phi/2) \]

Multiple Soil Layers - Use Geometry

Minimum Distance between Wall and Deadman

\[ = ABCD = L_{w2} \tan \alpha_2 + L_{w1} \tan \alpha_1 + L_{d2} \tan \beta_2 + L_{d1} \tan \beta_1 \]
DESIGN GUIDELINES FOR THE USE OF
THE SOLIDER PILE AND LAGGING WALL SPECIFICATIONS

The specifications are adaptable and require the wall designer to show site specific details on the Contract Plans. The main purpose of these guidelines is to provide a checklist of the necessary information that must be placed on the Contract Plans by the wall designer. In addition to serving as a checklist, these guidelines also include some information on design issues that relate to wall constructability. These guidelines are intended to be used with the Bridge Detail (BD) Sheet BD-EE9 R1 Excavation and Embankment Soldier Pile with Lagging Sample Details, available at https://www.nysdot.gov/portal/page/portal/main/business-center/engineering/cadd-info/bridge-details-sheets-repository/bdee9.pdf

The item numbers for these specifications are serialized to allow for separate bidding when multiple walls are on a single project. For projects with only one wall, the "nn" will be "01".

I. Function of the Wall - The specifications do not differentiate between permanent walls and temporary walls. The specifications may be used for either situation, with the appropriate details placed on the Contract Plans.

A. Short Term Structural Function (temporary walls) - Used material is acceptable for structural steel and untreated wood is acceptable for lagging. Walls outside the roadbed limits may either be completely removed or cut off and left in place. If, however, the wall is located within the roadbed limits, total removal is not allowed, thereby eliminating long-term settlement concerns. The specifications allow used material for structural steel, so no Special Note is necessary. Untreated wood lagging, however, must be specified on the Contract Plans. Refer to Section VIII B. for the appropriate Special Notes for temporary walls.

B. Long Term Structural Function (permanent walls) - These walls remain in place and require new materials. Special Notes are required for this situation. Refer to Section VIII A. for the appropriate Special Notes for permanent walls.

C. Support of Railroad Tracks- In general, soldier pile and lagging walls are not permitted for the support of railroad tracks. Contact the Regional Geotechnical Engineer or refer to the Geotechnical Engineering Bureau Design Manual for exceptions and limitations.

II. Payment Lines and Limits

A. Indicate Payment Lines for those items that will be computed from the Contract Plans:

   Lagging - top of lagging to bottom of lagging as shown in the elevation view on the BD Sheet.
B. Indicate Payment Limits for those items that will be measured in the field:

Soldier Piles - top of pile to tip of pile, as shown in Sections X-X and Y-Y on the BD Sheet.

Holes in Earth - existing ground surface to bottom of hole in earth. The bottom of the hole in earth can be either the top of rock when a rock socket is present (as shown in Section Y-Y on the example drawing) or the tip of the pile when there is no rock socket.

Note that the upper payment limit of holes in earth may not always be the same as the upper payment limit of soldier piles.

Rock Sockets - top of rock to bottom of socket as shown in Section Y-Y on the BD Sheet.

III. Holes in Earth and Rock Sockets - The specifications allow soldier piles to be either driven or placed in a hole. Holes are necessary for one (or more) of the following reasons:

- Rock sockets are required.
- Possibility of encountering obstructions or very compact material.
- To minimize vibrations.

If holes are specified, the minimum diameter of the hole should be selected to provide a 3 in. (75 mm) minimum clear space around the soldier pile (i.e. soldier pile diagonal dimension plus 6 in. (150 mm)).

IV. Soldier Piles - Provide only the relevant soldier pile information outlined in the table on the BD Sheet. Factors to consider in selection of a soldier pile section are:

A. Pile Section - Select either an HP section or a relatively square W section because:

For Driven Piles

- The section modulus is nearly the same in the x and y directions and, therefore, small rotations during placement will not result in a deficient section.
- The pile section will fit a standard drive head.
- The reinforced shoes for driving are standard.
- The driving stresses will be evenly distributed.

For Piles Placed in Holes

- The required hole diameter is minimized.
B. **Flange Width** - Select a soldier pile section with a minimum flange width of 11 in. (275 mm). This will provide a minimum bearing area for the lagging of 3 in. (75 mm), plus 1 ½ in. (38 mm) of clearance between the end of the lagging and the web (necessary for concrete lagging).

C. **Availability** - Select soldier pile sections which are available domestically. The Manual of Steel Construction indicates the availability of sections.

D. **Yield Stress** - Unless otherwise indicated on the Contract Plans, ASTM A36 steel will be furnished. If a higher yield stress is necessary, it must be indicated by a Special Note (see Section VIII C.).

V. **Backfilling of Holes in Earth and Rock Sockets** - Two types of backfill are allowed in the specifications: concrete and (excavatable) grout. The designer must specify the backfill type(s) and limit(s) on the Contract Plans (refer to Section Y-Y on the BD Sheet). Some things to consider when selecting type(s) and limit(s) of backfill are:

- Concrete must be used in rock sockets (a requirement of the specifications).
- The backfill between the bottom of the hole in earth (or the top of rock socket, if any) and the dredgeline may be either grout or concrete. Concrete would be appropriate for permanent walls.
- Grout must be used above the dredgeline, since it can be excavated.

VI. **Lagging** - Show the lagging type. For the type of lagging chosen, show the following:

- Treated wood (permanent walls) - indicate full dimension thickness.
- Untreated wood (temporary walls) - indicate full dimension thickness.
- Precast concrete panels - show the panel design using Detail A on the BD Sheet. The Geotechnical Engineering Bureau can, if requested, provide the maximum moment. The design of the panels is to be provided by the Regional Design Group, the Structures Division or the Design Consultant.
- Steel sheeting - indicate minimum section modulus.

VII. **Waling and Bracing** - Show the following information, if applicable:

- Elevation of walers and braces.
- Spacing of braces.
- Section modulus of walers.
- Design section of braces.
VIII. Examples of Special Notes to be Placed on the Contract Plans

A. Long Term Structural Function (permanent walls)

The soldier pile and lagging wall shown will be left in place. Used material is not permitted for Item 17551.0462nn M - Installing Soldier Piles for Soldier Pile and Lagging Wall.

B. Short Term Structural Function (temporary walls)

1. Located inside of roadbed limits (Refer to NYSDOT Standard Specifications, page 1-2, for the definition of roadbed limits).

   When no longer necessary for excavation support, remove lagging to a minimum of 2 ft. (0.6 m) below subgrade surface or 4 ft. (1.2 m) below final ground surface. Cut off and remove soldier piles to a minimum of 2 ft. (0.6 m) below subgrade surface or 4 ft. (1.2 m) below final ground surface.

2. Located outside of roadbed limits.

   a. For walls where no adjacent structure or utility is present, no Special Notes are necessary because the specifications address this situation.

   b. For walls where adjacent structures or utilities might be damaged by removal operations:

      When no longer necessary for excavation support, remove lagging to a minimum of 2 ft. (0.6 m) below subgrade surface or 4 ft. (1.2 m) below final ground surface. Cut off and remove soldier piles to a minimum of 2 ft. (0.6 m) below subgrade surface or 4 ft. (1.2 m) below final ground surface.

C. Other Special Notes

1. If a higher yield stress is necessary for the soldier piles:

   Provide soldier pile sections meeting the requirements of ASTM A572 Grade 50 Steel.

2. For situations where a casing will be necessary for installing holes in earth (i.e. loose cohesionless soil, high groundwater, adjacent structures, utilities, etc.):

   Temporary sleeves or casings are required for Item 17551.0460nn M - Holes in Earth for Soldier Pile and Lagging Walls. No extra payment will be made for the casing.

3. For situations where it appears installing holes in earth will be very difficult and possibly require special equipment and/or procedures:

   Due to the presence of ________, progressing the Holes in Earth for Soldier Pile and Lagging Wall, Item 17551.0460nn M, may require special equipment and/or procedures. No extra payment will be made for special equipment and/or procedures.
SELECTING A SOLDIER PILE SECTION FOR A SOLDIER PILE AND LAGGING WALL WITH ROCK SOCKETS

The bending moment in a soldier pile varies with depth and the material in which it is embedded. The maximum bending moment \( (M_{\text{max}}) \) expected to occur in the soldier pile is used to size the pile. The \( M_{\text{max}} \) for a cantilevered soldier pile wall with some or all of its embedment in rock (i.e., rock sockets) is traditionally dependant on the elevation of the rock surface assumed during design.

During construction, it is likely that the actual rock surface will vary somewhat from the elevation(s) assumed in design. This occurs because the amount of subsurface information available to the designer is generally insufficient to precisely define the rock profile. During construction, if the actual rock elevation is found to be lower than the assumed rock elevation, the soldier pile section specified on the Contract Plans is often no longer adequate. When this occurs, the first step is for the wall designer to review the assumptions from the original analysis and compare them to the actual site conditions (i.e. soil conditions, ground water elevation, surcharge loads, etc.). A re-analysis with the revised assumptions may prove the soldier pile section shown on the Contract Plans is still adequate. If a re-analysis indicates the section is insufficient, possible remedies and their associated consequences, are as follows:

Remedy- Increase the section modulus of the soldier pile by either ordering new steel or welding steel cover plates to the flanges of the existing soldier piles.
Consequence- Delays, orders-on-contract, claims.

Remedy- Reduce the factors of safety in the original design.
Consequence- Not acceptable for permanent walls or critical temporary walls.

Remedy- Change the wall design by adding anchors.
Consequence- R.O.W. restrictions, additional design, delays, requires specialty Contractor and equipment, orders-on-contract, claims.

Remedy- Change the wall design by reducing the soldier pile spacing.
Consequence- If decreasing the pile spacing is an option, payment will be required for the additional quantities of drilling and soldier piles.

The most effective way to ensure safety and avoid costly delays and orders-on-contract is to specify a soldier pile section that is able to accommodate likely variations in rock elevation encountered during construction.

The following design recommendations provide a rational approach to sizing soldier piles for walls with rock sockets:
I. **Determine the likelihood of a varying rock surface at the project site.**
   A. The most obvious indication of this condition is differing rock elevations in the available subsurface explorations. In cases where there are few drill holes near the proposed wall location, consider requesting additional drill holes or a seismic refraction survey to better define the rock profile.
   B. Discuss the probable rock profile with the Area and Regional Geotechnical Engineer.
   C. At the time the rock socket design request is made (refer to Section III.), consult with an Engineering Geologist on the variability of the rock surface at the project site. In general, the Regions with the most variable rock surfaces are 1, 2, 7, 8 and 11.
   D. Based on the results of A, B, and C above, decide if the rock is likely to differ by more than 2 ft. (0.6 m) from the assumed rock elevation. The specification allows for a 2 ft. (0.6 m) difference between the rock elevation shown on the Contract Plans and the actual rock elevation before the E.I.C. is obligated to contact the Geotechnical Engineering Bureau for recommendations.

II. **Sizing a soldier pile section.**
   A. General
   For a typical cantilevered soldier pile wall with all pile embedment in soil, $M_{\text{max}}$ occurs at a depth of between $0.5H^*$ (for compact soils) and $1.0H^*$ (for loose or soft soils) below the dredge line, where $H$ is the exposed height of the wall (refer to Figure 1).

   * These ratios are the result of a study performed by the Structures Foundation Section of the Geotechnical Engineering Bureau. The study was based on a “typical” cantilevered soldier pile wall constructed in New York State. The assumptions used in the study are as follows:

   - Temporary wall with a factor of safety of 1.25 on $K_p$.
   - A 2 ft. (0.6 m) traffic surcharge: 250 psf (12.0 kPa).
   - No slope above or in front of the wall.
   - One soil layer with a unit weight of 120 pcf (18.8 kN/m$^3$) and friction angles ranging from $22^\circ$ to $37^\circ$.
   - Wall friction ($\delta$) equals zero.
   - Groundwater at the dredge line.
   - A predrilled hole with a diameter of 24 in. (600 mm).
   - Soldier pile spacing of 6 ft. (1.8 m) and 8 ft. (2.4 m).
   - An exposed wall height ranging from 8 ft. (2.4 m) to 16 ft. (5.0 m).
For a typical cantilevered soldier pile wall with some or all pile embedment in rock (i.e., rock sockets), the location of $M_{\text{max}}$ is not straightforward and it is customary to use the larger of the following bending moments to size the pile:

1. The moment at the rock surface, or
2. The maximum moment between the dredge line and the rock surface.

Whichever case results in a larger moment depends on the distance between the dredge line and the rock surface, and is discussed in Steps C and D below.

B. Analysis

When the Geotechnical Engineering Bureau’s “CASH” program is used, the output provides the bending moment values in one foot increments of pile depth. The wall designer should run the CASH program assuming a soldier pile wall with all pile embedment in soil (hereafter referred to as the “all soil” case). This output enables the wall designer to see the effect on the pile bending moment if the rock surface is lower than assumed. It also provides the depth of $M_{\text{max}}$ below the dredge line for the “all soil” case ($D_{\text{max}}$), which is necessary for Steps C and D below. If CASH or a computer program that provides the moment distribution with depth is not accessible, the moments below the dredge line for the “all soil” case can be calculated by hand at several depths.
C. Rock surface at a depth of $D_{\text{max}}$ or greater (Refer to Figure 2)
In general, if the rock surface is located lower than $D_{\text{max}}$ below the dredge line, the $M_{\text{max}}$ will occur somewhere between the dredge line and the rock surface. Regardless of the variability of the rock surface, the soldier pile should be sized using the $M_{\text{max}}$ as identified in the “all soil” CASH run.

![Diagram](Figure 2)

*Figure 2*
Bending Moment vs. Depth for a Typical Cantilevered Soldier Pile Wall Embedded in Soil and Rock
(Rock at a Depth $\geq D_{\text{max}}$ Below Dredge line)

D. Rock surface between dredge line and $D_{\text{max}}$ (Refer to Figure 3)
For a rock surface located higher than $D_{\text{max}}$ below the dredge line, the $M_{\text{max}}$ will occur at rock surface. It is assumed that the rock socket provides a rigid support (i.e., the pile is concreted into rock) and the soldier pile experiences no increase in bending moment below the top of the socket.
The $M_{\text{max}}$ for a rock surface located at $D_{\text{max}}$ can be several times larger than the $M_{\text{max}}$ for a rock surface at the dredge line. If the actual rock surface is lower than assumed in design, the applied soldier pile bending moment can be significantly greater than originally assumed, and the following cases must be considered when sizing the soldier piles:

**CASE 1- Rock surface IS NOT likely to vary by more than 2 ft. (0.6 m) from the assumed elevation:**

As an absolute minimum requirement, the soldier pile should be sized using the moment 2 ft. (0.6 m) below the assumed rock elevation (this moment can be found on the “all soil” Cash output).

**CASE 2- Rock surface IS likely to vary by more than 2 ft. (0.6 m) from the assumed elevation:**

Serious consideration should be given to sizing the soldier pile using the $M_{\text{max}}$ identified in the “all soil” CASH run. Another approach is to design the wall with a large enough spacing so that the spacing can be reduced during construction, if necessary. If this approach is considered, the cost of the
additional quantities for drilling and steel must be weighed against the cost of sizing the soldier piles using $M_{\text{max}}$ as discussed above. If rock appears to be highly variable, the designer should investigate a different wall type, such as an anchored wall, in order to avoid the use of rock sockets altogether.

III. Rock Socket Design

Regardless of who designs the wall (Geotechnical Engineering Bureau, M.O. Structures Division, Regional Design Group, or Design Consultant), the rock socket designs must be provided by an Engineering Geologist of the Geotechnical Engineering Bureau. In addition to the information about the rock at the project site, the Engineering Geologist must be provided with the following information to design a rock socket:

- Soldier pile spacing,
- Flange width,
- Maximum bending moment, and
- Hole diameter.
DESIGN GUIDELINES FOR THE USE OF
THE SHEETING AND EXCAVATION PROTECTION SYSTEM SPECIFICATIONS

The specifications are adaptable and require the wall designer to show site specific details on the Contract Plans. Design guidelines are outlined in the NYS Department of Transportation Bridge Manual, Section 4 Excavation, Sheeting and Cofferdams, available at: https://www.nysdot.gov/portal/page/portal/divisions/engineering/structures/manuals/bridge_manual_4th_ed

These guidelines are also intended to point out how support system items are related to excavation items and to explain which excavation items include protection system provisions. These guidelines are intended to be used with the Bridge Detail (BD) Sheets:

Sheeting in Stage Construction

Braced Sheeting Systems

DESIGN GUIDELINES FOR THE USE OF
THE GROUTED TIEBACK SPECIFICATIONS

The specifications are adaptable and require the wall designer to show site specific details on the Contract Plans. The main purpose of these guidelines is to provide a checklist of the necessary information that must be placed on the Contract Plans by the wall designer. In addition to serving as a checklist, these guidelines also include some information on design issues that relate to wall constructability. These guidelines are intended to be used with the Bridge Detail (BD) Sheet BD-EE11 Excavation and Embankment Tieback Wall Details, available at: https://www.nysdot.gov/portal/page/portal/main/business-center/engineering/cadd-info/bridge-details-sheets-repository/bdee11.pdf
DESIGN GUIDELINES FOR THE USE OF
THE STEEL TIES SPECIFICATIONS

The specifications are adaptable and require the wall designer to show site specific details on the Contract Plans. The main purpose of these guidelines is to provide a checklist of the necessary information that must be placed on the Contract Plans by the wall designer. In addition to serving as a checklist, these guidelines also include some information on design issues that relate to wall constructability. These guidelines are intended to be used with the Bridge Detail (BD) Sheet BD-EE11 Excavation and Embankment Tieback Wall Details, available at: https://www.nysdot.gov/portal/page/portal/main/business-center/engineering/cadd-info/bridge-details-sheets-repositoty/bdee11.pdf

1. Show the position of the steel ties (plan location, elevation, etc.).

2. Show the design load of the steel ties. The design load should include a factor of safety of 1.5.

3. Indicate if the steel ties will be installed inside a carrier conduit. Carrier conduits are used only to facilitate construction of the steel ties and are not related to corrosion protection. The most common situation where the use of a carrier conduit is advantageous is when traffic lanes have to be maintained between the wall and the deadman, i.e. traffic is located over the proposed location of the steel ties. In general, it is difficult to install steel ties (whether they be threaded bars with a coupler or seven wire strand cables) in stages. Conduit, however, can be installed in stages by trenching, or in one operation by drilling (if no obstructions are present). Once all the conduit is installed, the steel ties can be pushed through while traffic is maintained above.

4. If steel ties (or steel ties with carrier conduit) will be installed in trenches, indicate excavation and backfill limits and payment items for trenches.

5. A. Walls that are constructed from the "top down" (or walls that are excavated in front): These walls are constructed by excavating downward to some depth below the proposed steel tie elevation, installing the steel tie, and then continuing the excavation.
   1. Show the maximum depth of excavation permitted below the proposed steel tie elevation. This number is usually 1 ½ ft. or 2 ft. (0.45 m or 0.6. m).
   2. Check the wall stability for the temporary condition before the steel tie is installed. For walls with more than one level of ties, multiple wall stability calculations will be required.

B. Walls that are constructed from the "bottom up" (or walls that are backfilled behind): These walls are constructed by backfilling behind the wall up to the proposed steel tie elevation, installing the steel tie, and then continuing the backfilling.
   1. Show the elevation the backfill should be placed to before the proposed steel tie is
2. Check the wall stability for the temporary condition before the steel tie is installed. For walls with more than one level of ties, multiple wall stability calculations will be required.

6. The specification allows the Contractor the option of using threaded steel bars or seven wire strand cables. If seven wire strand cables are selected, they must be loaded and locked off immediately after installation (i.e. before any further wall excavation/backfill). The lock off load serves to remove slack from the cables and set the locking wedges in the anchor head.

   The lock-off load must be shown on the Contract Plans and is dependent on the type of wall constructed as follows:

   A. Walls constructed from the "top down": The lock-off load is 80 percent of the design load.
   B. Walls constructed from the "bottom up": The lock-off load is 2 kips per strand (9 kN per strand).

   For either type of wall construction, check for adequate passive resistance behind the wall to resist the lock-off load.

7. Show corrosion protection at the anchor heads for permanent steel ties.
EXAMPLE - CANTILEVERED SHEETING WALL (US CUSTOMARY UNITS)

Step 1: Using the Simplified Method, determine the depth of embedment and required section modulus for the following situation (permanent sheeting).

Given:
\[ \gamma = 115 \text{pcf} \]
\[ \gamma_s = 52.6 \text{pcf} \]
\[ \phi = 32^\circ \]

Step 2: Rankine Theory for a level backfill:
\[ K_a = \frac{1 - \sin \phi}{1 + \sin \phi} = 0.31 \]
\[ K_p = \frac{1 + \sin \phi}{1 - \sin \phi} = 3.25 \]
\[ K_p'' = \frac{K_p}{1.5} = 2.18 \]

Step 3: Compute the pressures:
\[ p_1 = (K_a)(q) = (0.31)(250) = 77.5 \text{psf} \]
\[ p_2 = (K_a)(\gamma)(H) = (0.31)(115)(10) = 356.5 \text{psf} \]
\[ p_3 = (K_a)(\gamma_s)(D) = (0.31)(115-62.4)(D) = 16.31 D \text{psf} \]
\[ p_4 = (K_p'')(\gamma_s)(D) = (2.18)(115-62.4)(D) = 114.67 D \text{psf} \]

Compute the forces:
\[ F_1 = (p_1)(H) = (0.31)(250)(10) = 775.0 \text{lbs/ft.} \]
\[ F_2 = \frac{1}{2}(p_2)(H) = \frac{1}{2}(356.5)(10) = 1782.5 \text{lbs/ft.} \]
\[ F_3 = (p_1+p_2)(D) = (77.5+356.5)(D) = 434.0 D \text{lbs/ft.} \]
\[ F_4 = \frac{1}{2}(p_3)(D) = \frac{1}{2}(16.31 D)(D) = 8.16 D^2 \text{lbs/ft.} \]
\[ F_5 = \frac{1}{2}(p_4)(D) = \frac{1}{2}(114.67 D)(D) = 57.34 D^2 \text{lbs/ft.} \]
Step 4: Determine depth of embedment (D). (To compute: $\Sigma M_{@o} = 0$ and solve for D).

$$\Sigma M_{@o} = (1/3)(D)(F_4) + (1/2)(D)(F_3) + (D + 1/3H)(F_2) + (D + 1/2H)(F_1) - (1/3)(D)(F_5) = 0$$

$$-16.39D^3 + 217D^2 + 2557.5D + 9816.7 = 0$$

$$D = 21.7\text{ ft.}$$

The depth of embedment is increased by 20% to account for the differences which exist between using the Simplified vs. Conventional Method of analysis.

$$D = (D)(1.2) = 26\text{ ft.}$$

Step 5: Find the point of zero shear (y):

$$\Sigma F_H = 0 = F_1 + F_2 + F_3 + F_4 - F_5$$

$$0 = y^2 - 8.83y - 52.0$$

$$y = \frac{8.83 \pm \sqrt{8.83^2 - (4)(1)(-52.0)}}{2(1)}$$

$$y = 12.87\text{ ft.}$$

Step 6: Find the maximum moment which occurs at the point of zero shear:

$$\Sigma M_{@o} = M_{\text{max}} = -16.39y^3 + 217y^2 + 2557.5y + 9816.7$$

$$= 43.7\text{ kip-ft.}$$

Step 7: Determine minimum section modulus:

$$\frac{M_{\text{max}}}{\sigma_{\text{all}}} = 21.0\text{ in}^3\text{ per foot of wall}$$

$$\sigma_{\text{all}} = 25\text{ ksi}$$
EXAMPLE - ANCHORED SHEETING WALL \textit{(US CUSTOMARY UNITS)}

Step 1: Using the Free Earth Support Method, determine the depth of embedment, required section modulus and anchor design load for the following situation (temporary sheeting).

\begin{align*}
q &= 350 \text{ psf} \\
\gamma &= 120 \text{ pcf} \\
\gamma_s &= 57.6 \text{ pcf} \\
\phi &= 32^\circ
\end{align*}

Step 2: Rankine Theory for a level backfill:

\begin{align*}
K_a &= \frac{1 - \sin \phi}{1 + \sin \phi} = 0.31 \\
K_p &= \frac{1 + \sin \phi}{1 - \sin \phi} = 3.25 \\
K_p'' &= K_p = 2.60
\end{align*}

Step 3: Compute the pressures:

\begin{align*}
p_1 &= (K_a)(q) = (0.31)(350) = 108.5 \text{ psf} \\
p_2 &= (K_a)(\gamma)(H) = (0.31)(120)(22) = 818.4 \text{ psf} \\
p_3 &= (K_a)(\gamma_s)(D) = (0.31)(57.6)(D) = 17.86D \text{ psf} \\
p_4 &= (K_p'')(\gamma_s)(D) = (2.60)(57.6)(D) = 149.76D \text{ psf}
\end{align*}

Since the water level is at the same elevation on both sides of the wall, the net water pressure is zero.
Step 3:  (Cont.)
Compute the forces:

\[
\begin{align*}
F_1 &= (p_1)(H) = (108.5)(22) = 2387.0 \text{ lbs/ft.} \\
F_2 &= (\frac{1}{2})(p_2)(H) = (\frac{1}{2})(818.4)(22) = 9002.4 \text{ lbs/ft.} \\
F_3 &= (p_1 + p_2)(D) = (108.5+818.4)(D) = 926.9 D \text{ lbs/ft.} \\
F_4 &= (\frac{1}{2})(p_3)(D) = (\frac{1}{2})(17.86 D)(D) = 8.93 D^2 \text{ lbs/ft.} \\
F_5 &= (\frac{1}{2})(p_4)(D) = (\frac{1}{2})(149.76 D)(D) = 74.88 D^2 \text{ lbs/ft.}
\end{align*}
\]

\[
\text{Moment Arm} \quad \frac{1}{2} (22) - 4.0 = 7.0 \\
\frac{2}{3} (22) - 4.0 = 10.67 \\
(22 - 4.0) + D/2 = 18.0 + D/2 \\
(22 - 4.0) + 2/3 D = 18.0 + 2/3 D \\
(22 - 4.0) + 2/3 D = 18.0 + 2/3 D
\]

Step 4: 
Sum moments about the anchor to determine depth of embedment:

\[
\begin{align*}
\Sigma M_{AL} &= 0 \\
&= (7.0)(F_1) + (10.67)(F_2) + (18.0 + D/2)(F_3) + (18.0 + 2/3 D)(F_4) - (18.0 + 2/3 D)(F_5) \\
&= 16709.0 + 96055.61 + 16684.2 D + 463.45 D^2 + 160.74 D^2 + 5.95 D^3 - 1347.84 D^2 - 49.92 D^3 \\
&= 112764.61 + 16684.2 D - 723.65 D^2 - 43.97 D^3 \\
D &\approx 16.35 \text{ ft.}
\end{align*}
\]

The depth of embedment is increased by 20 % to minimize lateral deflection
of the sheeting at its base.

\[
D = 1.2(D) = 1.2(16.35) = 19.62 \text{ ft.} \approx 20 \text{ ft.}
\]

Step 5: 
Determine anchor load (sum the horizontal forces):

\[
\Sigma F_H = 0 \\
F_1 + F_2 + F_3 + F_4 - F_5 - AL = 0 \\
2387.0 + 9002.4 + 15154.82 + 2387.19 - 20017.11 - AL = 0 \\
AL = 8914.3 \text{ lbs per foot of wall}
\]

A safety factor of 1.5 is applied to the anchor load to determine the anchor design load.

\[
1.5(AL) = 13371.5 \text{ lbs per foot of wall}
\]
Step 6: Determine depth of zero shear (assume that the point of zero shear will occur a distance S from the top):

\[ q = 350 \text{ psf} \]

\[ H = 22.0 \text{ ft.} \]

\[ p_5 = (K_a)(\gamma)(s) = (0.31)(120)(s) = 37.2 \text{ s} \]

\[ F_6 = (p_1)(s) = 108.5 \text{ s} \]

\[ F_7 = (\frac{1}{2})(p_5)(s) = (\frac{1}{2})(37.2 \text{ s})(s) = 18.6 \text{ s}^2 \]

\[ \Sigma F_H = 0 \quad F_6 + F_7 - AL = 0 \]

Using the quadratic equation:

\[ s = \frac{-108.5 \pm \sqrt{(108.5)^2 - (4)(18.6)(-8914.3)}}{2(18.6)} \]  

\[ s = 19.17 \text{ ft.} \]

Step 7: Determine maximum moment (sum moments about the point of zero shear):

\[ M_{\text{max}} = AL(s - 4.0) - (s/2)(F_6) - (s/3)(F_7) \]

\[ = (8914.3)(15.17) - (9.59)(2079.95) - (6.39)(6835.29) \]

\[ = 135229.93 - 19946.72 - 43677.5 \]

\[ = 71.6 \text{ kip-ft.} \]

Step 8: Determine minimum section modulus:

\[ S = \frac{M_{\text{max}}}{\sigma_{\text{all}}} = 34.4 \text{ in}^3 \text{ per foot of wall} \]

\[ (\sigma_{\text{all}} = 25 \text{ ksi}) \]
EXAMPLE-
CANTILEVERED SHEETING WALL (INTERNATIONAL SYSTEM OF UNITS)

Step 1: Using the Simplified Method, determine the depth of embedment and required section modulus for the following situation (permanent sheeting).

Given:
\[
\gamma = 18.0 \text{ kN/m}^3 \quad \gamma_s = 8.19 \text{ kN/m}^3
\]
\[
\phi = 32^\circ
\]

Step 2: Rankine Theory for a level backfill:
\[
K_a = \frac{1 - \sin \phi}{1 + \sin \phi} = 0.31
\]
\[
K_p = \frac{1 + \sin \phi}{1 - \sin \phi} = 3.25
\]
\[
K_p'' = K_p = 2.18
\]

Step 3: Compute the pressures:
\[
p_1 = (K_a)(q) = (0.31)(12.0) = 3.72 \text{ kN/m}^2
\]
\[
p_2 = (K_a)(\gamma)(H) = (0.31)(18.0)(3.0) = 16.72 \text{ kN/m}^2
\]
\[
p_3 = (K_a)(\gamma_s)(D) = (0.31)(18.0-9.81)(D) = 2.54 \text{ D kN/m}^2
\]
\[
p_4 = (K_p'')(\gamma_s)(D) = (2.18)(18.0-9.81)(D) = 17.88 \text{ D kN/m}^2
\]

Compute the forces:
\[
F_1 = (p_1)(H) = (0.31)(12.0)(3.0) = 11.16 \text{ kN/m}
\]
\[
F_2 = (\frac{1}{2})(p_2)(H) = (\frac{1}{2})(16.72)(3.0) = 25.08 \text{ kN/m}
\]
\[
F_3 = (p_1+p_2)(D) = (3.72+16.72)(D) = 20.44 \text{ D kN/m}
\]
\[
F_4 = (\frac{1}{2})(p_3)(D) = (\frac{1}{2})(2.54 \text{ D})(D) = 1.27 \text{ D}^2 \text{ kN/m}
\]
\[
F_5 = (\frac{1}{2})(p_4)(D) = (\frac{1}{2})(17.88 \text{ D})(D) = 8.94 \text{ D}^2 \text{ kN/m}
\]
Step 4: Determine depth of embedment (D). (To compute: \( \Sigma M_{@o} = 0 \) and solve for D).

\[
\Sigma M_{@o} = (1/3)(D)(F_4) + (1/2)(D)(F_3) + (D + 1/3 H)(F_2) + (D + 1/2 H)(F_1) - (1/3)(D)(F_5) = 0
\]

\[-2.56 D^3 + 10.22 D^2 + 36.24 D + 41.82 = 0\]

\[D = 6.5 \text{ m}\]

The depth of embedment is increased by 20% to account for the differences which exist between using the Simplified vs. Conventional Method of analysis.

\[D = (D)(1.2) = 7.8 \text{ m}\]

Step 5: Find the point of zero shear (y):

\[\Sigma F_H = 0 = F_1 + F_2 + F_3 + F_4 - F_5\]

\[0 = y^2 - 2.66 y - 4.72\]

\[0 = \frac{2.66 \pm \sqrt{2.66^2 - 4(1)(-4.72)}}{2(1)} \quad \text{(quadratic equation)}\]

\[y = 3.88 \text{ m}\]

Step 6: Find the maximum moment which occurs at the point of zero shear:

\[\Sigma M_{@o} = M_{max} = -2.56 y^3 + 10.22 y^2 + 36.24 y + 41.82\]

\[= 186.8 \text{ kN-m}\]

Step 7: Determine minimum section modulus:

\[S = \frac{M_{max}}{\sigma_{all}} = 1083 \times 10^3 \text{ mm}^3 \text{ per meter of wall}\]

\[(\sigma_{all} = 172.5 \times 10^3 \text{ kN/m}^2)\]
EXAMPLE - ANCHORED SHEETING WALL \textit{(INTERNATIONAL SYSTEM OF UNITS)}

Step 1: Using the Free Earth Support Method, determine the depth of embedment, required section modulus and anchor design load for the following situation (temporary sheeting).

\[ q = 16.75 \text{ kN/m}^2 \]

\[ D = 1.2 \text{ m} \]

\[ H = 6.7 \text{ m} \]

\[ \gamma = 19.0 \text{ kN/m}^3 \]

\[ \gamma_s = 9.2 \text{ kN/m}^3 \]

\[ \phi = 32^\circ \]

Step 2: Rankine Theory for a level backfill:

\[ K_a = \frac{1 - \sin \phi}{1 + \sin \phi} = 0.31 \]

\[ K_p = \frac{1 + \sin \phi}{1 - \sin \phi} = 3.25 \]

\[ K_p'' = \frac{K_p}{1.25} = 2.60 \]

Step 3: Compute the pressures:

\[ p_1 = (K_a)(q) = (0.31)(16.75) = 5.19 \text{ kN/m}^2 \]

\[ p_2 = (K_a)(\gamma)(H) = (0.31)(19.0)(6.7) = 39.46 \text{ kN/m}^2 \]

\[ p_3 = (K_a)(\gamma_s)(D) = (0.31)(9.2)(D) = 2.85 D \text{ kN/m}^2 \]

\[ p_4 = (K_p'')(\gamma)(D) = (2.60)(9.2)(D) = 23.92 D \text{ kN/m}^2 \]

Since the water level is at the same elevation on both sides of the wall, the net water pressure is zero.
Step 3:  (Cont.)

Compute the forces:

- **F₁** = \( (p₁)(H) \) = (5.19)(6.7) = 34.77 kN/m
  Moment Arm \( \frac{1}{2} (6.7) - 1.2 = 2.15 \)

- **F₂** = \( \frac{1}{2}(p₂)(H) \) = \( \frac{1}{2}(39.46)(6.7) \) = 132.19 kN/m
  \( \frac{2}{3} (6.7) - 1.2 = 3.27 \)

- **F₃** = \( (p₁ + p₂)(D) \) = (5.19 + 39.46)(D) = 44.65 D kN/m
  \( (6.7 - 1.2) + D/2 = 5.50 + D/2 \)

- **F₄** = \( \frac{1}{2}(p₃)(D) \) = \( \frac{1}{2}(2.85 D)(D) \) = 1.43 D² kN/m
  \( (6.7 - 1.2) + 2/3 D = 5.50 + 2/3 D \)

- **F₅** = \( \frac{1}{2}(p₄)(D) \) = \( \frac{1}{2}(23.92 D)(D) \) = 11.96 D² kN/m
  \( (6.7 - 1.2) + 2/3 D = 5.50 + 2/3 D \)

Step 4:  Sum moments about the anchor to determine depth of embedment:

\[ \sum M_{AL} = 0 \]

\[
= (2.15)(F₁) + (3.27)(F₂) + (5.50 + D/2)(F₃) + (5.50 + 2/3 D)(F₄) - (5.50 + 2/3 D)(F₅) \\
= 74.76 + 432.26 + 245.58 D + 22.33 D² + 7.87 D³ + 0.95 D² - 65.78 D² - 7.97 D³ \\
= 507.02 + 245.58 D - 35.58 D² + 2/3 D - 7.02 D³
\]

\[ D \approx 4.95 \text{ m} \]

The depth of embedment is increased by 20% to minimize lateral deflection of the sheathing at its base.

\[ D = 1.2(D) = 1.2(4.95) = 5.9 \text{ m} \]

Step 5:  Determine anchor load (sum the horizontal forces):

\[ \sum F_H = 0 \]

\[ F₁ + F₂ + F₃ + F₄ - F₅ - AL = 0 \]

\[ 34.77 + 132.19 + 221.02 + 35.04 - 293.05 - AL = 0 \]

\[ AL = 129.97 \text{ kN per meter of wall} \]

A safety factor of 1.5 is applied to the anchor load to determine the anchor design load.

\[ 1.5(AL) = 194.96 \text{ kN per meter of wall} \]
Step 6: Determine depth of zero shear (assume that the point of zero shear will occur a distance $S$ from the top):

$$q = 16.75 \, \text{kN/m}^2$$

$$H = 6.7 \, \text{m}$$

$$F_6 = (p_1)(s) = 5.19 \, s$$

$$F_7 = (\frac{1}{2})(p_5)(s) = (\frac{1}{2})(5.89 \, s)(s) = 2.95 \, s^2$$

$$\sum F_H = 0 \quad F_6 + F_7 - AL = 0$$

$$2.95 \, s^2 + 5.19 \, s - 129.97 = 0$$

Using the quadratic equation:

$$s = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$s = 5.82 \, \text{m}$$

Step 7: Determine maximum moment (sum moments about the point of zero shear):

$$M_{\text{max}} = AL(s - 1.2) - (s/2)(F_6) - (s/3)(F_7)$$

$$= (129.97)(4.62) - (2.91)(30.21) - (1.94)(99.92)$$

$$= 600.46 - 87.91 - 193.84$$

$$= 318.71 \, \text{kN} \cdot \text{m}$$

Step 8: Determine minimum section modulus:

$$S = \frac{M_{\text{max}}}{\sigma_{\text{all}}} = 1848 \times 10^3 \, \text{mm}^3 \, \text{per meter of wall}$$

$$\sigma_{\text{all}} = 172.5 \times 10^3 \, \text{kN/mm}^2$$
Section 4
Structure Excavation, Sheeting and Cofferdams

4.1 General Guidelines for Structure Excavation Protection and Support

The designer should become familiar with the appropriate specifications in the most current version of the *Standard Specifications for Construction and Materials*. The following guidelines shall in no way supersede the specifications. The intent of these guidelines is to explain the differences between the types of systems that are used to support excavations and those used to protect the workers and to identify:

- When they are used.
- Who is responsible for the design.
- What is to be shown on the Plans.

This section is intended to provide guidance on the commonly used excavation items in bridge construction. Users should refer to Chapter 9 of the *Highway Design Manual* (HDM) for guidance on excavation protection systems for trench and culvert excavations.

These guidelines conform to OSHA definitions, which differentiate between a support system as being a "structure . . . which provides support to an adjacent structure, underground installation, or the sides of an excavation" and a protective system, which protects workers from cave-ins. "Protective systems include support systems, sloping and benching systems, shield systems, and other systems that provide the necessary protection."

The Department's responsibility in designing excavations is to provide support of the roadway and adjacent structures and utilities. The Contractor's responsibility in performing excavations is to provide protection for the workers from cave-ins.

It is assumed that designers are familiar with the design procedures necessary to do the designs. If, however, geotechnical design assistance is needed, refer to "Geotechnical Design Procedure for Flexible Wall Systems" GDP-11 or contact the appropriate Departmental Geotechnical Engineer.

If support or protective systems are used in the vicinity of a railroad right-of-way, special requirements are usually necessary. Contact the appropriate Railroad Liaison for additional information. (See Chapter 23 of the *Highway Design Manual*.)

Protection for employees working in an excavation shall be provided except when:

- The excavation is made entirely in stable rock; or
- The excavation is less than 5 feet deep and an examination of the ground by a competent person gives no indication of a potential cave-in.

For excavations less than 5 feet in depth, only the excavation items need to be shown on the plans. OSHA regulations do not require any special steps be taken regarding worker protection.
For excavation depths from 5 feet through 20 feet, one of the following scenarios shall be used:

1. If there is no encumbrance with elements which would require support, (e.g. traffic lane, underground utilities, structures or their foundations, or the existing right of way etc.) within a safe slope that meets OSHA guidelines (typically: 1 vertical to 1.5 horizontal) measured from the bottom of the excavation to existing ground, it is considered to be in compliance with OSHA regulations that cover worker protection. In this case, only excavation and backfill items need to be specified and the cost estimate shall be based on the payment lines shown on the plans.

2. If there is interference within a safe slope that meets OSHA guidelines (typically the 1 vertical and 1.5 horizontal) but vibrations are minor and repairable subsidence is not considered to be a problem, and there is no interference at least 10 ft. from edge of excavation, then a steeper slope of up to 1 vertical to 1 horizontal may be used, if approved by the Regional Geotechnical Engineer or Geotechnical Engineering Bureau. The cost estimate shall be based on the payment lines shown on the plans.

3. If 1 or 2 above cannot be satisfied, an appropriate sheeting support system is required and shall be designed and detailed on the contract drawings, by the Department or the Department’s Consultant.

For excavations greater than 20 feet, a support system or slope lay back must be site specifically designed and detailed on the contract plans. If a slope lay back is feasible as determined by the Regional Geotechnical Engineer or Geotechnical Engineering Bureau, it shall be designed and detailed on the plans and serve as a support system, and the cost estimate shall be based on the payment lines shown on the plans. A support system shall be designed and specified (i.e., a sheeting item or soldier pile and lagging wall) to provide for worker protection where a designed slope lay back is not feasible.

See the BD-EE series for appropriate excavation and embankment details and item numbers.

4.2 Unclassified Excavation and Disposal

This is a general excavation Item (203.02) to remove material not provided for in another Item. Typically, this involves large excavations using large equipment. No special care, other than reaching grade, is required.

No provisions for a support system are included in this item. Additional items for support or protective systems must be added, as necessary, for support of the excavation or to protect workers.
4.3 Structure, Trench and Culvert, and Conduit Excavation

The Structure Excavation Item (206.01) provides a small, neat excavation using smaller equipment. The Trench and Culvert Items (206.02 and 206.04) provide a neat excavation in a confined space; typically for pipe or culvert excavations. The Conduit Excavation Item (206.03) also provides a neat excavation in a confined space; typically for conduit or direct buried cable excavations. For all Items, special care is required to provide an excavation with an undisturbed bottom.

The designer’s attention is called to Item 206.04 - Trench and Culvert Excavation - O.G., which specifies that the top payment line is “the ground surface prior to commencing work.” Over time, the typical construction contract has changed from building a road on new location to rehabilitating an existing facility. Today’s operations on existing location requiring the maintenance of traffic dictates how a contractor sequences the work. This new item should result in the best method of measurement for most construction contracts.

However, there are some instances where it is desirable to use the old method of measurement for trench and culvert excavation. For these instances Item 206.02 - Trench and Culvert Excavation, whose only purpose is to keep the old top payment line and method of measurement, is still appropriate. The instances where this item should be used are:

1. Road built on new location.
2. Construction taking place on existing road where a majority of the road is closed and traffic rerouted by a detour detailed in the plans.
3. When, after considering M&P/T, excavation work, road configuration and other factors, the logical and probable sequence of work the Contractor will choose is general excavation/fill first then trench and culvert excavation second.

The designer, when using Item 206.02 Trench and Culvert excavation under #3, should always consult the Regional Construction Office to confirm the decision. Both items can be used on the same project provided clear details are shown in the contract documents.

The following information is to be shown on the Contract Plans:

- Location
- Typical sections showing payment lines.

4.4 Removal of Substructures

This item (202.19) is used only to remove concrete and masonry. If excavation is needed to remove the substructure, the excavation should be shown and paid for under the Structure Excavation Item (206.01). Item 202.19 is used to partially or fully remove stone or concrete substructures that are not to be repaired or altered and reused.
4.5 Excavation Protection System

This Item (552.16) should only be used for Trench and Culvert excavations greater than 5 feet and less than 20 feet in depth. It provides for worker protection only where vibration or minor repairable subsidence are not considered a problem and no lay-back option is available due to ROW constraints, traffic, etc. An EPS is not acceptable for stage construction of highways or bridges or culverts. EPS is also not acceptable to protect workers from a one sided excavation, such as a cut into an existing slope. See Chapter 9 of the Highway Design Manual for details.

4.6 Interim Sheeting

4.6.1 Interim Steel Sheeting

This Item (552.15) uses steel sheeting to provide temporary support during progression of an excavation. This sheeting is then cut off to an elevation specified in the Contract Plans and the remainder is left in place. The decision to leave in place is usually dictated by soil conditions and will be made by others. The Geotechnical Group, Rails, Structures or even the Department of Environmental Conservation may have input during design and should be consulted. For example, sheeting may be left in place when there is stage construction, when pulling the sheeting may leave voids, or when the sheeting is adjacent to a structure and pulling the sheeting may cause structural damage to the adjacent structure. Sheetings may be previously used material, but must be in satisfactory condition and suitable for the intended application.

This sheeting is to be designed by the State or the State's Consultant. The following information is to be shown on the Contract Plans:

- Plan location of the sheeting placement
- Typical section(s) showing:
  - Elevations for the top and toe of the sheeting.
  - Elevation for the bottom of the excavation.
  - Minimum embedment below the bottom of the excavation.
  - Elevation at which sheeting is to be cut off.
  - Payment lines.
  - Location of wales or bracing, if required.
- Minimum section modulus for the sheeting
- If required, minimum section modulus of wales and size of bracing
Table 1 showing the soil parameters used for the design:

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>ELEVATION (Feet)</th>
<th>UNIT WEIGHT (lbs/ft³)</th>
<th>FRICTION ANGLE (Degrees)</th>
<th>COHESION (lb/in²)</th>
<th>WALL FRICTION ANGLE (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Notes: Divide the passive earth pressure coefficient (K_p) by 1.25.
Groundwater is assumed at Elevation _______.1
A surcharge load of ____ lb/in² is assumed at the top of the wall.1 and 2
Sheeting cannot be driven below Elevation _______, due to
_______ (choices: rock, boulders, compact material, obstructions,
artesian water pressure).1 and 2
Any other pertinent information1

1 If the sheeting is associated with a structure for which a Foundation Design Report (FDR) has been prepared,
the FDR will provide this information. If, however, an FDR has not been prepared or the sheeting is not in the
vicinity of the structure, this information is to be provided by the Geotechnical Engineering Bureau or the
Regional Geotechnical Engineer for inclusion on the plans.
2 If applicable, this note should be added.

Table 4-1
Soil Design Parameters

4.6.2 Interim Timber Sheeting

This Item (552.14) uses timber sheeting to provide temporary support during progression of an
excavation. This sheeting is then cut off to an elevation specified in the Contract Plans and the
remainder is left in place. The decision to leave in place is usually dictated by soil conditions
and will be made by others. The Geotechnical Group, Rails, Structures or even the Department
of Environmental Conservation may have input during design and should be consulted. For
example; sheeting may be left in place when there is stage construction, when pulling the
sheeting may leave voids, or when the sheeting is adjacent to a structure and pulling the
sheeting may cause structural damage to the adjacent structure. The timber may be used
material and of any acceptable species. It shall be free of any defects that may impair its
strength or tightness.

This sheeting is to be designed by the State or the State's Consultant. The following information
is to be shown on the Contract Plans:
- Plan location of the sheeting placement
  - Typical section(s) showing:
    - Elevations for the top and toe of the sheeting
    - Elevation for the bottom of the excavation
    - Minimum embedment below the bottom of the excavation
    - Elevation at which sheeting is to be cut off
    - Payment lines
4.7 Temporary Sheeting

4.7.1 Temporary Steel Sheeting

This Item (552.13) uses steel sheeting to provide temporary support during progression of an excavation. When no longer needed for excavation support, the sheeting shall be removed. The Contractor may leave the sheeting in place only with the written approval of the Engineer. The sheeting may be used material, but must be in satisfactory condition and suitable for the intended application.

This sheeting is to be designed by the State or the State’s Consultant. The following information is to be shown on the Contract Plans:

- Plan location of the sheeting placement
- Typical section(s) showing:
  - Elevations for the top and toe of the sheeting.
  - Elevation for the bottom of the excavation.
  - Minimum embedment below the bottom of the excavation.
  - Payment lines.
  - Location of wales or bracing, if required.
- Minimum section modulus for the sheeting
- If required, minimum section modulus of wales and size of bracing
- Show the same table used for Interim Steel Sheeting (Section 4.6.1).

4.7.2 Temporary Timber Sheeting

This Item (552.12) uses timber sheeting to provide temporary support during progression of an excavation. When no longer needed for excavation support, the sheeting shall be removed. The Contractor may leave the sheeting in place only with the written approval of the Engineer. Unless stated otherwise on the Contract Plans, the timber may be used material and of any acceptable species. It shall be free of any defects that may impair its strength or tightness.

This sheeting is to be designed by the State or the State’s Consultant. The following information is to be shown on the Contract Plans:

- Plan location of the sheeting placement
- Typical section(s) showing:
  - Elevations for the top and toe of the sheeting.
  - Elevation for the bottom of the excavation.
  - Minimum embedment below the bottom of the excavation.
  - Payment lines.
  - Location of wales or bracing, if required.
4.8 Permanent Sheeting

4.8.1 Permanent Steel Sheeting

This Item (552.11) uses steel sheeting to provide permanent support. Associated work may or may not require an excavation. The sheeting is then left in place to function as a structure. Unless stated otherwise on the Contract Plans, only new, unused ASTM A328 steel is to be used.

This sheeting is to be designed by the State or the State’s Consultant. The following information is to be shown on the Contract Plans:

- Plan location of the sheeting placement
- Typical section(s) showing:
  - Elevations for the top and toe of the sheeting.
  - Elevation for the bottom of the excavation, if applicable.
  - Minimum embedment below the bottom of the excavation, if applicable.
  - Payment lines.
  - Location of wales or bracing, if required.
- Minimum section modulus for the sheeting
- If required, minimum section modulus of wales and size of bracing
- Show the same table used for Interim Steel Sheeting (Section 4.6.1) except in the first note change 1.25 to 1.5 for permanent conditions.

4.8.2 Permanent Timber Sheeting

This Item (552.10) uses timber sheeting to provide permanent support. Associated work may or may not require an excavation. The sheeting is then left in place to function as a structure. Unless stated otherwise on the Contract Plans, the timber shall be new, unused material of any acceptable species. It shall be free of any defects that may impair its strength or tightness.

This sheeting is to be designed by the State or the State’s consultant. The following information is to be shown on the Contract Plans:

- Plan location of the sheeting placement
- Typical section(s) showing:
  - Elevations for the top and toe of the sheeting
  - Elevation for the bottom of the excavation, if applicable
  - Minimum embedment below the bottom of the excavation, if applicable
  - Payment lines
  - Location of wales or bracing, if required
- Minimum cross section (use actual dimensions) and stress grade for the timber
If required, minimum cross section (use actual dimensions) and stress grade for the timber of wales and bracing.

Show the same table used for Interim Steel Sheeting (Section 4.6.1) except in the first note change 1.25 to 1.5 for permanent conditions.

### 4.9 Cofferdam and Waterway Diversion Guidelines

The designer should become familiar with the specifications for cofferdams in the most current version of the Standard Specifications for Construction and Materials. The following guidelines shall in no way supersede the specifications.

Cofferdams are temporary enclosures to keep excavations free from earth, water, ice, or snow and to permit the excavation to be carried to elevations shown on the Contract Plans. These elevations may be lower than the planned bottom of excavation due to an undercut. Permanent substructure protection systems are not to be paid for under the cofferdam item.

A waterway diversion is a temporary structure that diverts or pumps water around an area so that excavation or work can be accomplished. The use of a waterway diversion is primarily to provide water quality protection. The area from which water is diverted does not need to be earth, water, ice or snow free. A waterway diversion structure is not a substitution for or equal to a cofferdam. Unlike cofferdams, a temporary waterway diversion structure does not need to be designed by a registered Professional Engineer.

The use of cofferdams, permanent sheeting, stream diversions and associated temporary access fills requires permits, approvals and coordination with various State and Federal regulatory agencies (Department of Environmental Conservation, Corps of Engineers, Adirondack Park Agency, Department of State, U.S. Fish and Wildlife Service, National Marine Fisheries Service, New York City Department of Environmental Protection, U.S. Coast Guard). Permits contain conditions that must be adhered to and shall be included in the Contract Documents (proposal/plans). Regulatory agencies may place seasonal restrictions on work in the waterway, may require restoration plans, and limit the types of materials to be used. The Designer should coordinate with the Regional Landscape/Environmental Unit (RL/E Unit) early in the project design to facilitate environmental reviews and permit/coordination procedures. The Designer must also coordinate with the Regional Hydraulics Engineer regarding the location and number of cofferdams and temporary access fills that may be in place at any given time and the number of construction seasons they will be in place. The Regional Hydraulics Engineer can also assist when choosing between a cofferdam or waterway diversion structure or determine if both are necessary.

A cofferdam item **should be included** in contract plans only if the proposed bottom of footing elevation for a substructure is **below** the Ordinary High Water (O.H.W.) elevation. A cofferdam item is generally **not** called for:

- When existing substructure removal is performed in water (this operation **need not** be performed in a "dewatered" condition unless required by specific project requirements), or
To install stream bank protection (turbidity curtains, dikes, waterway diversions or other erosion and sediment control measures should be utilized, as appropriate, to limit turbidity at the substructure removal site or when performing bank stabilization activities. At times, a closed system may be utilized to confine turbidity without having to be dewatered. Those measures should be paid for under the appropriate Standard Specifications Section 209 pay items).

A temporary waterway diversion structure may be used for operations where stream flow needs to be relocated around a work site but the work site does not require dewatering. For example, placing stone fill along a slope, or excavating for and placing stone fill for keyways.

At the request of the designer, in consultation with the Regional Hydraulics Engineer, the Regional Landscape Architect and/or Environmental Engineer and permitting agency, the cofferdam item shall include additional streambank protection based upon installation timing and waterway flows. No less than a 2-year storm event potential shall be taken into account in designing temporary streambank protection.

When permanent sheeting is called for on the Contract Plans to protect against vessel impact, a cofferdam item shall be included to provide for the cost of de-watering and construction protection. The Contractor will have the option of installing separate cofferdam protection, or incorporating the permanent sheeting in the cofferdam system. If the latter option is chosen, the cofferdam item will cover all additional bracing required to strengthen the sheeting system, if required, and any work necessary to return the permanent sheeting to its required function after the cofferdam operation is complete. On occasion, anchor spuds are driven to facilitate construction of the cofferdam system and they are included in the price bid for the cofferdam.

When the sole purpose of the system is to protect dewatering and construction operations, the entire system will be covered under the cofferdam item.

Where stream diversion or other alternates are allowed as a substitution, the work shall be paid for at the price bid for the cofferdam at that location.

Cofferdams will be paid for on an **each** basis and shown as an enclosed area on the Contract Plans. This will expedite environmental reviews and permit procedures prior to PS&E. Use a separate serialized item number for each cofferdam to assure that varying field conditions are accounted for at each location. Cofferdams will be classified as either Type 1 or Type 2:

**Type 1 (Item 553.01nnnn)** cofferdams are required for a water depth exceeding 8 ft., measured from the bottom of excavation to anticipated Ordinary High Water or when special conditions warrant. They must be designed by a Professional Engineer licensed and registered to practice in New York State retained by the Contractor. The design is submitted to the Engineer-in-Charge for review by the DCES a minimum of twenty (20) working days prior to installation.

**Type 2 (Item 553.02nnnn)** cofferdams are limited to a maximum anticipated depth of 8 ft., measured from the bottom of excavation to anticipated Ordinary High Water. They must be designed by a Professional Engineer licensed and registered to practice in New York State retained by the Contractor. The Contractor submits to the Engineer-in-Charge, for review, the methods to be employed a minimum of ten (10) working days prior to installation. No design computations are required to be submitted.
The Designer shall select the appropriate cofferdam type based on anticipated water elevation and bottom of excavation. Stream integrity characteristics such as high velocity, ice pressure and scour potential may warrant a Type 1 cofferdam even if the depth is less than 8 ft.

For cost estimating purposes, assume that the cofferdam extends 2 ft. above Ordinary High Water and 3 ft. laterally beyond the limits of the proposed footing. See the appropriate section of this manual related to navigable water clearances for additional information. The Contractor shall determine the actual field limits required to satisfy conditions of the specification. (Such as not interfering with battered piles.)

When a cofferdam is used in conjunction with a tremie seal, the designer shall include Note 44 from Section 17.3 on the Contract Plans indicating the critical water elevation at which the system should be flooded in order to prevent the tremie seal from becoming buoyant. The Geotechnical Engineering Bureau will provide the flooding elevation. See Section 11 for additional information on the design of tremie seals.

The location(s) of sediment removal areas shall be indicated on the Contract Plans. The designer should obtain input from the Regional Landscape/Environmental Unit. See Section 17.3, Notes 40 – 44, for standard cofferdam notes to be placed on the contract plans. In some streams the Ordinary High Water elevation can be several feet higher than the Low Water elevation. This could lead to a cofferdam design of excessive size and cost that may be inappropriate for the majority of the construction operation. In consultation with the Regional Hydraulics Engineers it may be appropriate to designate by a note on the plans a more realistic elevation above which the system should be flooded to avoid overloading rather than expect the cofferdam to serve the most severe field condition as inferred in the specification.
## EXCAVATION REQUIREMENTS

**Table 4-2**

<table>
<thead>
<tr>
<th>Item 203.02</th>
<th>Unclassified Excavation and Disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEM 206.01</td>
<td>Structure Excavation</td>
</tr>
<tr>
<td>ITEM 206.02</td>
<td>Trench and Culvert Excavation</td>
</tr>
<tr>
<td>ITEM 206.04</td>
<td>Trench and Culvert Excavation - O.G.</td>
</tr>
<tr>
<td>ITEM 206.03</td>
<td>Conduit Excavation and Backfill</td>
</tr>
</tbody>
</table>

**Removal of Substructures**

| Item 580.01 | Removal of Structural Concrete         |

**Removal of Structural Concrete**

- **Purpose**: General excavation item to remove material not provided for in another item—large excavations using large equipment.

- **Provide**: Small, carefully excavated area with smaller equipment.

- **Provide**: An excavation in a confined space.
  - Example: Pipe and culvert excavations.
  - Example: Conduit and direct buried cable excavations.

- **To partially or fully remove stone or concrete substructures that are not to be repaired or altered and reused.**
  - **Note**: Does not include excavation.

- **Removal of structural concrete from structural concrete elements.**
  - Examples: Patching of abutments and piers; abutment backwall removal to a defined elevation where vertical reinforcing is to remain and the backwall reconstructed.

**Disposal**

- **Included**
- **Included**: No, except select material.

**Dewatering**

- **Included**
- **Included**: No, Yes, Yes, Yes, Yes, Yes, N/A

**Layback Option Available to Contractor**

- **Yes**
- **Yes** if detailed without a support or protection system item.

**Excavation Support System Design Responsibility**

- **Contractor**: If no system is specified (excavation without support system).
- **State or Consultant**: If support system is specified.

**Special Care Required**

- **None, other than reaching grade.**

**Bottom of Excavation to be undisturbed.**

**To not damage remaining concrete, if any is to remain.**

**Payment**

<table>
<thead>
<tr>
<th>Pay Unit</th>
<th>Cubic Yard</th>
</tr>
</thead>
<tbody>
<tr>
<td>urple Yard</td>
<td>Cubic Yard</td>
</tr>
<tr>
<td>4-11</td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td>552.10</td>
<td>Temporary Sheeting</td>
</tr>
<tr>
<td>552.11</td>
<td>Permanent Sheeting</td>
</tr>
<tr>
<td>552.12</td>
<td>Interim Sheeting Support System (Left in Place)</td>
</tr>
<tr>
<td>552.14</td>
<td>Excavation Protection System (for details see Section 9.3.12 of HDM)</td>
</tr>
</tbody>
</table>

*If detailed without a support system. See Guidelines Table 4-3 Excavation Requirements
### Cofferdam Requirements

**Table 4-4**

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Pay Unit</th>
<th>Review by New York State:</th>
</tr>
</thead>
<tbody>
<tr>
<td>553.01</td>
<td>Cofferdams (Type 1)</td>
<td>Each</td>
<td>Contractor, NYS Professional Engineer</td>
</tr>
<tr>
<td>553.02</td>
<td>Cofferdams (Type 2)</td>
<td>Each</td>
<td>Contractor, NYS Professional Engineer</td>
</tr>
<tr>
<td>553.03</td>
<td>Temporary Waterway Diversion Structures</td>
<td>Each</td>
<td>Contractor, NYS Professional Engineer</td>
</tr>
<tr>
<td>Item 4-13</td>
<td>Depth: Exceeding 8 ft. or special conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>intended:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Methods to be employed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Divert flow</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temporary Waterway Diversion Structures</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Materials**: New or used timber or steel sheeting, impermeable earth-filled bags, precast concrete, commercially designed system. Such as a Portadam.
- **New or used timber or steel sheeting**: Pre-cast concrete, commercially designed system.
- **Impermeable earth-filled bags**: Pre-cast concrete, commercially designed system.
- **Pay Unit**: Each
- **Review by New York State**: Contractor, NYS Professional Engineer, contractor, NYS Professional Engineer, contractor, NYS Professional Engineer.
- **Depth**: Exceeding 8 ft. or special conditions.