STATE OF OHIO
DEPARTMENT OF TRANSPORTATION

SPECIFICATION FOR DESIGN OF CANTILEVER SOLDIER PILE WALLS

June 11, 2019

A. DEFINITION

Soldier pile walls consist of a row of drilled shafts spaced at typically a 4-foot to 8-foot center-to-center spacing. HP-section or W-section steel beam sections (soldier piles) are inserted vertically into the shafts, with the webs of the steel sections placed parallel to the direction of the loading from the retained soil mass. Structural concrete is poured into the shafts up to the bottom of the proposed depth of lagging. Low-strength mortar (LSM), per C&MS Item 613 is often poured on top of the structural concrete to finish filling the holes. The soil and LSM is then excavated down to the top of the structural concrete. As excavation progresses, treated timber or precast concrete lagging panels are inserted in-between the steel soldier pile beams for temporary support, held in place by the flanges of the beams. A final cast-in-place facing is applied to the front of the steel soldier pile beams, attached by the use of welded shear studs. The final facing is considered structural, and shall be designed to resist the entire earth pressure load.

B. P-Y METHOD ANALYSIS

Once the load on the soldier pile is determined, we need to determine the reaction of the soldier pile to the load, including the soldier pile head displacement, the shear and moment distributions, and determine whether the soldier pile is structurally capable of resisting the load. Any capable p-y analysis software, such as COM624P, LPILE, or FBPIER may be used. ODOT currently uses the program LPILE, developed by Ensoft, Inc., therefore, the examples in this section will refer to this program.

1. Distributed Lateral Loading per Pile

Active earth pressure (EH) loading on the wall shall be as represented as a triangular distributed load as per the AASHTO LRFD Bridge Design Specifications, Figures 3.11.5.6-1 and 3.11.5.6-2, between the top of the wall and the Design Grade. The actual load distribution is complex, and impossible to determine without direct measurement or back-calculation through measurement of displacements; however, a triangular load distribution is a close enough approximation of the actual condition to develop a realistic calculation of distributed shear, moment, and displacement in the soldier pile. Where the wall is within the influence zone of a live load, a live load surcharge (LS) shall be added to the active earth pressure load between the top of the wall and the Design Grade.

The wall loading is represented solely as a horizontal distributed load, with no vertical component, as this is a more conservative assumption, providing the maximum lateral loading. Research has shown that the vertical load component is either insignificant, or tends to provide a small amount of compression to drilled shaft foundations, which marginally increases bending resistance. If using LPILE, the distributed load must be converted into units of pounds per inch (lb/in) of length along the soldier pile.

The soldier pile model in the p-y analyses shall be from proposed top of pile elevation to the estimated tip elevation. We do not advocate the method of representing the load on the soldier pile as a single resultant point load, and "cutting off" the top of the pile at the point of application of this resultant load. This method does not realistically predict either the shape or magnitude of shear and moment distributions, and cannot predict the displacement at the soldier pile head.

2. p-y Modification Factors for Group Action

If drilled shaft foundations are placed at a center-to-center spacing closer than 3.75 diameters, a p-multiplier reduction in the soil resistance p, for the p-y curve behavior of the soil, must be considered. The loss in capacity is due to soil-structure-soil interaction, and an overlap in the region of the soil that provides passive resistance to the deflection of the drilled shaft foundations when placed in a closely-spaced group. This effect does not occur where drilled shafts are embedded in a relatively much stiffer material, such as bedrock, where the stress field effects are very limited, and the material does not deform substantially under the design loadings. Therefore, apply the p-multiplier from the Design Grade to the top of bedrock or to the bottom of the drilled shaft foundations, whichever is shallower.

Reese, Isenhower, and Wang, "Analysis and Design of Shallow and Deep Foundations" (2006) publish an equation for the pile group p-multiplier for a single row of piles placed side by side, $p_m = 0.64(S/D)^{0.34}$, for $1 \leq S/D < 3.75$, where $0.5 \leq p_m \leq 1.0$. This is an empirical relationship based on testing by a number of researchers in a number of different soil types. We recommend this equation for determination of the p-multiplier.

3. Soil Layering and p-y Models

Set the ground surface in LPILE equal to the Design Grade, and model all soil layers below the Design Grade as in the proposed condition.

4. Drilled Shaft Length

The drilled shaft foundations shall be embedded in a solid stratum such that deflection at the soldier pile head will be constrained to appropriate serviceability limits (see Section B.8, below, for details of the required serviceability limits). Total drilled shaft length shall also be selected such that the drilled shaft is geotechnically stable (see Section B.9, below).

5. Steel Soldier Pile Beam Section

Analyze the pile structurally as a steel pile without concrete, although the steel beam section is actually embedded in a concrete shaft. However, assume that the concrete encased section is restrained from both local and lateral buckling by the concrete embedment. We acknowledge that this is conservative, as it is generally recognized that the concrete stiffens the web and allows an increased shear and bending resistance due to tension field effects and composite action. However, at present there is little research into the shear resistance of concrete encased steel sections. The AISC code addresses concrete encased steel sections and specifies that the shear resistance be based on the steel section alone. In the case of steel beam section reinforced drilled shafts, the concrete exists primarily to transfer load to the steel member, and we are relying on the steel for shear and bending resistance. Although this produces a conservative design, we recommend this approach until more research is available into the behavior of composite sections. In the case of the un-encased section of the soldier pile, this approach is not overly-conservative, as the steel sections are exposed above the concrete to support the lagging. This portion of the pile is not considered to be braced against buckling, and both lateral torsional bucking and flange local buckling will need to be checked.

6. Section Type, Dimensions, and Cross-section Properties

When analyzing a soldier pile, select "Elastic Section (Non-yielding)" under the Section Type in LPILE. This Section Type will result in an elastic analysis (corresponding to LPILE Analysis Type 4, "Computations of Ultimate Bending Moment and Pile Response with User-Specified EI," in previous versions of LPILE) which uses a constant beam stiffness, which is unaffected by deflection of the beam.

Select the Structural Shape "Circular without Void" under Dimensions and Properties. In order to develop the proper reaction from the soil in LPILE, set the Elastic Section Diameter equal to the nominal borehole diameter for the drilled shaft foundation. However, set the Moment of Inertia and Area under Elastic Section Properties equal to the actual values of I_X and A_S for the embedded HP-section or W-section steel beam. Set the Modulus of Elasticity equal to that for a steel section alone (approximately 29,000,000 psi), not for a composite section.

Set the ground surface as level or inclined per the proposed slope of the Design Grade.

Unless there is a constructability concern which dictates a smaller rock socket diameter, the diameter of the drilled shaft foundation should be the same over its entire length. The structural steel used in a steel soldier pile beam section shall have 50 ksi yield strength. For a soldier pile drilled shaft foundation, Class QC 1 concrete may be used, instead of Class QC 5 concrete per C&MS Item 524 Drilled shafts. If the drilled shafts are of 7 feet or greater in nominal diameter, QC 4 Mass Concrete must be specified instead.

7. Pile-Head Loadings and Options

At head, the soldier pile should be free to move both laterally and rotationally. In LPILE, there are multiple Pile-Head Loading Type options to define boundary conditions and loading at the pile head. The option "1 Shear [F] & 2 Moment [F-L]" should be selected, with a value of zero (0) input for both the shear and moment loading. This defines a pile which is free at the head, with a moment and shear which will decrease to zero at the pile head. All other options define rotational or displacement fixity of the pile head or define a deformation at the pile head.

Set the option "Compute Top Y vs. L?" to "Yes," as this will aid in determining the required length of the drilled shaft foundation to resist the lateral loading (see Sections B.8 and B.9.a below).

Horizontal earth pressure (EH) loading on the soldier piles shall be represented as a triangular distributed load – as noted in Section B.1 – with a value of zero at the retained ground surface (pile head), and a maximum at the depth of the Design Grade. If the horizontal distance between the soldier piles and traffic loading is less than or equal to half the retained height (the depth between the pile head and Design Grade), also apply an (unfactored) vehicular live load surcharge (LS) to the soldier piles equal to two feet of soil with a unit weight γ_s = 125 pcf, per AASHTO LRFD Bridge Design Specifications, Article 3.11.6.4.

Run LPILE twice for each loading case; running analyses with unfactored loading for the Service (I) Limit State, to determine soldier pile head deflection; and with factored loading for the Strength (I) Limit State, to determine the structural capacity of the soldier pile. For the factored Strength Limit State condition, use a load factor of γ_{LS}=1.75 for the vehicular live load surcharge (LS) and a load factor of γ_{EH}=1.50 for the horizontal earth pressure (EH), per AASHTO LRFD Bridge Design Specifications, Article 3.4.1.

8. LPILE Output

After the computational analysis of the soldier pile behavior is completed, there are several items which should be inspected immediately. LPILE can produce a plot of "Top Deflection versus Length" (see Section B.7, above). For both the unfactored Service Limit State analysis and the factored Strength Limit State analysis, the length(s) at which either of these plots climbs to infinity or becomes indeterminate is the point at which the soldier pile length becomes too short, and a length will have to be chosen beyond this point. If it appears that several iterations may be required to determine the optimal soldier pile length through incremental increases, it may be more efficient to analyze a soldier pile which is known to be too long, and then cut down the soldier pile length to the optimal point. Note that we do not recommend an embedment of less than 10 feet below the Design Grade, regardless of the results of the deflection plots.

LPILE also generates a plot of Lateral Deflection versus Depth and calculates a (maximum) Pile-head deflection. For the unfactored Service Limit State analysis, the maximum Pile-head deflection must be limited to 1% or less of the retained height (the depth between the pile head and Design Grade); however, if the soldier pile wall is to be installed within 10 feet of the edge of pavement, the Pile-head deflection must be limited to 2" or less. Use whichever serviceability limit requires the least deflection. If the soldier pile deflects more than the required serviceability limit, we consider this to represent failure, and a stiffer soldier pile beam section or larger diameter drilled shaft foundation will have to be selected and re-analyzed.

LPILE also provides maximum values for shear and moment in the soldier pile. Use these values, from the factored Strength Limit State analysis, in the structural analysis of the soldier pile, in order to determine if it is structurally capable of resisting the loading without failing in either bending or shear.

9. Geotechnical Resistance

A check of geotechnical resistance against overturning of the soldier pile shall also be performed. The check of geotechnical resistance is not a consideration of the structural capacity of the soldier pile, but of the geotechnical resistance of the soil and bedrock to resist excessive overturning movement of the soldier pile. Two options are available for performing this check:

a. LPILE Deflection Analysis

This is by far the simpler method to check geotechnical resistance. Consider the Pile-head deflection calculated by LPILE from the factored Strength Limit State analysis. If the deflection does not indicate failure – either failure of the program to converge at a solution, an infinite deflection, or a very large deflection (typically around 100 inches) – then the soldier pile is considered to be stable, with adequate geotechnical resistance against overturning. It is acceptable for the Strength Limit State analysis deflection to be quite large, as long as the Service Limit State analysis deflection meets the required serviceability limits (see Section B.8, above). The LPILE plot of Top Deflection versus Length can be helpful to find the point of optimized soldier pile length.

b. Moment Equilibrium Analysis

Demonstrate moment equilibrium about the toe of the soldier pile, per AASHTO LRFD Articles 3.11.5.6, 11.6.3.5, and 11.8.4.1, with reference to AASHTO LRFD Figures 3.11.5.6-1 and 3.11.5.6-2, and utilizing the methodology as outlined in AASHTO LRFD Commentary C11.8.4.1. Please note that Figures 3.11.5.6-1 and 3.11.5.6-2 do not include the effects of vehicular live load surcharge (LS), which will have to be added by the engineer. Also note that the figures do not utilize load or resistance factors (all loads shown are nominal); apply appropriate load and resistance factors as described by AASHTO LRFD Commentary C11.8.4.1.

If the soldier pile exhibits excessive deflection or cannot achieve moment equilibrium at the analyzed length, this is considered failure. In this case, deeper embedment of the soldier pile or a larger diameter drilled shaft foundation may be required to meet the requirements of geotechnical resistance against overturning.

Please note that ODOT does not advocate utilizing the Geotechnical Strength Limit State check per *FHWA Geotechnical Engineering Circular No. 10, Publication FHWA-NHI-10-016, Drilled Shafts: Construction Procedures and LRFD Design Methods* (GEC 10), Section 12.3.3.3.1. We consider this check to produce overly conservative results.

C. Steel Beam Section Design

After determining the Service Limit State lateral deflection of the pile and the Strength Limit State moment and shear distributions for the single pile load by analysis with an appropriate software package, such as LPILE, COM624P, or FBPIER, check that the soldier pile is capable of resisting the calculated factored maximum moment and maximum shear force.

At this time, ODOT is utilizing Load and Resistance Factor Design (LRFD) methods, per AASHTO LRFD Bridge Design Specifications, for the design of steel beam sections resisting shear and moment due to lateral earth loadings. Per FHWA Policy Memorandum Related to Structures, dated June 28, 2000, Load and Resistance Factor Design (LRFD) Specifications are required for all new culverts, retaining walls, and other standard structures on which States initiate preliminary engineering after October 1, 2010. It is no longer acceptable to use Load Factor Design (LFD) methods or Allowable Stress Design (ASD) methods.

We recommend using steel with a minimum yield stress (F_y) of 50 ksi (ASTM A709[M] grade 50) for soldier pile beam sections. Per ODOT Bridge Design Manual, Section 302.4.1.1.C, ASTM A709[M] grade 36 is not recommended and is being discontinued by the steel mills.

1. Minimum Concrete Cover for Steel Soldier Pile

Ensure that the steel soldier pile can fit within the drilled shaft foundation with the minimum required concrete cover per BDM 301.5.7 and C&MS 509.04.B for steel reinforcements. The minimum concrete cover between soil and steel reinforcement for a drilled shaft of 4 feet or less in diameter is 3 inches. The minimum concrete cover between soil and steel reinforcement for a drilled shaft greater than 4 feet in diameter is 6 inches.

2. Load and Resistance Factor Design (LRFD)

For LRFD, use a load factor of γ_{LS}=1.75 for the vehicular live load surcharge (LS) and a load factor of γ_{EH}=1.50 for the horizontal earth pressure (EH), per AASHTO LRFD Bridge Design Specifications, Article 3.4.1. Use factored loading and resistance for structural capacity (flexure and shear) design of the steel soldier pile beam section. Use a resistance factor φ_f=1.00 for flexural resistance and a resistance factor φ_v=1.00 for shear resistance per AASHTO Article 6.5.4.2. Check the flexure resistance of the steel beam section according to AASHTO Article 6.10.8. Check the shear resistance of the steel beam section according to AASHTO Article 6.10.9. For the portion of the steel section embedded in the concrete drilled shaft foundation, assume that it has continuous lateral bracing and transverse stiffening. For the portion of the steel soldier pile beam section that extends above the drilled shaft foundation, assume it is unbraced, and analyze the steel section for flexural buckling with an unbraced length equal to the exposed length, per AASHTO Article 6.9.4.1.2.

3. Iterative Design Process

Use an assumed steel section for LPILE (or other comparable software) analysis to determine the soldier pile head deflection (unfactored loading) and distributed and maximum moment and shear (factored loading) for the beam. Check that the selected steel section is capable of resisting the calculated maximum moment and maximum shear per AASHTO LRFD procedures, and check that the soldier pile head deflection is less than the required serviceability limit (see Section B.8 above). If these requirements are not met, select a more capable steel section. If the minimum capable steel soldier pile beam section will not fit within the selected nominal drilled shaft foundation diameter with the minimum required concrete cover, a larger diameter drilled shaft will need to be considered. If the deflection, flexure, and shear requirements are greatly exceeded, consider selecting a lighter steel section (and possibly smaller diameter drilled shaft) to save cost.

Every time a new steel section or a new nominal drilled shaft diameter are selected, recalculate the soldier pile reaction with LPILE, and check the deflection and the flexure and shear resistance of the steel section per AASHTO LRFD specifications.

D. PLAN NOTES

The following plan notes are provided for inclusion in the plans for soldier pile walls. Most of the plan notes are applicable to all soldier pile walls. Choose the appropriate lagging note depending on whether timber or precast concrete lagging is to be used.

Designer Notes: These notes are for soldier pile and lagging walls with the soldier pile placed into a drilled hole. The notes assume that the retaining wall was designed to rely only on the soldier pile and that the concrete in the drilled shaft is only to fill the void and is not structurally significant. These notes are not appropriate for walls with tiebacks.

Indicate on the plans the steel section required for the soldier pile (e.g. HP 10x42) and the length of the soldier pile that will be galvanized (if any). Edit the note to indicate the maximum depth to bedrock assumed for the design. Show LSM filling the drilled hole above the concrete when necessary. It may not be necessary in all situations.

When precast concrete lagging is to be used, show the design of the precast lagging in the plans, including dimensions, rebar sizes, and locations. Modify the required concrete strength for the lagging if necessary. For the design of the lagging, assume that at least 4 inches at each end of the lagging will be supported by the soldier pile flange.

If the soldier pile and lagging wall will be permanent, provide drainage in the plans consisting of either drainage backfill behind the lagging, or prefabricated geocomposite drain (PGD) strips attached to the face of the lagging (for timber lagging only).

Item 507, Steel Piles, Misc.: Soldier Piles

This work consists of furnishing and placing steel soldier piles into drilled holes. Furnish soldier piles consisting of structural steel members that meet the plan requirements and conform to ASTM A572, Grade 50. Galvanize soldier piles as shown on the plans and in accordance with C&MS 711.02. Do not field weld or splice steel soldier piles.

The Department will measure soldier piles along the axis of the soldier pile from the top of wall elevation to the bottom of the drilled shaft, as determined by the Engineer. The Department will pay for Soldier Piles at the contract unit price per foot for Item 507, Steel Piles, Misc.: Soldier Piles.

Item 524, Drilled Shafts, __" Diameter, Above Bedrock, As Per Plan
Item 524, Drilled Shafts, __" Diameter, Into Bedrock, As Per Plan

This work consists of furnishing and installing drilled shafts for soldier pile and lagging walls. The drilled shafts are reinforced with soldier piles instead of reinforcing steel cages. The soldier piles extend above the top of the drilled shaft. Furnish and install the drilled shafts in accordance with C&MS 524 except as modified and supplemented below.

Excavate the hole for the drilled shaft within 3 inches of the plan location. Place the soldier pile within the hole so it is vertical and not inclined more than 1 inch between top to bottom. Place the soldier pile so that the flanges are parallel to the centerline of the row of drilled shafts. Do not allow the orientation of the flanges to vary by more than 10 degrees. Support the soldier pile so that it does not move during concrete placement.

Use Class QC 5 concrete according to C&MS 511. Place concrete to the elevation for the top of the drilled shaft. The Contractor may place concrete using the free fall method provided the depth of water is less than 6 inches and the concrete falls without striking the sides of the hole. Pouring concrete along the web of the soldier pile is acceptable.

Check the position, the vertical alignment and orientation of the soldier pile immediately after concrete placement. Make corrections as necessary to meet the above tolerances. If shown on the plans, fill the hole above the bottom of the lagging to the existing ground surface with Item C&MS 613 Low Strength Mortar Backfill (LSM).

Remove concrete and LSM as necessary from around the soldier pile in order to place the lagging. Place lagging so that the soldier pile flange overlaps the end of the lagging by at least __ inches at both ends of the lagging. Wait at least 12 hours after placing concrete before placing lagging.

Sequence of Installation: The installation sequence shall be such that no drilled shaft is installed adjacent to either an open drilled shaft excavation or a drilled shaft in which the concrete has less than a 48 hour cure. Installing the shafts in an alternating sequence or any other sequence that meets this criteria is permissible.

Protection of Unattended Open Shafts: Care shall be exercised as to cover unattended open shafts. Temporary covers shall be of adequate strength to prevent a person or animal from falling in. No drilled shaft excavation shall be left un-poured overnight.

The contractor shall be responsible for the means and methods used to construct the drilled shafts and place lagging. Any temporary grading, excavation, embankment, aggregate, drainage, sheeting, etc. needed to complete the work shall be included in the bid price for the drilled shafts. The cost of any excavation and subsequent replacement of embankment (per Item 203 Embankment) shall be included in the various bid items for the drilled shafts and lagging, unless separately itemized. No separate payment will be made.

Method of Measurement: The Department will measure Drilled Shafts Above Bedrock, As Per Plan, along the axis of the drilled shaft from the existing ground surface to the top of bedrock, as determined by the Engineer. The Department will measure Drilled Shafts Into Bedrock, As Per Plan, along the axis of the drilled shaft from top of bedrock to the bottom of the drilled shaft, as determined by the Engineer.

Payment is full compensation for constructing the drilled shafts, including furnishing and placing concrete and LSM, removal of concrete or LSM from around the soldier pile in order to place lagging.

Item Special - Retaining Wall, Misc.: Timber Lagging

This work consists of furnishing and placing timber lagging between the soldier piles as temporary support for the retained soil. Furnish timber lagging consisting of construction grade, untreated hardwood with a minimum thickness of __ inches. To permit drainage, provide 1/4 to 1/2-inch spaces between lagging boards using 3/8-inch thick spacer blocks or other means acceptable to the Engineer. Place the lagging boards between the flanges of the soldier piles and bearing against the flanges on the exposed side of the wall so that the soldier pile flange overlaps the end of the lagging by at least 2 inches at both ends of the lagging boards. Excavation for placement of the lagging shall be performed in such a manner that the lagging is tight against the excavation cut face. Any voids behind the lagging shall be backfilled with suitable compacted material as directed by the Engineer. The cost of any such backfilling required, including material, placement and compaction, shall be incidental to the cost of the lagging.

The Department will pay for Timber Lagging at the contract unit price per square foot for Item Special, Retaining Wall, Misc.: Timber Lagging.

Item Special – Retaining Wall, Misc.: Precast Concrete Lagging

This work consists of furnishing and placing precast reinforced concrete panels between the soldier piles to function as lagging for the retaining wall. Provide precast concrete lagging from a precast concrete manufacturer certified according to Supplement 1073. Provide class QC1 concrete with a 28-day design strength of at least 4000 psi according to C&MS 499. Provide epoxy coated reinforcing steel according to C&MS 709.00. In lieu of epoxy coating, a corrosion inhibiting concrete admixture may be used at the specified dosage rate. A qualified product list of corrosion inhibiting admixtures is on file at the Laboratory. Manufacturers should recognize that the corrosion inhibitor may affect the strength, entrained air content, workability, etc. of their concrete mixes. The manufacturer's choice to use one of these corrosion inhibitors does not alleviate meeting all design requirements. Do not allow the dimensions of the lagging or location of the reinforcing steel to vary by more than ¼-inch. Permanently mark each panel to indicate which face will be placed against the soil. Place the panel between the flanges of the soldier piles and bearing against the flanges on the exposed side of the wall so that the soldier pile flange overlaps the end of the lagging by at least one inch more than the concrete cover over the reinforcing steel at both ends of the lagging. When installing the precast concrete lagging panels, place hardwood wedges to hold the lagging panels against the front inside flange of the steel piles.

Payment for all labor, equipment, and material required to fabricate, transport, and install the precast reinforced concrete panels shall be made at the contract unit price per square foot for Item Special, Retaining Wall, Misc.: Precast Concrete Lagging.

Item 513 - Welded Stud Shear Connectors

Weld headed steel studs to the flanges of the soldier pile in order to connect the concrete wall facing to the soldier pile. Attach headed studs according to C&MS 513.22 and as shown in the plans. The contractor may attach the studs either before placing the soldier pile in the drilled hole or after excavating in front of the wall. Protect the headed studs from damage until the concrete wall facing is poured. Repair or replace damaged headed studs at no expense to the department.

Item 518, Structure Drainage, Misc.: Prefabricated Geocomposite Drain

This work consists of furnishing and placing prefabricated geocomposite drain (PGD) strips against the timber lagging, in place of conventional wall drainage per C&MS 518.

A. Furnishing. Furnish PGD in rolls, or in another acceptable manner, wrapped with an opaque, waterproof wrapping. Label or tag each roll or package to provide product identification sufficient to determine the product type, manufacturer, quantity, lot number, roll number, and date of manufacture. Prior to installation, protect the PGD from mud, dirt, dust, debris, harmful ultraviolet light, direct sunlight or temperature greater than 140 ˚F (60 °C). Furnish 3-inch (76mm) wide, plastic tape for the sealing, seaming, and splicing the PGD. Furnish waterproof tape designed for underground applications that provides a strong bond that does not deteriorate over time in a buried condition. Furnish fittings and accessories provided by the manufacturer if available.

B. Preparation. Prepare the surface of the lagging, on which the PGD is to be placed, to be free of soil, debris, and excessive irregularities that prevent continuous contact between the lagging surface and the PGD.

C. Placement. Place PGD strips between the soldier piles, from edge of soldier pile to edge of soldier pile to provide continuous coverage over the face of the wall. Unroll PGD directly onto the prepared surface. Do not drag the PGD across the ground. Tension the PGD to remove any creases or wrinkles. Do not expose PGD to weather or direct sunlight for longer than 5 days. Place the geotextile fabric side to face toward the backfill or retained soil.

Construct the PGD in horizontal or vertical courses. Place the PGD in direct contact with the wall and secure to the surface using either adhesives per manufactures recommendation or nails as follows. Secure with 2-inch (51 mm) or longer concrete nails along with washers or wood battens of not less than 9 square inches (5887 square mm). Space the concrete nails no more than 3 feet (0.9m) apart, both horizontally and vertically. Use at least one horizontal row of nails in each horizontal course of PGD, or use at least one vertical column of nails in each vertical course of PGD. Do not affect the drainage area and the downward flow in the drain by the adhesive or fasteners.

D. Splicing and covering. Form horizontal or vertical seams between courses by utilizing the flap of geotextile extending from one course and lapping over the flap on that of the next course. Securely fasten the overlapped flaps with a continuous strip of 3-inch (76mm) wide, waterproof, plastic tape.

Where splices are necessary without a geotextile flap, place and center a 12-inch (0.3m) wide continuous strip of geotextile over the seam and fasten with continuous strips of 3-inch (76mm) wide, waterproof, plastic tape.

As an alternative method of splicing, either horizontally or vertically, rolls of PGD may be joined together by turning back the geotextile flap at the roll edges and interlocking the drainage core approximately two inches. Fold the flap under and tape it beyond the seam with 3-inch (76mm) wide, waterproof, plastic tape. Shingle lap the core and fabric in the direction of water flow.

To prevent soil intrusion, cover all exposed edges of the PGD core by tucking the geotextile flap over and behind the core edge. Alternatively, a 12-inch (0.3m) wide strip of geotextile may be used to wrap the edge, taping it to the geotextile side 8 inches (203mm) in from the edge with a continuous strip of 3-inch (76mm) wide, waterproof, plastic tape and folding the remaining 4 inches (102 mm) over and behind the core edge. Caps (bottom, top, or end) provided by the manufactures can also be used according to manufacturer's instructions.

Construct all seams, splices, and caps to prevent soil or concrete material from entering the PGD.

E. Connecting to Weep Holes and Pipe Outlet. Connect the PGD to the drainage system as shown on the plans or per manufacturer's recommendations if not shown in the plans. Maintain a positive outlet for the water in the PGD at all locations.

Do not seal, block or restrict weep holes with the PGD. If available, use weep hole fittings provided by the manufacturer and installed to the manufacturer's instructions. If the PGD core is not perforated at the weep hole location, make a hole in the PGD core matching the diameter of the weep hole or larger to accommodate the pipe or fitting. When making holes in the core, do not damage the geotextile fabric.

Use manufacturer provided outlet fittings that transition between the PGD and the outlet pipe, and prevent material from entering the outlet pipe. If manufacturer fittings are not available, provide smooth-lined or corrugated outlet fittings according to manufacturer's recommendations. Fasten and seal outlet fittings to the wall drains according to manufacturer's recommendations.

F. Repair. Patch or replace damaged PGD. Remove the damaged area and place a PGD patch and splice the edges according to section D. If the damaged portion is larger than 50 percent of the PGD roll width, cut across the entire width of the roll to remove the damaged portion and splice according to section D.

If damage is limited to tears in the geotextile fabric, place a geotextile patch extending 6 inches (152 mm) beyond the damaged area in all directions or to the edge of the roll, and seal the entire perimeter with 3-inch (76 mm) wide, waterproof, plastic tape.

Replace and repair damaged PGD at no additional expense to the Department.

G. Permanent Face Construction. Replace or repair any PGD component that is damaged during the wall face construction.

H. Prefabricated Geocomposite Drain. All numerical values listed in the required property tables shown below represent minimum average roll values (MARV) per ASTM D 4759 unless indicated otherwise. Values for the weaker principal direction should be used. Testing shall be performed in accordance with the methods referenced in this specification. Sampling of lots shall be in accordance with ASTM D 4354.

Furnish Prefabricated Geocomposite Drain (PGD) consisting of a drainage core with geotextile fabric bonded to one side. Use drainage core material consisting of a preformed, stable, polymer plastic material with a cuspated or geonet structure. Use drainage core that supports the geotextile and provides a bonding surface for the geotextile at intervals not exceeding 1-1/8 inches (29mm) in any direction. Supply core that provides at least 14 square inches per square foot of flat area in contact with the geotextile.

Furnish a geotextile fabric composed of over 85% of polyester, polypropylene, polyolefin, or polyamide fibers by weight, that are formed into a stable network to ensure the performance during handling, installation, and service life. Use geotextile fabric that is resistant to chemical attack, rot, and mildew. Use geotextile fabric that is free of treatments or coatings that would adversely change the hydraulic properties of geotextile after installation. Furnish PGD that has the geotextile fabric covering the full length of the drainage core and has minimum 3-inch (76mm) wide flaps/flanges of fabric extending beyond both longitudinal edges of the drainage core. Do not supply PGD that has ripped or torn geotextile fabric.

Submit Certified Test Data showing the product will meet or exceed the requirements listed in **Table 1 and Table 2.**

Table 1. Physical, mechanical and hydraulic requirements for the core of the PGD

<table>
<tr><td rowspan="2">Property</td><td rowspan="2">Test Method</td><td rowspan="2">Unit</td><td colspan="3">Required value,
conventional abutment/wall height in ft (m)</td></tr>
<tr><td><10 (3)</td><td>10 (3) to 30 (9)</td><td>30 (9) to 50 (15)</td></tr>
<tr><td>Thickness</td><td>ASTM D5199</td><td>in (mm)</td><td colspan="3">0.4 (10) to 1.0 (25)</td></tr>
<tr><td>Compressive Strength</td><td>ASTM D1621</td><td>psf (kPa)</td><td>4625 (221)</td><td>10625 (508)</td><td>16625 (796)</td></tr>
<tr><td>In-plane flow rate*</td><td>ASTM D4716</td><td>gal/min/ft (l/min/m)</td><td>5 (62)</td><td>15 (186)</td><td>25 (310)</td></tr>
</table>

* Tested under a confining pressure of 3,600 psf (172kPa) and a hydraulic gradient of 1.0.

Table 2. Strength and hydraulic requirements for the fabric of the PGD

<table>
<tr><td rowspan="2">Property</td><td rowspan="2">Test Method</td><td rowspan="2">Unit</td><td colspan="3">Requirement, percent in situ soil passing 0.075 mm</td></tr>
<tr><td><15</td><td>15 to 50</td><td>>50</td></tr>
<tr><td>Permittivity</td><td>ASTM D4491</td><td>sec^{-1}</td><td>≥0.5</td><td>≥0.2</td><td>≥0.1</td></tr>
<tr><td>AOS</td><td>ASTM D4751</td><td>mm</td><td><0.43</td><td><0.25</td><td><0.22</td></tr>
<tr><td>Grab Strength</td><td rowspan="2">ASTM D4632/D4632M</td><td>N (lb)</td><td colspan="3">≥700 (157)</td></tr>
<tr><td>Elongation</td><td>%</td><td colspan="3">≥50</td></tr>
<tr><td>Trapezoidal Tear Strength</td><td>ASTM D4533/D4533M</td><td>N (lb)</td><td colspan="3">≥250 (56)</td></tr>
<tr><td rowspan="2">Puncture Strength</td><td>ASTM D6241</td><td>N (lb)</td><td colspan="3">≥1375 (309)</td></tr>
<tr><td>ASTM D4833</td><td>N (lb)</td><td colspan="3">≥260 (58)</td></tr>
</table>

I. Basis of Payment. The following estimated quantity has been carried to the General Summary to complete the above work:
Item 518, Structure Drainage, Misc.: Prefabricated Geocomposite Drain, ____ SF