* 1. section 504
	Mechanically Stabilized Earth Walls

DESCRIPTION

* + 1.

This work consists of constructing a Concrete Panel Facing Mechanically Stabilized Earth (MSE) Retaining Wall System at the locations and to the lines and grades shown on the plans. Either metallic or geosynthetic reinforcement (woven fabrics or geogrids) as specified in this specification may be used as MSE reinforcement in the reinforced structure backfill zone. The retained structure backfill zone is the structure backfill retained by the reinforced structure backfill zone as shown on the plans.

MATERIALS

* + 1. Shop Drawings.

 The Contractor shall submit one electronic submittal of shop drawings and certified material test reports for review prior to construction of the wall. See subsection 504.07, for a complete list of submittal requirements. Shop drawings shall be submitted in accordance with subsection 105.02.

The shop drawings shall provide the details necessary to demonstrate compliance with the Contract, including:

1. *Wall Layouts.* Wall layouts shall conform to lines and grades on the plans including start, corner, and end stations, leveling pad step breaks, total number of panels, and top and bottom of wall elevations. For walls with rail anchoring slabs, the top of panel elevations shall be within 8 inches of the elevation shown on the plans measured from the bottom of the anchoring slab. The construction batter required to achieve the batter shown on the plans shall be shown on the shop drawings. If temporary walls are required for the construction of the permanent wall, the permanent wall vendor shall provide the shop drawings and certified material test reports for temporary walls.
2. *Panel and Reinforcement Locations.* Unless otherwise shown on the plans, each layer of soil reinforcement shall be connected to the back of each facial panel and the panel numbering and placement sequence shall be shown. The back of each panel shall be logically numbered with its location.

Panel to panel, panel to reinforcement connection detail, and limits of special panels at curved wall corner shall be shown.

1. *Wall Elevations.*  Except for the top of the leveling pad, wall elevations given on the plans are based on the desirable wall height. The actual panel and reinforcement elevations shall be marked on the shop drawings by taking into account the supplied panel as well as special panel heights for matching the front and top finished grade.
2. *Soil Reinforcement Material.*  The soil reinforcement type, Minimum Average Roll Value of the Ultimate tensile strength TULT (MARV) for geosynthetic soil reinforcement or yield strength for metallic soil reinforcement, spacing, lengths, elevations, and the corresponding wall design height shall be shown on the shop drawings. The starting and ending stations for change in grade of reinforcement material shall be shown for walls with different grade of reinforcement material at the same elevation. Material grade shall be clearly identified on each roll of reinforcement to avoid errors in placement. Elevations of the reinforcement layers shall be as specified on the shop drawings.
3. *Soil Reinforcement Length (RL)*. The soil reinforcement length shall be measured from the front face of wall for panel less than 12 inches deep and from the back face of wall for panel greater than 12 inches deep to the end of the soil reinforcement as measured to the neat end. Soil reinforcement lengths shall not be less than the lengths specified on the plans.

The Reinforcement Lengths shown on the shop drawings shall be the reinforcement length required for internal stability and pull-out only. External stability (bearing pressure, sliding, and overturning) and global stability shall already be checked by the design Engineer.

1. *Panel Size and Soil Reinforcement Spacing*.

Except for full height panels, the maximum panel size is 50 square feet and the minimum panel height shall be 30 inches.

For full height panels, the maximum panel width shall be 10 feet and the maximum panel height shall be 40 feet. Differential deflection between adjacent panels shall be limited to 1/500. The vendor shall supply design calculations regarding panel concrete crack size control during shipment and construction and estimated joint width and differential deflection limits. The use of full height panels with widths greater than 10 feet or heights greater than 40 feet shall be approved by the Engineer.

The maximum vertical spacing between layers of adjacent soil reinforcement shall not exceed 30 inches. Except the half height panel used at the top and bottom of the wall, including all partial and extended height panels at the top of the wall, there shall be at least two layers of reinforcement per panel.

The first and bottom layers of reinforcement shall be within 15 inches measured from the top of panel and from the top of leveling pad accordingly.

Shiplap joints shall be required at horizontal and vertical joints for segmental panel walls and all vertical joints for full height panel walls. The gap between two adjacent panels shall be 1/2 to 1 inch. Shiplap joints are not required at the vertical joints of segmental and full height panel when a minimum of 12 inches’ depth of continuous crushed rock wrapped with Class 1 Geotextile is installed behind the joints as shown in the shop drawings. Geotextile (Class 1) and crushed rock will not be measured and paid for separately, but shall be included in the work. Neoprene cushions shall be provided at horizontal joints as shown on the plans.

1. *Long Term Design Strength (LTDS) of Reinforcement*.

The design charts on the plans define the strengths required for the zone of mechanical reinforcement of soil. Based on the total summed LTDS, the reinforcement proposed by the shop drawings for a specific wall height shall meet or exceed the total LTDS shown on the plans. This proposed reinforcement shall allow for a maximum of plus or minus 15 percent variation in each individual layer.

Metallic (Inextensible) Soil Reinforcement. The net section at the soil reinforcement to block connection shall be used for the sacrificial thickness calculation. The following minimum sacrificial thickness for reinforcement shall be applied to the 75-year LTDS calculations:

|  |  |
| --- | --- |
| Galvanization Loss | 15 µm/year for first 2 years4 µm/year for subsequent years |
| Carbon Steel Loss  | 12 µm/year after zinc depletion |

Steel Soil Reinforcement

$$LTDS= \frac{ϕA\_{c}F\_{y}}{b}$$

Where:

Φ = 0.75 (Strip reinforcement)

 = 0.65 (Grid reinforcement)

Ac = Area of reinforcement corrected for corrosion loss (in2)

Fy = minimum yield strength of steel (ksi)

b = unit width of reinforcement (ft)

1. Geosynthetic Soil Reinforcement. Geosynthetic soil reinforcement shall be either a geogrid or woven geotextile. For polyester (PET), polypropylene (PP), and polyethylene (PE) reinforcement, the LTDS of material shall be determined using the following K percentages to ensure the required design life. Unless otherwise specified, LTDS shall not exceed the following K percent of its ultimate tensile strength, TULT (MARV), i.e.

LTDS = K \* TULT (MARV)

$$Where K=\frac{ϕ}{RF\left(ID\right) Χ RF\left(D\right) Χ RF (CR)}$$

$RF\left(ID\right):$ Installation damage reduction factor

$RF\left(D\right):$ Durability reduction factor

$RF\left(CR\right):$ Creep reduction factor

Meet AASHTO LRFD and/or FHWA GRS design method for 75 years’ design life.

1. Geogrid or Geotextile sheet reinforcement (PE, PET, PP):

|  |  |  |
| --- | --- | --- |
| **Products** | **K (Geogrid)** | **K ( Geotextile)** |
| PE and PP | 27% | 18% |
| PET | 35% | 30% |

1. Woven Geotextile shall meet minimum bi-axial MARV of ultimate tensile of 4,800 LB/FT and a minimum tensile strength of 2,400 LB/FT at 5 percent strain based on ASTM D4595.
2. All products not listed above: Follow AASHTO equations 11.10.6.4.3b-1 and 11.10.6.4.3b-2 using independently certified test results.
3. *Design Heights and Supplied Reinforcing Material.* Unless otherwise defined on the plans, the wall design height shall be measured vertically from the top of the leveling pad to the top of the concrete rail anchoring slab for walls with railing, or to the top of the cast-in-place concrete coping for walls without railing. For walls that are in front of a bridge abutment that is founded on a GRS foundation, the design height used to determine the soil reinforcement length shall be measured vertically from the top of the leveling pad to the top of the roadway carried by the bridge and the wall. Bridge approach slabs shall not be considered in the design of the MSE wall.

For both geosynthetic and metallic reinforcement, the required reinforcement LTDS and the supplied LTDS (determined in accordance with the K factors or depletion of material as defined above) with corresponding brand and grade of material shall be marked clearly on the elevation view or in a tabulation summary. The LTDS of the supplied reinforcement grade must meet or exceed the required LTDS corresponding to the reinforcement spacing provided.

1. *Tiered Walls*. For the reinforcement layouts of tiered walls, the overall geometry, the reinforcement length, and the sum of the LTDS provided from all layers in all tiers shall be in close conformity with the retaining wall system shown on the plans in order to ensure that local, global, and internal stability requirements have been met.
2. *Obstructions*. Details for the placement of soil reinforcement around obstructions (i.e. steel piles, concrete piers, concrete boxes, pipes, etc.) shall be shown on the shop drawings. Design calculations shall be provided showing that the internal stability of the wall meets the required safety factors in the area of the obstruction.
3. *Table of Quantities*. A table comparing the Structure Backfill (Class 1), Mechanical Reinforcement of Soil, Geomembrane, and Panel Facing quantities shown on the plans to the quantities shown in the shop drawings and the percent difference (positive percent indicates an increase in shop drawing quantities from the plans) shall be shown on the shop drawings. Structure Backfill (Class 1), Mechanical Reinforcement of Soil, Geomembrane, and Panel Facing quantities shall be calculated in accordance with the Contract. The Contractor shall notify the Engineer of the difference in plan and shop drawing quantities before wall construction begins.
4. *Placement Schedule*. Geomembrane placement schedule and clearances to soil reinforcements shall be shown.
5. *Vertical Slip Joints*. Locations of vertical slip joints for differential settlement relief shall be as specified in subsection 504.13.
	* 1. Backfill.

 Unless otherwise specified on the plans, wall backfill material in the reinforced structure backfill zone and the associated trapezoidal retained structure backfill zone shall conform to the requirements for Structure Backfill (Class 1) of Section 206. For reinforcement tensile stress and associated pullout, a friction angle of 34 degrees shall be assumed for Structure Backfill (Class 1). Structure Backfill (Class 1) shall be considered to be non‑aggressive soil for corrosion and durability computations. All reinforcing elements shall be designed to ensure a minimum design life of 75 years for permanent structures.

* + 1. Leveling Pad.

 Concrete for the leveling pad shall be Concrete (Class D) conforming to the requirements of Section 601. Unless specified on the plans, the maximum vertical step shall be no greater than 36 inches. The leveling pad shall be reinforced as shown on the plans. When the toe of wall is founded on slope steeper than 1.5 (H) to 1 (V), the leveling pad shall be constructed with reinforced concrete with same reinforcing schedule as at its steps. Leveling pad concrete shall be cured for at least 12 hours before placement of the concrete panels.

* + 1. Geomembrane and Joints.

 A geomembrane shall be installed on all walls at the top of the reinforced structure backfill zone and retained structure backfill zone to intercept surface runoff and prevent salt penetration into the backfill of the wall as shown on the plans. The geomembrane shall meet the requirements of subsection 712.07 for geomembrane, and be LLDPE with a minimum thickness of 30 mils. It shall be spliced with a dual track field seamed joint in accordance with ASTM D4437 and ASTM D5820. For small local coverage areas, less than 30 square feet, the membrane may be spliced using a 6 inch minimum overlap and an adhesive or a single seam portable thermal welding tool, as suggested by the membrane manufacturer and approved by the Engineer. Unless otherwise shown on the plans, the membrane shall have a minimum coverage length measured perpendicular to the wall face of at least the Pay Length for Geomembrane (PLG) as shown on the plans. The membrane shall be installed with a slope between 20:1 (minimum) and 10:1 (maximum), as shown on the plans, from the block facing to a drainage system located at the cut or pre-filled slope as shown on the plans. The Contractor shall provide a site-specific working drawing that indicates sheet splices, pattern, slope, and daylight location. Prior to membrane installation, the working drawing shall be submitted by the Contractor and approved by the Engineer.

The drainage system shall consist of a 12-inch-wide geocomposite strip drain inserted into a slot in the geomembrane, at 10-foot maximum spacing, that collects the water from the membrane and conveys it to a water collector system at the toe of the excavation slope as shown on the plans. The water collector system shall consist of a 4-inch diameter perforated collector pipe surrounded by Filter Material Class B and wrapped with Class 1 Geotextile. A 4-inch diameter non-perforated drain pipe, at 100-foot maximum spacing, shall be used to discharge the water in the water collector system out the face of the wall.

Alternatives for the drainage system shown on the plans may be used by the Contractor. A detailed layout of this equivalent water collection system shall be provided by the Contractor and approved by the Engineer.

For tiered walls, a geomembrane shall be installed between the top of the bottom wall and the toe of the top wall as shown on the plans.

* + 1. Pre-Cast Concrete Panel Facing Unit and Panel Joint Material.

 The pre-cast concrete panels shall conform to the requirements shown on the plans and these specifications including the color, texture, dimensions and pattern. These facing units shall be factory made with an approved Class D or G Concrete and shall conform to the requirements of Section 601. The Contractor may elect to use an approved self-consolidating Class D or G Concrete. Pre-cast panels shall be cured in accordance with AASHTO M170.

* + 1. Certifications, Calculations, and Testing Reports.

 The Contractor shall provide the following reports, certifications, calculations, and checklists as needed to accompany the shop drawing submittal. The Contractor’s Engineer shall electronically seal all engineering calculations, as stated in subsections 504.02(f), 504.02(g), 504.02(j), 504.02(k), 504.07(e), 504.07(f), 504.07(g), and 504.07(h).

1. *Certification of TULT (MARV).* For geosynthetic reinforced system only, the Contractor shall submit a certification letter from the manufacturer which provides the TULT (MARV) and certifies the TULT (MARV) of the supplied materials have been determined in accordance with ASTM D4595 or ASTM D6637 as appropriate.
2. *Mill Report for Metallic Reinforcements and Connectors*. This includes, but is not limited to, mill certifications on weldability, ultimate tensile strength, and yield strength.
3. *Report of The Panel-Reinforcement Connection Test*. The test report shall be prepared and certified by an independent laboratory. The panel to reinforcement connection test method shall conform to the industrial standards. The report shall provide data on the ultimate as well as service limit state.
4. *Report for Soil to Reinforcement Interface Pullout Test*. The test report shall be prepared and certified by an independent laboratory. The soil to reinforcement interface pullout test method shall conform to the requirements of ASTM D6706. Tests shall include the full range of overburden pressures defined by wall design heights.
5. *Certification of Facial Panel to Reinforcement Long-Term Connection Strength*. Certification shall include calculations to demonstrate that the facial panel to reinforcement connection meets or exceeds current AASHTO 75 years’ design life requirements.
6. *Certification of Reinforcement Pullout*. Certification shall be provided with detail calculations to demonstrate that reinforcement pullouts meet or exceed current AASHTO requirements. For metal reinforcement breakage and pullout, calculations shall include a combination of 75 years’ material depletion of carbon steel and galvanization loss.
7. *Report and Certification for the Initial Concrete Compression Strength, Shipping and Handling Stress*. Cylinder compressive test is acceptable to verify the initial concrete strength of panel at time of shipping. Concrete tensile stress shall not exceed the modulus of rupture. The report shall include calculations of panel cracking stress according to the proposed method of lifting and shipping. Before panel shipping from precast yard to wall site, the Engineer will approve the time of shipping, method of lifting and supporting condition during shipping, as well as storage condition at the site before panel installation.
8. *Calculations*. Calculation of the LTDS of reinforcement shall conform to current AASHTO LRFD or latest interim requirements.
9. *Efflorescence and Air Content Test*. Panel shall be visually efflorescence free. Efflorescence control agent shall be used in concrete mix design. When fly ash is used as the efflorescence control agent, the fly ash shall be ASTM C618 Class F fly ash and shall be a minimum of 20 percent by weight of the total cementitious material content. Air Content shall be determined in accordance with AASHTO T152. Concrete shall be tested a minimum of the first three batches each day and then once per five batches for the rest of the day to assure specified air entrainment.
10. *Submittal Checklist*. The Contractor shall submit the wet cast facing or Panel Faced MSE Wall Submittal Checklist, Form 1402 with the Certifications, Calculations and Testing Report submittal package included with the shop drawing submittal.
	* 1. Hybrid or Smaller Panel MSE Wall Systems.

A hybrid system is one which combines elements of both externally and internally stabilized systems.

An externally stabilized system uses a physical structure to hold the retained soil. The stabilizing forces of this system are mobilized either through the weight of a shape stable structure or through the restraints provided by the embedment of wall into the soil, if needed, plus the tieback forces of anchorages.

An internally stabilized system involves reinforced soils to retain fills and sustain loads. Reinforcement may be added to either the selected fills as earth walls or to the retained earth directly to form a more coherent stable slope. These reinforcements can either be layered reinforcements installed during the bottom-to-top construction of selected fills, or be driven piles or drilled caissons built into the retained soil. All this reinforcement shall be oriented properly and extend beyond the potential failure mass.

Hybrid MSE wall systems may be used unless otherwise noted on the plans. Hybrid MSE wall systems are subject to the same design requirements for MSE walls and this specification. The shop drawings for the Hybrid MSE wall system shall include a combination of design calculations and appropriate test results to demonstrate that it meets or exceeds the regular system. Hybrid MSE wall systems shall have a modular facing and be stabilized by a counterfort or a coherent mass such as interlocked wire basket system. The Certifications, Calculations, and Testing Reports in subsection 504.07(e) are not required for Hybrid MSE wall systems. The facing to soil reinforcement connection test, subsection 504.07(c), may be waived only if the soil reinforcing spacing is less than or equal to 8 inches or the facing is secured and stabilized by hybrid components with primary reinforcement spacing less than 24 inches.

The Contractor shall provide the following additional reports, certifications and calculations to accompany the shop drawing submittal for Hybrid MSE wall systems:

1. The facing to counterfort or coherent mass long-term connection test.
2. 75-year design of wire basket and filter fabrics for avoiding migration of fine soil.

The Contractor shall submit the dry cast facing MSE Wall Submittal Checklist, Form 1401, or the wet cast facing MSE Wall Submittal Checklist, Form 1402, with the Certifications, Calculations, and Testing Report submittal package included with the shop drawing submittal.

CONSTRUCTION REQUIREMENTS

* + 1. Approval and Qualifications of MSE Wall Installer.

 The job site wall foreman shall have experience in construction of at least five transportation related MSE walls within the last three years. Transportation related MSE walls are walls that carry or are adjacent to vehicular traffic and are constructed with MSE reinforcement in the reinforced structure backfill zone. The foreman shall have prior experience or adequate training on the products that the Contractor elects to use on the project. The resume and credentials of the foreman shall be submitted to the Engineer for approval prior to the Pre-construction Conference. The foreman shall be on the site for 100 percent of the time during which the work is being done.

* + 1. Wall Test Segment.

 The wall test segment shall be the first segment of the wall constructed. The wall test segment shall be constructed in the presence of the Technical Representative and the Engineer and shall include construction of each of the five elements listed in subsection 504.11. The minimum length of the wall test segment shall be 40 feet or the full length of the wall if less than 40 feet. A wall test segment shall be constructed for the first wall constructed from each wall product used on the project.

* + 1. Technical Representative of Wall Product Supplier.

 The Contractor shall arrange for a technical representative (Tech Rep) of the manufacturer of the selected wall products to be present during the construction of each wall test segment. If the selected wall products are supplied from different manufacturers, a Tech Rep from each wall product shall be present. The Tech Rep shall be present for construction of the wall test segment and each of the following elements:

* + 1. Placement of a minimum of the first four layers of primary soil reinforcement and backfill.
		2. If obstructions (i.e. steel piles, concrete piers/abutments, concrete boxes, pipes, etc.) exist, placement of primary soil reinforcement and backfill at obstructions.
		3. Placement of a minimum of the first two rows of panels or a minimum of a four-foot wall height.
		4. If a vertical slip joint is required, construction of the vertical slip joint in a minimum of a two row portion of panels or a minimum of a four-foot wall height.
		5. If corners are required, construction of a corner representative of the corners in the wall in the project in a minimum of a two row portion of panels or a minimum of a four-foot wall height.

Before construction of the wall test segment, the Tech Rep shall provide the Contractor and the Engineer the following:

* + 1. Technical instructions as required for the construction of the earth retaining wall system.
		2. Product specific specifications for the placement of the soil reinforcement and backfill in accordance with the wall system.
		3. Guidelines for placing the facing units and attaching them to the soil reinforcement in accordance with the system requirements.
		4. Technical assistance to the facing unit fabricator.

At the completion of the wall test segment, the Tech Rep shall provide the following:

1. Documentation that the wall test segment was constructed in accordance with the product specific specifications. This documentation shall include a location description (starting and ending stations and elevations) of the wall test segment.
2. Documentation that the job site wall foreman is familiar with the wall products used to construct the walls on the project.

After completion of the wall test segment the Tech Rep shall be available when there is any special field condition such as change of geological condition, when there are equipment or personnel changes, or when requested by the Engineer.

* + 1.
		2. Facial Panel Quality Control, Placing Plan, and Daily Placement Logs.

 Before the start of wall construction, the Contractor shall provide a panel-placing plan and shall supply daily placement logs to the Engineer weekly and at the completion of the wall. The daily placement log shall consist of an elevation view of the wall showing the dates, number of panels placed, and the serial numbers of the panels placed. The panel quality control shall contain multiple submittals if required by subsections 504.07(g) and (h). Panels shall be labeled with a serial number for each panel and corresponding certification with one set of random samples tested for each 220 panels or 5,500 square feet of wall face. At least one certification with supporting test results is required for each wall. Test results will be reviewed and pre-approved by the Engineer before shipment. The Contractor shall coordinate and mark the panel and backfill placing sequence on the daily placement logs. The log serves as means for the Engineer to identify where each panel was placed.

* + 1. Wall With Curved Alignments, Tight Curved Corners, and Sections Adjacent To Bridge Abutment.

 The Contractor shall provide a placement plan that shows curved layouts, special corner panel, sequence of panel placement, and construction offsets as recommended by the manufacturer. The Contractor shall install vertical slip joints as shown on the shop drawings for tight curved corners (8-foot radius or less) and dissimilar foundations such as bridge abutments, to avoid panels with random cracks.

* + 1. Excavation and Backfill.

 The base of leveling pad shall receive the same compaction as cut area required by subsection 203.07. The Contractor shall report to the Engineer in writing density test results for any unsatisfactory bearing material that does not meet the minimum 90 percent compaction for walls less than 16 feet high and 95 percent of AASHTO T 180 for walls higher than 16 feet. If the excavation for the placement of the leveling pad exposes an unsatisfactory bearing material, the Engineer may require removal and replacement of that material. The removed material shall be replaced with Structure Backfill (Class 1) compacted in conformance with subsection 206.03. The Engineer with the assistance of the geotechnical engineer of record will provide the limits including the depth of removal. As directed by the Engineer, and if required, Structure Backfill (Class 1) shall be reinforced with soil reinforcements in conjunction with wick drains and outlet pipes.

The Contractor shall grade the foundation for the bottom of the wall for a width equal to or exceeding the limits of the Reinforcement Length (RL) plus 18 inches as shown on the plans. This graded area shall be compacted with an appropriate vibratory roller weighing a minimum of 8 tons for at least five passes or as directed by the Engineer. For cut wall with continuous seepage, phasing of foundation construction or a different drainage and foundation improvement plan may be necessary.

The reinforced structure backfill zone and the retained structure backfill zone portion immediately behind the wall as defined on the plans shall be Structure Backfill (Class 1). Recycled asphalt, recycled concrete, and flow-fill material shall not be substituted for Structure Backfill (Class 1). Each compacted layer of backfill within a distance equal to the reinforcement spacing away from the back of the panels shall not exceed 4 inches. The triangular or trapezoidal portion behind the concrete panels and above the spill of backfill, as shown on the plans, shall be filled with 3/8-inch or larger crushed rock, filter aggregates with filter fabric, or wall system specific fill as approved by the Engineer. Density tests behind and parallel to the wall in the triangular or trapezoidal portion above the backfill spill zone are not required. Each compacted layer of backfill shall be in even increments up to 8 inches thick. The fill and compaction operation shall start 3 feet from the wall back face and progress toward the end of the reinforcement. All Structure Backfill (Class 1) including fill material under the wall and on-site material as allowed by subsection 504.03 shall be compacted to a density of at least 95 percent of the maximum density according to AASHTO T 180. For on-site foundation material containing more than 30 percent retained on the 3/4 inch sieve, a method of compaction consisting of a conventional heavy vibratory roller starting with minimum 5 passes shall be used to establish the number of passes required to exceed the 95 percent T180.

At least 6 inches of material shall be in place prior to operation of tracked vehicles over soil with reinforcement. Only power operated roller or plate compaction equipment weighing less than 1,000 pounds is allowed within 3 feet of the front of the wall face. The reinforcement shall not be connected to the wall until the compacted fill is at or slightly higher than the location of the connector.

Backfill containing frost or frozen lumps shall not be used. Backfill that has been placed and becomes frozen shall be removed and replaced at the Contractor's expense. If cold weather conditions prevent the placement of Structure Backfill (Class 1), the Contractor may use Filter Material Class B as backfill without compaction at the Contractor’s expense and approved by the Engineer. The Contractor shall provide a test report, prepared and certified by an independent laboratory, that the internal friction angle of soil for the Filter Material Class B meets or exceeds that shown on the plans.

The Contractor shall place additional panels including partial height panels and properly compacted fill material to return the finished grade to the plan elevations if settlement, as determined by the Engineer, has occurred. A final inspection before the installation of rail anchoring slab will be made after construction settlement, if any, has occurred or 30 days after the completion of the wall. The Contractor shall provide immediate temporary stormwater protection and wind erosion control at the end of each day during construction. If settlement occurs as the result of loss of backfill due to wind or water erosion, non‑conforming backfill such as frozen fill or over-saturated fill, or if the backfill does not meet compaction requirements, the Contractor shall remove the backfill, wash the soil reinforcement, and bring the elevation to the finished grade at the Contractor's expense. Before final project acceptance, the Contractor shall repair all backfill losses due to wind and water erosion.

To avoid the foundation of the leveling pad being washed out by rain, the area in front of the wall and around the leveling pad shall be backfilled as soon as practicable.

* + 1. Reinforcement.

 Steel reinforcement shall be slack free and geosynthetic reinforcement shall be slightly pre-tensioned. The minimum coverage ratio for geogrid reinforcement shall be 67 percent and the spaces between rolls shall be staggered between layers of soil reinforcement. The minimum coverage ratio for woven fabric reinforcement shall be 100 percent and an overlap between rolls is not required. Soil reinforcement shall not be cut to avoid obstruction unless shown on the shop drawings.

* + 1. Leveling Pad.

 The foundation of the leveling pads shall meet the requirement of subsection 504.04 for steel and concrete. The leveling pad shall be level within the tolerance of 1/8 inch for any two points along the length of a panel, and within 1/4 inch for any two points 10 feet apart.

Cushion or shimming material (expansion joint material, concrete mortar grout, roofing felt, or geosynthetic reinforcement) shall be used to support panels directly founded on the leveling pad. Before starting a new course of panels, the Contractor shall take steps to ensure that the wall elevations are matched at the neighboring panels. Cushion or shimming material shall be used to obtain necessary panel elevations at next leveling pad step. No more than two shims (each 3/16 inch thick) shall be required to level the panels on the leveling pad.

* + 1. Wooden Wedges.

 Wooden wedges may be used to help to hold the panels at the correct batter during the backfill operation. The wooden wedges shall be made from hard wood (such as oak, maple or ash). Wooden wedges shall be removed as soon as the precast panels above the wedged panels are completely erected and backfilled. There shall not be more than three rows of wooden wedges in place at one time. Panels that crack or spall due to failure to remove the wooden wedges shall be repaired or replaced.

* + 1. Panel Facing.

 For walls that support a roadway, the wall layout line at the leveling pad shall be set back and pre-measured with appropriate batter (5 to 8 percent) from the top of the panels according to the offset with respect to the centerline of the road. For walls adjacent to a roadway, the wall layout line at the leveling pad shall be directly offset from the centerline of the road. An overall negative batter (wall face leaning outward) between the bottom and the top of the wall is not allowed. Unless otherwise noted on the plans for battered walls, the final wall face shall be vertical, or have a positive batter of not greater than 5 percent for construction control purpose. The surface of the wall face shall be tested with a 10-foot straightedge laid along the surface in horizontal and vertical directions. Except as necessary for horizontal alignment of the wall, convex deviation of the wall face from the straightedge (belly wall) shall not be allowed, and concave deviation from the straightedge shall be less than 1/2 inch.

Walls without a rail-anchoring slab, cast-in-place reinforced concrete coping with uniform exposed height is required to match the required finished elevations as well as to retain the panels’ lateral deformation.

For walls with rail anchoring slabs, the top of panel elevations shall be within 8 inches of the bottom of the anchoring slab. Cast-in-place concrete or saw-cut partial height panels may be used to accomplish this.

Where the geomembrane for drainage interferes with the continuation of reinforcement, the panels beyond the termination shall be reinforced with the same grade of additional soil reinforcing material to maintain the total amount of reinforcement per panel. To avoid leaking or soil erosion through the joint, a filter fabric at least 12 inches wide shall be glued to the panels behind all vertical joints.

As shown on the plans, facing panels directly exposed to spray from deiced pavements and indirect windborne spray shall have three coats of water resistant or repellant concrete sealer applied to the front face of the wall before the wall is opened to traffic.

All damages to a completed wall or parts of a completed wall, including blemishes and discoloring of panels, shall be replaced or repaired before final payment is made. Sand blasting may be used if approved by the Engineer.

* + 1. Fill under Leveling Pad.

 For walls requiring fill under the planned elevation of the leveling pad, the Contractor may lower the elevation of the leveling pad as approved by the Engineer, except that the finished elevation at the top of the wall shall not be altered. As requested by the Contractor, and with the Engineer’s approval, the higher wall shall be redesigned with longer reinforcement length and revised reinforcement schedule.

METHOD OF MEASUREMENT

* + 1.
		2. MSE retaining walls will not be measured for payment in the field, but will be paid for by the calculated quantities shown on the plans for the five major components of the wall: structure excavation, structure backfill, concrete panel facing, mechanical reinforcement of soil, and geomembrane. The Contractor's construction of a system that requires increased or decreased quantities of any of the components to complete the wall to the dimensions shown will not result in a change in pay quantities. Exceptions will be made when field changes are ordered or when it is determined that there are discrepancies on the plans in an amount of at least plus or minus five percent of the plan quantity.
1. The panel facing quantity was calculated for the square foot of wall front face area from the top of the leveling pad (or average pad elevations) as shown on the plans to the top of the anchoring slab for walls with railing, or to the top of the cast in place coping for walls without railing.
2. The structure excavation quantity was calculated for the total volume of earth to be removed before the installation of the reinforced zone as shown on the plans.
3. The structure backfill quantity was calculated for the total volume behind the wall (the retained structure backfill zone) including the material in the reinforced zone as shown on the plans.
4. The mechanical reinforcement of soil quantity was calculated for the total volume of the reinforced zone as shown on the plans.
5. Geomembrane was calculated as the design height (DH) plus soil reinforcement length (RL) plus 1.5 feet, disregarding the slope of the membrane.

The square foot and cubic yard quantities computed for payment are the wall plan quantities based on the height measured at 20-foot maximum intervals along the wall layout line.

BASIS OF PAYMENT

* + 1.

The accepted quantity will be paid for at the contract unit price per unit of measurement for the pay items listed below:

Payment will be made under:

**Pay Item** **Pay Unit**

Panel Facing Square Foot

Structure excavation will be paid for under the Section 206 Pay Item Structure Excavation. Structure backfill will be paid for under the Section 206 Pay Item Structure Backfill (Class 1). Soil reinforcement will be paid for under the Section 206 Pay Item Mechanical Reinforcement of Soil. Geomembrane will be paid for under the Section 420 Pay Item Geomembrane.

Rail anchoring systems (slabs) at the tops of walls and leveling pads at the bottom of wall will be measured and paid for separately under the Section 601Pay Item Concrete and the Section 602 Pay Item Reinforcing Steel.

Payment will be full compensation for all work and materials required to construct the concrete panel facing MSE wall. Miscellaneous items such as dual track welding of geomembrane, drainage ditches, rundowns, filter material, filter fabric, grout, pins, shimming material, 1/4 inch thick expansion joint material, concrete coating and providing a technical representative will not be measured and paid for separately but shall be included in the work.

* + 1. Panel Facing Payment Reductions.

 In this subsection, a “panel” refers to either a concrete panel or a hybrid unit. Each of the following shall be considered a defect:

1. Dislocated Panel. A dislocated panel is an individual panel or its corner located outward more than 1/4 inch from the adjacent panels.
2. Cracked Panel. A cracked panel is an individual panel with any visible crack when viewed from a distance equal to the wall height in natural light.
3. Corner Knock Off. A corner knock-off is a panel with any missing facial corners or architectural edges.
4. Substandard panel. Substandard panels are concrete panels installed in wall segments that do not meet the certified values for compressive strength. Each substandard panel counts as one defect.
5. Oversize Joints. Panels with oversize joints are two adjacent panels that do not meet the required values in subsection 504.02(f).
6. Panels Failing the 10-Foot Straightedge Test. Straightedge test failures are joints that deviate from even by more than 1/4 inch when measured by placing a 10-foot straightedge across the joint.

Defects shared by two adjacent panels such as oversized joint, dislocated panel and panels not passing 10-foot straight edge test will be count as one defect.

In the completed wall, or completed portion of the wall the number of defects, as described above, in each 40-foot section (horizontal or arc length) will be counted. If there are defects, the number of defects in the 40-foot section will be considered for price reduction according to the table below. For panels subjected to price reduction, if the defects are repairable or the overall quality of wall can be improved, with the consent from the Engineer, the Contractor may elect to repair and reduce the percent of price reduction. If the finished wall facing profile outside of acceptable zone or into negative batter is not repairable, the non-repairable portion shall receive a 21 percent price reduction for each wall pay item. A walkthrough inspection will be made as requested by the Contractor before final payment.

|  |  |
| --- | --- |
| **No. of Defects in 40 Foot Section** | **Percent of Price Reduction for that section** |
| 2 | 3 |
| 3 | 9 |
| 4 | 15 |
| 5 | 21 |
| > 5 | Rejection |

When the number of defects exceeds five, the Engineer will reject the entire wall or portions thereof. The Contractor shall replace the rejected wall at his own expense.

Soil nail wall

DESCRIPTION

* + 1. Soil Nail Wall. This work consists of constructing a permanent soil nailed wall (also referred to as ground nail wall) as specified herein, and as shown on the plans. Temporary soil nail walls and the final facing are not covered in this specification. The work includes:
1. Excavating staged lifts in accordance with the plans and approved submittals.
2. Drilling soil nail holes to the diameter and length required to develop the specified capacity as shown on the plans.
3. Installing soil nails including placement and grouting.
4. Performing soil nail testing and providing test results to the Engineer.
5. Providing and installing the specified drainage features.
6. Providing and installing bearing plates, washers, nuts, couplers, and other required miscellaneous materials.
7. Constructing the initial shotcrete face.

Materials

* + 1. Materials shall meet the following requirements:
1. Concrete shall be Class D, conforming to the requirements of Section 601.
2. Reinforcing Steel shall conform to the requirements of Section 602.
3. Shotcrete shall conform to the requirements of Section 641.
4. Forms and falsework shall conform to the requirements of subsections 601.09 and 601.11.
5. Geocomposite strip drains shall comply with Section 712.12.
6. Underdrains and pipes shall comply with Sections 712.11 and 712.13.
	* 1. Soil Nails
7. *Solid Bar Soil Nail.* Bars shall conform to AASHTO M31 for Grade 75 or ASTM A 722 for Grade 150. Bars shall be threaded, continuous without splices or welds, new, straight, undamaged, epoxy-coated or encapsulated as shown on the plans. Bars shall be threaded a minimum of 6 inches on the wall anchorage end to allow proper attachment of bearing plate and nut. Threading may be continuous spiral deformed ribbing provided by the bar deformations (continuous thread bars) or may be cut into a reinforcing bar. If threads are cut into a reinforcing bar, the next larger bar number designation from that shown on the plans shall be provided at no additional cost.
8. *Bar Coupler.* Bar couplers, where allowed by the plans, shall be designed to develop the full ultimate tensile strength of the bar as certified by the manufacturer.
9. *Fusion Bonded Epoxy Coating.* Epoxy coating for bars and end hardware shall conform to ASTM A775 or A934. The minimum thickness shall be 0.012 inch and shall be electrostatically applied. Bend test requirements are waived. Coating at the wall anchorage end of epoxy-coated bars may be omitted over the length provided for threading the nut against the bearing plate. Coating at the end of the bar of epoxy-coated bars may be omitted over the length provided for threading a coupler if bars are to be joined. Galvanization may be substituted for epoxy. Bars should be galvanized according to ASTM A767/A767M. A minimum galvanization coating of 3.4-mil thickness is required. Galvanization shall be applied in accordance with ASTM A153 for nuts, plates, and other hardware.
10. *Encapsulation.* Encapsulation shall be a sheathing of either corrugated HDPE tube with a minimum 0.06-inch thickness conforming to AASHTO M252 or corrugated PVC tube with a minimum 0.04-inch thickness conforming to ASTM D1784, Class 13464-B. The level of corrosion protection shall be as shown on the plans.
11. *Centralizer.* Centralizers shall be manufactured from Schedule 40 PVC pipe or tube, or other material not detrimental to the soil nail steel or corrosion protection. Wood shall not be used. Centralizers shall be
	1. Securely attached to the soil nail bar.
	2. Sized to position the soil nail bar within 1 inch of the center of the drill hole.
	3. Sized to allow tremie pipe, grout tube, or casing insertion along the full length of the drill hole.
	4. Sized to allow grout to freely flow up the drill hole.
12. *Soil Nail Grout*. The minimum compressive strength for grout should be 1,500 pounds per square inch (psi) at 3 days, and 3,000 psi at 28 days, as tested in accordance with ASTM C109. If sand is used in the grout mixture, it shall meet the requirements of subsection 703.01. A batch ticket shall be supplied for each grout delivery to be used during construction of the soil nail wall. If grout is mixed on site, all materials shall be weighed and recorded prior to mixing or incorporation into the mixer. The water/cementitious ratio and specific gravity may be used as a primary quality control of the neat cement grout mix if the Contractor can demonstrate the materials and mix design consistently produce a grout of the minimum specified strength. Neat cement grout cubes shall be molded by the Contractor in the presence of the Engineer and tested by the Department on the grout used in production soil nails and the adjacent test soil nail.
13. *Fine* *Aggregate*. Fine aggregate shall conform to subsection 703.01.
14. *Cementitious* Materials. Cementitious materials shall conform to Section 701. The cement used for shotcrete and grout shall meet the sulfate resistance requirements of subsection 601.04.
15. *Admixtures*. Admixtures shall conform to Section 711. Admixtures that control bleed, improve flowability, reduce water content, reduce washout, and retard set may be used in the grout as approved by the Engineer. Accelerators are not permitted. Expansive admixtures may be used only in grout used for filling sealed encapsulations. Admixtures shall be compatible with the grout and mixed in accordance with the manufacturer’s recommendations.
16. *Film Protection.* Polyethylene film for moisture loss control shall conform to AASHTO M171.
	* 1. Bearing Plates, Washers, Nuts, and Headed Studs.

(a) *Bearing Plates.* Bearing plates shall conform to AASHTO M183/ASTM A36.

(b) *Beveled Washers*. Beveled washers shall conform to ASTM F436, with an angle matching the inclination of the soil nail to provide uniform bearing.

(c) *Nuts*. Nuts shall be hexagonal and fitted with beveled washer or spherical seat to provide uniform bearing to develop the full ultimate tensile strength of the bar as certified by the manufacturer and conform to AASHTO M292/ASTM A194. ,.

1. *Headed Studs*. Headed studs on the bearing plate shall conform to requirements of Section 509.12.
	* 1. Welded Wire Fabric. Welded Wire Fabric shall conform to AASHTO M55, AASHTO M221, or ASTM A1064.
2. construction requirements
	* 1. Contractor Qualifications. The Contractor shall provide on-site supervisors and drill operators with experience installing permanent soil nails on at least 3 permanent soil nail retaining wall projects during the past 3 years totaling at least 10,000 square feet of wall face area and at least 500 permanent soil nails.
		2. Submittals. The following documents shall be submitted in accordance with subsection 105.02. No work relating to soil nail wall construction including ordering materials shall be performed before the following submittals have been reviewed and reviewed by the Engineer.
3. *Qualifications*. The soil nailing Contractor shall submit a brief description of at least 3 completed projects, including the owning agency’s name, address, current phone number, location of project, project contract value, square foot of wall, the number of nails, scheduled completion date, and actual completion date for the project.
4. *Personnel*. At least 14 calendar days before starting soil nail work, the soil nailing Contractor shall identify on-site supervisors and drill operators assigned to the project, and submit a summary of each individual’s experience. Only those individuals designated as meeting the qualifications requirements shall be used for the project. The soil nailing Contractor shall not substitute for any of these individuals without written approval by the Engineer. The Engineer will review the soil nailing Contractor qualifications and staff within 15 working days after receipt of the submission. The Engineer may suspend the work if the soil nailing Contractor substitutes unqualified personnel for qualified personnel during construction. If work is suspended due to the substitution of unqualified personnel per subsection 504.06, the Contractor shall be fully liable for additional costs resulting from the suspension of work and no adjustment in contract time resulting from the suspension of the work will be allowed.
5. *Construction Plan*. At least 14 days before starting soil nail work, the soil nailing Contractor shall submit a Construction Plan to the Engineer for review that includes the following:
6. The start and finish date and proposed detailed wall construction sequence. Include schedule entries and anticipated durations for each lift excavation, soil nail installation for each lift, grout curing, soil nail testing, and shotcrete placement and curing.
7. Drilling and grouting methods and equipment, including the drill hole diameter proposed to achieve the specified pullout resistance values shown on the plans and any proposed variation of these along the wall alignment.
8. Soil nail grout mix design, including compressive strength test results supplied by a qualified independent testing lab verifying the specified minimum 3-day and 28-day grout compressive strengths. Previous test results for the same grout mix completed within one year of the start of grouting may be submitted for verification of the required compressive strengths.
9. Soil nail grout placement procedures and equipment.
10. Shotcrete materials and methods including methods to address soil fall out, perched water, and anti-washout as needed based on site condition or review of the Geotechnical Report in accordance with subsection 102.05.
11. All materials, methods, and control procedures for the initial shotcrete facing.
12. Soil nail testing methods and equipment setup.
13. Identification number and certified calibration records for each test jack, pressure gauges, and load cell to be used. Jack, load cell, and pressure gauge shall be calibrated as a unit. Calibration records shall include the date tested, the device identification number, and the calibration test results and shall be certified for an accuracy of at least 2 percent of the applied certification loads by a qualified independent testing laboratory within 6 months prior to submittal.
14. Certificates of Compliance for:
	1. The soil nail bar yield or ultimate tensile strength.
	2. Soil nail bar steel type.
	3. Bearing plates, washers, nuts, and couplers.
	4. Corrosion protection.
	5. Geocomposite strip drain and underdrain material.

The Engineer will review the soil nailing Contractor’s Construction Plan within 10 working days after the submission.

* + 1. Protection and Cleanup. During work operations, the Contractor shall take such precautions as may be necessary to prevent shotcrete overspray, drill cuttings, equipment exhaust, oil, wash water, and other materials from defacing or damaging private and public property including adjacent landscaping in accordance with subsections 107.12 and 107.25. The Contractor shall furnish all equipment as may be necessary to handle wastewater and material from the operations, and clean up all waste resulting from the operations. The Contractor is responsible for the stability of the highway facility and nearby structures.
		2. Storage and Handling. Soil nail bars shall be stored and handled in a manner to avoid damage, excessive bending, permanent deformation, or corrosion. Bars exhibiting abrasions, cuts, welds, weld splatter, corrosion, or pitting shall be replaced. Bars exhibiting damage to encapsulation or epoxy coating shall be repaired or replaced. Repaired epoxy coating areas shall have a minimum 0.012-inch thick coating. Bars exhibiting damage shall be repaired or replaced at the Contractor’s expense.
		3. Excavation. The Contractor shall be responsible for providing the necessary survey and alignment control during the excavation for each lift, locating drill holes, and verifying limits of the soil nail wall installation. Prior to any excavation, surface water controls shall be installed around the wall area as needed to prevent surface water, seepage, or springs from flowing within or into the excavation or as determined by the Engineer. The Engineer shall be notified 14 days prior to the beginning of excavation to allow scheduling of qualified representatives of the soil nail wall design professional engineer to observe the excavation and drilling as needed. The Engineer and the soil nail wall design engineer shall be contacted immediately if the Contractor encounters any ground conditions or materials during the excavation or drilling that is not shown on the plan set or unanticipated seepage, springs, or other sources of groundwater to allow for review of the design. The Contractor shall reference available Geotechnical Reports or other site condition reports in accordance with subsection 102.05 for additional information concerning the ground conditions that are anticipated during excavation.

During construction of the soil nail wall, excavation not associated with the soil nail wall construction shall not be performed within a horizontal distance equal to the total height of the final soil nail wall face excavation. The height of the exposed unsupported final excavation face cut shall not exceed the vertical soil nail spacing plus the required reinforcing lap or the short-term stand-up height of the ground, whichever is less. Each lift excavation shall be completed to the final wall excavation line and shotcrete applied in the same work shift, unless otherwise approved by the Engineer. Application of the shotcrete may be delayed up to 24 hours if the Contractor can demonstrate that the delay will not adversely affect the excavation face stability.

The Contractor shall modify excavation procedures and soil nail wall installation procedures to prevent the loss of material from the excavation face or from behind the previously installed shotcrete lift (chimneying). This may require adjustments to the sequencing between excavation, soil nail drilling and shotcreting to shorten the time the excavation lift is unsupported, drilling and installing the soil nails through temporary berms prior to final excavation and/or installing the initial shotcrete prior to drilling the soil nails. All voids that develop behind the shotcrete shall be filled with grout at no additional cost to the Department.

Excavation of the next-lower lift shall not proceed until soil nail installation, initial shotcrete face placement, attachment of bearing plates and nuts, and soil nail testing have been completed and accepted per subsection 504.17 in the current lift. Soil nail grout and shotcrete shall have achieved a compressive strength of at least 1000 psi before excavation of the next underlying lift.

Where the Contractor’s excavation and installation methods result in a discontinuous wall along any soil nail row, the ends of the upper lift excavation shall extend beyond the ends of the next lower excavation lift by at least 10 feet. Slopes at these discontinuities shall be constructed to prevent sloughing or failure of the temporary slopes. If sections of the wall are to be constructed at different times, the Contractor shall prevent sloughing or failure of the temporary slopes at the end of each wall section.

The Contractor shall remove all or portions of cobbles, boulders, rubble or other subsurface obstruction encountered at the cut line which will protrude in to the shotcrete facing including a method to safely secure remnant pieces remaining behind the excavation face and promptly backfilling voids resulting from removal of protrusions extending behind the excavation face. Voids, over-break or over-excavation beyond the plan wall excavation line resulting from the removal of face protrusions or the excavation operation shall be backfilled with shotcrete, concrete, or grout.

* + 1. Soil Nail Installation. Soil nail length and drill hole diameter used shall be those necessary to develop the specified load capacity to satisfy the acceptance criteria, but not less than the lengths or diameters shown on the plans. The Contractor shall modify their drilling procedures, as needed, to achieve the required soil nail pullout resistance specified in the plans. All work required to achieve the required soil nail pullout resistance including modifications to the drilling procedures will not be measured separately but shall be included in the unit price of the work. Holes shall be drilled for the soil nails at the locations, elevations, orientations, and minimum lengths shown on the plans. Drilling equipment and methods shall be suitable for the ground conditions and conform to the installation methods submitted by the soil nailing Contractor. Drilling muds or other fluids shall not be used to remove cuttings. If caving ground is encountered, cased drilling methods shall be used to support the sides of the drill holes. Self-drilling soil nail bars (also known as hollow, self-grouting or pressure grouted soil nail bars) shall not be used unless indicated on the plans. Soil nail bars shall be as shown on the plans. Provide centralizers per Section 504.03 (e).
		2. Grouting. The drill hole shall be grouted after installation of the soil nail bar and within 2 hours of completion of drilling. The grout shall be injected at the lowest point of each drill hole through a tremie pipe, grout tube, or casing. The outlet end of the grout tube or casing shall be kept below the surface of the grout as the conduit is withdrawn to prevent the creation of voids. The drill hole shall be completely filled in one continuous operation. Cold joints in the grout column are not allowed except at the top of the test bond length of proof tested production soil nails. Excessive grout take is defined as twice the theoretical grout volume to grout the drill hole. The Engineer shall be notified of excessive grout take to allow for modification of the wall design and construction. The Contractor shall maintain the stability of borings through the temporary unbonded length of proof test soil nails for subsequent grouting. If the unbonded test length of production proof test soil nails cannot be satisfactorily grouted subsequent to testing, the Contractor shall install a new soil nail in its place.

In some granular soils with an open matrix with no cohesion, the potential for drill hole collapse or grout leakage may be large. In this case, a grout containment device or “sock” may be used as approval by the Engineer to reduce excessive grout take in the highly permeable soil.

* + 1. Underdrain. The underdrain shall be installed in accordance with Section 605.03. The underdrain should be installed as part of the soil nail wall construction. If the underdrain is to be installed at a time after construction of the soil nail wall, the Contractor shall notify the Engineer to review any proposed excavation at the foot of the wall for stability.
		2. Soil Nail Testing. Both verification and proof testing of designated test soil nails shall be performed. Proof tests shall be performed on production soil nails at locations selected by the Engineer or as shown on the plans. Testing of a soil nail shall not be performed until the soil nail grout and shotcrete facing have cured for at least 72 hours or attained their specified 3-day compressive strength.

The Contractor shall provide all necessary equipment to perform the soil nail testing including, but not limited to, dial gauges, dial gauge support, jack and pressure gauge, electronic load cell with machined platens placed at either end of the load cell, and a reaction frame. In non-creep susceptible soils and as approved by the Engineer, the use of a load cell may be replaced with a dual pressure gauge system with the low reading gauge being used for soil nail acceptance.

The pressure gauge shall be graduated in 100-psi increments or less. The soil nail head movement shall be measured with a minimum of two dial gauges capable of measuring to 0.001 inch. The Contractor shall have available calibrated back up gauges and test loading equipment to minimize down time due to testing equipment failure.

The Contractor shall not apply loads greater than 80 percent of the minimum ultimate tensile strength of the tendon for Grade 150 bars or 90 percent of the yield strength of the tendon for Grade 75 bars. Preliminary results shall be submitted to the Engineer within 24 hours of the test completion. A full report containing test load results shall be submitted to the Engineer within 5 working days of the test completion.

* + 1. Verification Testing Of Sacrificial Soil Nails. The total number and location of tests shall be determined and spaced to evaluate soil nail performance in each soil strata encountered along the total length of the wall. A minimum of two verification tests shall be performed on sacrificial test soil nails at each soil nail wall as shown on the plans or as directed by the Engineer. Verification testing shall be performed prior to installation of production soil nails to confirm the appropriateness of the Contractor’s drilling and installation methods, and verify the required soil nail pullout resistance. If the Contractor makes changes to the drilling or soil nail installation operation or variability in the soil conditions is encountered, the Engineer may request additional verification tests.

Verification test soil nails shall have both bonded and unbonded lengths. Along the unbonded length, the soil nail bar shall not be grouted. The unbonded length of the test soil nails shall be at least 3 feet as measured from the back of the bearing plate to the top of the grout.

Verification tests shall be conducted according to the loading schedule of Table 504-1. Each load increment shall be held for at least 10 minutes. The Contractor shall record soil nail movements at each load increment and the time intervals shown in the table for each load step. Creep tests shall be performed at 0.75 VTL. The alignment load (AL) should be the minimum load required to align the testing apparatus and shall not exceed 5 percent of the VTL. The dial gauges shall be set to “zero” after applying the alignment load. Following application of the maximum load, the load shall be reduced to the alignment load and the dial gauge readings recorded as the permanent set.

Each load increment shall be held for at least 10 minutes. The Contractor shall monitor the verification test soil nail for creep at the 0.75 VTL load increment by measuring and recording soil nail movement. The load shall be maintained during the creep test within 2 percent of the intended load by use of the load cell. The test results shall be presented for the Engineers review and acceptance prior to production. The Engineer shall have 10 working days to review the report and based on the results, design modifications may be required.

The bonded length of the soil nail during verification tests (LB VT) shall be:

1. For Grade 75 and other mild steel in accordance with ASTM A615, the maximum bond length (LB VTmax), is defined as:

$$L\_{B VTmax} = \frac{A\_{t}∙f\_{y}∙C\_{RTY}}{r\_{PO}}$$

1. For Grade 150 and other high-strength steel in accordance with ASTM A722, the maximum bond length (LB VTmax), is defined as:

$$L\_{B VTmax} = \frac{A\_{t}∙f\_{u}∙C\_{RTU}}{r\_{PO}}$$

where:

CRTY = reduction coefficient for mild-grade steel = 0.9

CRTU = reduction coefficient for high-strength steel = 0.8

At = cross-sectional steel area of the test soil nail in square inches

fy = nominal yield strength of test soil nail (mild steel) in kips per square inch

fu = nominal tensile strength of test soil nail (high-strength steel) in kips per square inch

rPO = nominal pullout resistance in kips per foot of test soil nail per plans = π × qu × DDH

qu = nominal bond strength in kips per square foot

DDH = drill hole diameter in feet

1. If LB VTmax > 10 feet, select LB VT to be 10 feet ≤ LB VT ≤ LB VTmax.
2. If LB VTmax < 10 feet, to avoid tensile breakage, select LB VT = 10 feet and increase the test soil nail bar size as needed, and recalculate LB VTmax until LB VTmax > 10 ft.
3. The maximum (nominal) load during the verification test is defined as the Verification Test Load (VTL) and is calculated as VTL = LB VT × rPO

**Table 504-1**

**VERIFICATION TEST LOADING SCHEDULE**

|  |  |
| --- | --- |
| **Load** | **Hold Time (minutes)2** |
| AL1 | 1 |
| 0.13 VTL | 10 (recorded at 1, 2, 4, 5, 10) |
| 0.25 VTL | 10 (recorded at 1, 2, 4, 5, 10) |
| 0.38 VTL | 10 (recorded at 1, 2, 4, 5, 10) |
| 0.50 VTL | 10 (recorded at 1, 2, 4, 5, 10) |
| 0.63 VTL | 10 (recorded at 1, 2, 4, 5, 10) |
| 0.75 VTL (Creep Test)3 | 60 (recorded at 1, 2, 4, 5, 6, 10, 20, 30, 50, 60) |
| 0.88 VTL | 10 |
| 1.00 VTL4 | 10 |
| AL | 15 |
| 1. AL = alignment load, which is less than or equal to 0.05 VTL.
2. Soil nail movement shall be measured after each load increment has been achieved and at each time step.
3. Maintain the load during the creep test within 2 percent of the intended load by use of the load cell.
4. The Engineer may allow loading to failure to determine nominal soil conditions.
5. Permanent soil nail movement shall also be recorded
 |

.

* + 1. Proof Testing Of Production Soil Nails. Successful proof testing shall be performed on 5 percent of the production soil nails in each soil nail row or a minimum of one per row. Verification tests shall not be included in the 5 percent; except that the Engineer may allow the verification tests to be included based on the plans and site conditions. The Engineer will determine the locations and number of proof tests prior to soil nail installation in each row unless otherwise shown on the plans. Production proof test soil nails shall have both bonded and temporary unbonded lengths. Fully grouted test soil nails shall not be proof tested. The Contractor shall maintain the stability of the hole for the temporary unbonded test length for subsequent grouting. If the unbonded test length of production proof test soil nails cannot be satisfactorily grouted subsequent to testing, the proof test soil nail shall become sacrificial and shall be replaced with an additional production soil nail installed at the Contractor's expense. The temporary unbonded length of the test soil nail shall be at least 3 feet as measured from the back of the bearing plate to the top of the grout.

Proof tests shall be conducted according to the loading schedule of Table 504-2. Unless the soil is susceptible to creep per subsection 504.15, each load increment shall be held until readings are stable as defined by three readings within 0.005 inches taken one per minute over three minutes. The Contractor shall record soil nail movements at each load increment and the time intervals shown in the table for each load step. Creep tests shall be performed at 1.00 PTL. The alignment load (AL) shall be the minimum load required to align the testing apparatus and shall not exceed 5 percent of the PTL. Set dial gauges to “zero” after applying the alignment load. Following application of the maximum load, reduce the load to the alignment load and record the permanent set.

The creep period shall start as soon as the maximum test load (1.0 PTL) is applied and the soil nail movement shall be measured and recorded at 1 minute, 2, 3, 5, 6, and 10 minutes. Where the soil nail movement between 1 minute and 10 minutes exceeds 0.04 inch, the maximum test load shall be maintained for an additional 50 minutes and movements recorded at 20 minutes, 30, 50, and 60 minutes. All load increments shall be maintained within 5 percent of the intended load.

The bonded length of the soil nail during verification tests, LB PT, shall be:

1. For Grade 75 and other mild steel in accordance with ASTM A615, the maximum bond length (LB PTmax), is defined as:

$$L\_{B PTmax} = \frac{A\_{t}∙f\_{y}∙C\_{RTY}}{r\_{PO}∙0.75}$$

1. For Grade 150 and other high-strength steel in accordance with ASTM A722, the maximum bond length (LB PT max), is defined as:

$$L\_{B PTmax} = \frac{A\_{t}∙f\_{u}∙C\_{RTU}}{r\_{PO}∙0.75}$$

1. Select LB PT to be 10 ft or LB PTmax, whichever is smaller, to avoid tensile breakage.
2. Production proof test soil nails that are shorter than 13 feet may be tested with less than the minimum 10 feet bond length. The maximum load in the proof test (PTL) is calculated as PTL = LB PT × rPO × 0.75

**Table 504-2**

**PROOF TEST LOADING SCHEDULE**

|  |  |
| --- | --- |
| **Load** | **Hold Time (minutes)2** |
| AL1 | 1 |
| 0.17 PTL | Until Movement Stabilizes3 |
| 0.33 PTL | Until Movement Stabilizes |
| 0.50 PTL | Until Movement Stabilizes |
| 0.67 PTL | Until Movement Stabilizes |
| 0.83 PTL | Until Movement Stabilizes |
| 1.0 PTL (Creep Test)4 | 10 (recorded at 1, 2, 4, 5, 6, and 10) |
| AL | 1 |
| Notes: 1. AL = alignment load, which is less than or equal to 0.05 PTL.
2. Times are measured after the target load has been achieved in each increment.
3. If the soils reinforced with soil nails are relatively susceptible to deformation of creep, it is recommended to hold each load increment for 10 minutes and to record the soil nail movement at 1, 2, 5, and 10 minutes.
4. If the soil nail movement measured between 1 and 10 minutes exceeds 0.04 in., PTL must be maintained for 50 additional minutes and movements must be recorded at 20, 30, 50, and 60 minutes. The permanent soil movement must also be recorded.
 |

* + 1. Test Soil Nail Acceptance Criteria. A test soil nail shall be considered acceptable when the following criteria are met.
1. *Verification testing*. The following criteria shall be met for acceptance of the soil nail:
2. Pullout shall not occur at loads less than 1.00 VTL.
3. The total movement (ΔVTL) measured at VTL shall exceed 80 percent of the theoretical elastic elongation of the unbonded length (LUB), as defined by:

$$∆\_{VTL}>0.8\frac{VTL∙L\_{UB}}{E∙A\_{t}}$$

where E = Young’s modulus of steel (29,000 ksi).

1. The creep movement between the 1 and 10-minute readings at 0.75 VTL shall be less than 0.04 in.
2. The creep movement between the 6 and 60-minute readings at 0.75 VTL shall be less than 0.08 in.
3. The creep rate shall be linear or decreasing throughout the creep test load-hold period.
4. *Proof* *testing*. The following criteria shall be met to acceptance of the soil nail:
5. No pullout occurs.
6. The total soil nail movement (ΔPTL) measured at PTL shall be greater than 80 percent of the theoretical elastic elongation of the unbonded length, as defined by:

$$∆\_{PTL}>0.8\frac{PTL∙L\_{UB}}{E∙A\_{t}}$$

1. The creep movement shall be less than 0.04 in. between the 1 and 10-minute readings.
2. If this movement is exceeded, PTL shall be maintained for an additional 50 minutes with readings recorded at 20, 30, 50, and 60 minutes.
3. If the creep test is extended, the creep movement between the 6 and 60-minute readings shall be less than 0.08 in.
	* 1. Test Soil Nail Rejection. If a test soil nail does not satisfy the acceptance criterion in subsection
4. *Verification test soil nails*. The Engineer will evaluate the results of each verification test. The Contractor shall propose and provide plans and calculations for alternative methods for review and acceptance by the Engineer and shall install replacement verification test soil nails. Replacement test soil nails shall be installed and tested at the Contractor's expense. The production soil nails shall be installed using the same installation procedures (drill equipment, drill tooling, drill hole diameter, grouting, etc.) used to provide successful verification tests at no additional cost to the Department.
5. *Proof test soil nails*. The Engineer may require the Contractor to replace some or all of the installed production soil nails between a failed proof test soil nail and the adjacent passing proof test soil nail. Alternatively, the Engineer may require the installation and testing of additional proof test soil nails to verify that adjacent previously installed production soil nails have sufficient load carrying capacity. Installation and testing of additional proof test soil nails or installation of additional or modified soil nails as a result of proof test soil nail failures shall be at the Contractor's expense.
	* 1. Wall Drainage Network. All elements of the wall drainage network shall be installed and secured as shown on the plans. The drainage network shall consist of installing geocomposite strip drains, PVC connection pipes, wall footing drains, and weepholes as shown on the plans. Exclusive of the wall footing drains, all elements of the drainage network in the current lift shall be installed prior to shotcreting.

(a) *Geocomposite Strip Drains.* Geocomposite strip drains shall be centered between the columns of soil nails as shown on the Plans. The strip drains shall be at least 12 inches wide and placed with the geotextile side in contact with excavation face. The strips shall be secured to the excavation face and shotcrete shall be prevented from contaminating the geotextile. Strip drains shall be vertically continuous. Splices shall be made with a 12-inch minimum overlap such that the flow of water is not impeded. Drain plate and connector pipe shall be installed at the base of each strip as shown on the plans. Damage to the geocomposite strip drain which may interrupt the flow of water shall be repaired.

(b) *Underdrains.* Underdrains shall collect groundwater from the drainage network and be installed at the bottom of each wall as shown on the plans. The drainage geotextile shall envelope the footing drain aggregate and pipe and conform to the dimensions of the trench. The drainage geotextile shall overlap on top of the drainage aggregate as shown on the plans. Damaged or defective drainage geotextile shall be repaired or replaced.

* + 1. Initial Shotcrete Facing. The initial shotcrete facing shall be installed in accordance with Section 641. Membrane curing compound shall not be used. Maturity meters shall be used to monitor all shotcrete in accordance with subsection 641.05.

(a) *Initial Face Finish.* Shotcrete finish shall be either an undisturbed gun finish as applied from the nozzle or a rod, broom, wood float, rubber float, steel trowel or rough screeded finish as shown on the Plans.

(b) *Attachment of Soil Nail Head Bearing Plate and Nut.* Bearing plate, washers, and nut shall be attached to each soil nail head as shown on the plans. While the initial shotcrete facing is still plastic and before its initial set, the plate shall be uniformly seated on the shotcrete by hand-wrench tightening the nut. Where uniform contact between the plate and the shotcrete cannot be provided, the plate shall be set in a bed of grout. After grout has set for 24 hours, the nut shall be hand-wrench tightened. Bearing plates and headed studs shall be located within the tolerances shown on the Plans.

1. *Shotcrete Facing Tolerances.* Construction tolerances for the shotcrete facing from plan location and plan dimensions shall be as shown in Table 504-3.

**Table 504-3**

**INITIAL SHOTCRETE FACING TOLERANCES**

|  |  |
| --- | --- |
| **Item** | **Tolerance** |
| Horizontal location of welded wire mesh, reinforcing bars, and headed studs measured horizontally from wall face | 3/8 in. |
| Location of headed-studs on bearing plate | 1/4 in. |
| Spacing between reinforcing bars | 1 in. |
| Reinforcing lap length | 1 in. |
| Thickness of shotcrete, if troweled or screeded | 9/16 in. [approximation of 0.6 in.] |
| Thickness of shotcrete, if left as shot | 1-1/8 in. [approximation of 1.2 in.] |
| Planeness of finish face surface, gap under 10-ft straightedge, if troweled or screeded | 9/16 in. [approximation of 0.6 in.] |
| Planeness of finish face surface, gap under 10-ft straightedge, if left as shot | 1-1/8 in. [approximation of 1.2 in.] |
| Soil nail head bearing plate deviation from parallel to wall face | * + 1. degrees
 |

* + 1. Forms and Falsework. Forms and falsework shall conform to subsections 601.09 and 601.11 respectively.
		2. Reinforcing Steel. Reinforcing steel shall be installed in accordance with this specification and Section 602.
		3. Structural Concrete. Structural concrete shall be placed in accordance with this specification and Section 601.
		4. Acceptance. Material for the soil nail retaining wall will be accepted based on the manufacturer production certification or from production records. Construction of the soil nail retaining wall will be accepted based on survey, visual inspection, and the relevant production testing records.

METHOD OF MEASUREMENT

* + 1. Soil nail walls will be measured by the quantities for the five major components of the wall: soil nail, initial shotcrete facing, verification testing, excavation and underdrain.

Soil nail will be measured by the linear foot of nail installed and accepted.

Verification testing will be measured by the number of verification tests performed.

BASIS OF PAYMENT

* + 1.

The accepted quantities, measured as provided above, will be paid for at the contract unit price for the pay items listed below that are shown on the bid schedule. Payment will be made under:

Payment will be made under:

**Pay Item Pay Unit**Soil Nail Linear Foot
Verification Testing Each

Payment for Soil Nail Wall will be full compensation for all work and materials required to complete soil nail wall. This work shall include but is not limited to soil nails, geocomposite strip drains, proof testing, drilling, grouting, bearing plates, end hardware (nuts, washers, couplers), certificates of compliance, and incidentals necessary to acceptably fabricate and construct the soil nail walls exclusive of any final facing items that may be tabulated on the plans.

All excavation work required to construct the soil nail wall and the initial shotcrete facing to the lines and grades indicated on the plans will be measured and paid for in accordance with Section 203 or 206. Additional earthwork outside of excavation for the wall installation and backfilling prior to or post wall construction will not be measured and paid for separately, but shall be included in the work.

Underdrain will be measured and paid for in accordance with Section 605.

Initial Shotcrete Facing will be measured and paid for in accordance with Section 641under Pay Item Initial Shotcrete Facing.

Incidental shotcrete required for over-break will be measured and paid for in accordance with Section 641 under Pay Item Shotcrete.

**Subsection 641.07 shall include the following:**

Initial Shotcrete Facing for soil nail wall, including the shotcrete steel and mesh reinforcement used for the temporary facing, will be measured by the actual square feet of shotcrete that is applied to the depth shown on the plans. Square feet of wall will be determined using the height measured at 20-foot maximum intervals along the wall layout line.

**Subsection 641.08 shall include the following:**

**Pay Item Pay Unit**

Initial Shotcrete Facing Square Foot