Make the following Section a part of the Standard Specifications:

"SECTION 657 - SOIL NAIL RETAINING WALL

657.01 Description. The Work shall consist of constructing permanent soil nail retaining walls as specified in the Contract Documents Furnish all labor, materials, and equipment required for completing the Work. Select the method of excavation, drilling method and equipment, and grouting procedures to meet the performance requirements specified herein.

Soil nailing work shall include excavating in accordance with the staged lifts shown in the Plans; drilling soil nail drill holes to the specified minimum diameter, length, and orientation indicated on the Plans; providing, placing and grouting the reinforcing bars into the drill holes; placing drainage elements; placing shotcrete reinforcement; applying initial and permanent shotcrete facing over the reinforcement; attaching bearing plates and nuts; and performing nail testing. Shotcrete facing and wall drainage construction are referred to the Section 628 - Shotcrete.

The term "Soil Nail" as used in these specifications is intended as a generic term and refers to a reinforcing bar grouted into a drilled hole installed in any type of ground conditions including soil and rock. Soil nail walls are built from the top down in existing ground.

Soil and rock properties, strength parameters, partial safety factors, design requirements and other criteria are shown on the Plans.

657.02 Soil Nail Contractor's Experience Requirements and Submittal.

The qualifications of the soil nailing Contractor shall conform to the minimum experience requirements below.

Submit a project reference list verifying the successful completion of at least three permanent soil nail retaining wall projects during the past 3 years totaling at least 15,000 square feet of wall face area and at least 150 permanent soil nails. A brief description of each project with the Owner's name and current phone number shall be included.

The soil nailing Contractor shall have his/her on-site staff personnel having sufficient experience in the construction of permanent soil nail retaining walls. As a minimum, the on-site supervisor and drill rig operators shall have experience installing permanent soil nails on at least three projects over the past 3 years.

At least 30 days before starting the wall or sacrificial pre-production verification testing of nails, the soil nail Contractor shall submit 8 copies of the completed project reference list and a list identifying the on site supervisors and

drill rig operators assigned to the project. The personnel list shall contain a summary of each individual's experience and be complete enough for the Engineer to determine whether each individual satisfies the required qualifications. The Engineer will accept or reject the submission. Work shall not be started nor materials ordered until the Engineer's written acceptance of the Contractor's qualification is given.

The Engineer may suspend the Work if the Contractor uses non-accepted personnel for the Work that has not been accepted by the Engineer. If work is suspended, the Contractor shall be fully liable for all resulting costs and no adjustment in contract time will result from the suspension.

657.03 Materials.

(A) General. No asbestos containing materials or equipment shall be used under this Section. The Contractor shall ensure that all materials and equipment incorporated in the project are asbestos-free.

(B) Materials. Furnish materials new and without defects. Remove defective materials from the job site at no additional cost to the State. Materials for soil nail structures shall consist of the following:

(1) Solid Bar Nail Tendons. ASTM A615, Grade 75, Epoxy Coated, Deformed bar continuous without splices or welds. New, straight, undamaged, and fully encapsulated, as shown on the Plans. Threaded a minimum of 6 inches on the wall anchorage end to allow for proper attachment of bearing plate and nut. Threading shall be continuous spiral deformed ribbing provided by the bar deformations.

(2) Encapsulation. Minimum 0.1-inch thick corrugated HDPE (AASHTO M252) or corrugated PVC (ASTM D1784). Encapsulation shall provide at least 0.25 inches of grout cover over the reinforcing bar. Encapsulation shall be resistant to ultra violet light degradation, normal handling stresses, and grouting pressures. The encapsulation shall be fabricated in the factory with a proper end cap on one side.

(3) Centralizers. Manufactured from Schedule 40 PVC pipe or tube, steel or other material not detrimental to the nail steel (wood shall not be used); securely attached to the nail bar, sized to position the nail bar within 1 inch of the center of the drill hole; sized to allow tremie pipe insertion to the bottom of the drill hole; and sized to allow grout to freely flow up the drill hole.

(4) Nail Grout. Grout for the soil nail retaining walls shall attain a minimum compressive strength of 4000 psi prior to testing. Testing for compressive strength shall conform to ASTM C-109 Mortar and Sand. See plans for additional grout requirements.

Water for mixing grout shall be potable, clean and free of injurious quantities of substances known to be harmful to Portland cement or steel.

(5) Admixtures. ASTM C494. Admixtures that control bleed, improve flowability, reduce water content and retard set may be used in the grout subject to review and acceptance by the Engineer. Accelerators are not permitted. Expansive admixtures may only be used in grout used for filling sealed encapsulations. Admixtures shall be compatible with the grout and mixed in accordance with the manufacturer's recommendations.

(6) Cement. ASTM C150, Type I, II, III or V.

(7) Film Protection. Polyethylene film per AASHTO M171.

(8) Shotcrete. Refer to the Section 628 - Shotcrete.

(C) Materials Handing and Storage. Store cement to prevent moisture degradation and partial hydration. Do not use cement that has become caked or lumpy.

Store steel reinforcement on supports to keep the steel from contacting the ground. Damage to the exposed nail steel as a result of abrasion, cuts, nicks, welds, and weld splatter shall be cause for rejection. Do not ground welding leads to nail bars. Protect nail steel from dirt, rust, and other deleterious substances prior to installation. Heavy corrosion or pitting of the exposed nails shall be cause for rejection. Place protective wrap over anchorage end of nail bar to which bearing plate and nut will be attached to protect the nail during handling, installation, grouting and shotcreting.

657.04 Construction Site Survey.

Prior to the start of any wall construction activity, the Contractor and Engineer shall jointly inspect the site to observe and document the pre-construction condition of the site, existing structures, and facilities. During construction, the Contractor shall observe the conditions above the soil nail wall on a daily basis for signs of ground movement in the vicinity of the wall. Immediately notify the Engineer if signs of movements, such as new cracks in existing structures, increased size of old cracks or separation of joints in

structures, foundations, streets or paved and unpaved surfaces, are observed. Submit observation report of the site within 7 day of inspection. Observation report shall contain all changes found at the site. If no changes were found, the report shall state it as so.

If the Engineer determines that the movements exceed those anticipated for typical soil nail wall construction and require corrective action, the Contractor shall take corrective actions necessary to stop the movement or perform repairs.

657.05 Submittals. Upon acceptance of the soil nailing Contractor's qualifications submittal set forth in Section 657.02, submit 8 copies of the following information, in writing, to the Engineer for review and acceptance.

Provide the following submittal items at least 30 days prior to initiating the soil nail wall construction (or pre-production verification tests on sacrificial test nails):

(A) The proposed start date and proposed detailed wall construction sequence including the following:

(1) Proposed mobilization and demobilization of the soil nail retaining wall construction equipment to and from the project site via restricted bridge crossings (such as no more than 8-ton gross weight).

(2) Proposed disposal site for the unsuitable materials from the clear and grubbing operation and the staged excavation.

(3) Plan describing how surface water will be diverted, controlled and disposed of.

(4) Proposed methods and equipment for excavating the soil and/or rock to the staged excavation lifts indicated in the Plans, including the proposed grade elevations for each excavation lift shown on a wall elevation view.

(5) Measures to ensure wall and slope stability during various stages of wall construction and excavation where discontinuous rows of nails will be installed (if applicable); information on space requirements for installation equipment; temporary shoring plans (if applicable); information on provisions for working in the proximity of underground facilities or utilities (if applicable).

(6) Proposed nail drilling methods and equipment.

(B) Nail grout mix design including the following:

(1) Type of Portland cement.

(2) Proportions of mix by weight and water-cement ratio.

(3) Manufacturer, brand name and technical literature for proposed admixtures.

(4) Compressive strength test results per ASTM C109 supplied by a qualified independent testing laboratory verifying the specified minimum 3 and 28-day grout compressive strengths. Previous test results for the proposed grout mix completed within one year of the start of grouting may be submitted for initial verification and acceptance of the required compressive strengths and start of production work.

(C) Proposed nail grout placement procedures and equipment.

(D) Proposed nail testing methods and equipment setup including the following:

(1) Details of the jacking frame and appurtenant bracing.

(2) Details showing methods of isolating test nails during shotcrete application (i.e., methods to prevent bonding of the soil nail bar and the shotcrete facing during testing).

(3) Details showing methods of providing the temporary unbonded length and of grouting the temporary unbonded length of test nails after completion of testing.

(4) Equipment list.

(E) Identification number and certified calibration records for each test jack and pressure gauge and load cell to be used. Jack and pressure gauge shall be calibrated as a unit. Calibration records shall include the date tested, identification number, and the calibration test results and shall be certified to an accuracy of at least 2 percent of the applied certification loads by a qualified independent testing laboratory within 180 days prior to submittal.

(F) Manufacturer Certificates of Compliance for the soil nail centralizers.

(G) Shop drawings for falsework (formwork), if applicable.

The Contractor will not be allowed to begin wall construction or incorporate materials into the work until the submittal requirements are satisfied and found acceptable to the Engineer. Changes or deviations from the accepted submittals must be resubmitted for acceptance. No adjustments in contract time will be allowed due to incomplete submittals.

Upon delivery of the encapsulated nail bars to the project site, provide Certified mill test results for the encapsulated nail bars from each heat specifying the ultimate strength, yield strength, elongation and composition.

657.06 Construction Requirements.

(A) Pre-Construction Meeting. A pre-construction meeting will be scheduled by the Engineer and held prior to the start of wall construction and pre-production verification tests on sacrificial test nails. The Engineer, designer, prime Contractor, soil nail Contractor and Owner's Geotechnical Engineer shall attend the meeting. The excavation Contractor, shotcreting Contractor and survey Contractor, if different than the prime or soil nail Contractor, shall also attend. Attendance is mandatory.

The pre-construction meeting will be conducted to clarify the construction requirements for the work, to coordinate the construction schedule and activities, and to identify contractual relationships and delineation of responsibilities among the prime Contractor and the various Subcontractors – particularly those pertaining to wall excavation, nail installation and testing, excavation and wall alignment survey control, and shotcrete facing construction. Soil nail wall construction requires excavation in staged lifts and excavation in the vicinity of the wall face requires special care and effort compared to general earthwork excavation. The Contractor shall take this into account during bidding.

(B) Site Drainage Control. Provide positive control and discharge of all surface water that will affect construction of the soil nail retaining wall. Maintain all pipes or conduits used to control surface water during construction. Repair damage caused by surface water at no additional cost to the State. Upon substantial completion of the wall, remove surface water control pipes or conduits from the site. Alternatively; with the acceptance of the Engineer, pipes or conduits that are left in place, may be fully grouted and abandoned or left in a way that protects the structure and all adjacent facilities from migration of fines through the pipe or conduit and potential loss of ground.

The regional groundwater table is anticipated to be below the level of the wall excavation based on the available geotechnical information. Localized areas of perched water or seepage may be encountered during excavation at the interface of geologic units or from localized groundwater

seepage areas. These perched groundwater conditions shall not be considered as "differing site conditions" by the Contractor.

Immediately contact the Engineer if unanticipated existing subsurface drainage features and/or structures are discovered during excavation. Suspend work in these areas until remedial measures meeting the Engineer's acceptance are implemented. Capture surface water runoff flows (and flows from existing subsurface drainage structures) independently of the wall drainage network and convey them to an outfall structure or storm sewer, as accepted by the Engineer. Cost of remedial measures required to capture and dispose of water resulting from encountering unanticipated man-made subsurface drainage features and/or structures will be paid for as Extra Work.

(C) Excavation. Coordinate the work and the excavation such that the soil nail wall is safely constructed. The Contractor shall protect, at all times, the existing structures and features above, below and around the soil nail walls during excavation for the soil nail wall. Perform the wall construction and excavation sequence in accordance with the Contract Documents and accepted submittals. Exercise care in the excavation for the soil nail retaining walls due to the cobbly and rocky nature of the subsurface materials at the soil nail retaining wall locations to minimize substantial excavation overbreak, which will require subsequent backfill with shotcrete at no additional cost to the State. Care shall also be taken and accounted for in the pricing to minimize the impact to the environment in the area. No excavations steeper than those specified herein or shown on the Plans shall be made above or below the soil nail wall without the written acceptance of the Engineer.

(D) Excavation and Wall Alignment Survey Control. Be responsible for providing:

(1) Both the survey reference and control points along the top of the wall alignment.

(2) necessary survey and alignment control during excavation of each lift,

(3) locating and drilling each drill hole within the allowable tolerances, and

(4) for performing the wall excavation and nail installation in a manner that will allow for constructing the shotcrete facing to the specified minimum thickness and such that the permanent concrete facing can be constructed to the specified minimum thickness and to the line and grade indicated in the Plans.

Where the as-built location of the front face of the shotcrete facing exceeds the allowable tolerance from the wall control line shown on the Plans, Be responsible for determining and bearing the cost of remedial measures necessary to provide proper attachment of nail head bearing plate connections and satisfactory placement of the permanent concrete facing, as called for on the Plans.

(E) General Excavation. Complete clearing, grubbing, grading and excavation above and behind the wall (if required) before commencing wall excavation. Do not over excavate the original ground behind the wall or at the ends of the wall, beyond the limits shown on the Plans. Do not perform general excavation that will affect the soil nail wall until wall construction starts. General excavation shall be coordinated with the soil nailing work and the excavation shall proceed from the top down in a horizontal staged excavation lift sequence with the ground level for each lift excavated no more than mid-height between adjacent nail rows, as illustrated on the Plans. Do not excavate the full wall height to the final wall alignment as shown on the Plans.

(F) Soil Nail Wall Structure Excavation. Structure excavation in the vicinity of the wall face will require special care and effort compared to general earthwork excavation. Take this special structure excavation requirement into account during bidding. Due to the close coordination required between the soil nail Contractor and the excavation Contractor, the excavation Contractor shall perform the structure excavation for the soil nail wall under the direction of the soil nail Contractor.

Excavate to the final wall face using procedures that will:

(1) Prevent over excavation;

(2) prevent ground loss, swelling, air slaking, or loosening;

(3) prevent loss of support for completed portions of the wall; and

(4) prevent loss of soil moisture at the face.

Costs associated with additional thickness of shotcrete or concrete or other remedial measures required due to irregularities in the cut face, excavation over-break due to the nature of the on-site materials (cobbly and rocky materials) or inadvertent over excavation, shall be borne by the Contractor.

The exposed unsupported final excavation face cut height shall not exceed the vertical nail spacing plus the required reinforcing lap or the short-term stand-up height of the ground, whichever is less. Complete

excavation to the final wall excavation line and apply the shotcrete in the same work shift, unless otherwise accepted by the Engineer. Application of the shotcrete, with the acceptance of the Engineer, may be delayed up to 24 hours if the Contractor can show that the delay will not adversely affect the excavation face stability. Minimize degradation of the cut face caused by changes in moisture. A polyethylene film over the face of the excavation may reduce degradation of the cut face caused by changes in moisture. Other methods may be used if accepted by the Engineer. Damage to the existing structures or structures included in the Work shall be repaired and paid by the Contractor where acceptance is granted for the extended face exposure period.

Excavation to the next lift shall not proceed until nail installation, shotcrete facing placement, attachment of bearing plates and nuts and nail testing has been completed and accepted in the current lift. Nail grout and shotcrete shall cure for a minimum of 72 hours or attained at least their **specified 3-day compressive strength** before excavating the next underlying lift. Excavating the next lift in less than 72 hours will only be allowed if the Contractor submits compressive strength test results, for test performed by a qualified independent testing laboratory, verifying that the nail grout and shotcrete mixes being used will provide the specified 3-day compressive strengths in the lesser time.

Notify the Engineer immediately if raveling or local instability of the final wall face excavation occurs. Unstable areas shall be temporarily stabilized by means of buttressing the exposed face with an earth berm or other methods. Suspend work in unstable areas until remedial measures are developed.

(G) Wall Discontinuities. Where the Contractor's excavation and installation methods result in a discontinuous wall along any nail row, the ends of the constructed wall section 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, prevent sloughing or failure of the temporary slopes at the end of each wall section.

(H) Excavation Face Protrusions, Voids or Obstructions. Remove all portions of cobbles, boulders, rubble or other subsurface obstructions encountered at the wall final excavation face that will protrude into the shotcrete facing. Determine method of removal of face protrusions, including method to safely secure remnant pieces left behind the excavation face and for promptly backfilling voids resulting from removal of protrusions extending behind the excavation face. Notify the Engineer of the proposed method(s) for removal of face protrusions at least 24 hours

prior to beginning removal. Voids, over-break or over-excavation beyond the plan wall excavation line resulting from the removal of face protrusions or excavation operations shall be backfilled with shotcrete or concrete, as accepted by the Engineer. Removal of face protrusions and backfilling of voids or over-excavations shall be considered incidental to the work.

(l) Nail Installation. Determine the required drill hole diameter(s), drilling method, grout composition and installation method necessary to achieve the nail pullout resistance(s) specified in the Contract Documents, in accordance with the nail testing acceptance criteria in the Nail Testing section.

No drilling or installation of production nails will be permitted in any soil/rock unit until successful pre-production verification testing of sacrificial test nails is completed in that unit and accepted by the Engineer. Install verification test nails using the same equipment, methods, nail inclination and drill hole diameter as planned for the production nails. Perform pre-production verification tests on sacrificial test nails with full-scale strain gage instrumentation in accordance with the Verification Testing Section prior to ordering materials. Acceptable pre-production verification tests on sacrificial test nails shall also be completed prior to starting wall excavation and installation of production nails in the specific lift. The number and location of the sacrificial test nails will be as indicated in the Contract Documents.

Sacrificial verification test nails shall be installed through the design finished slope face prior to the start of wall excavation. Subject to the Engineer's acceptance, sacrificial verification test nails may also be installed at different locations than specified providing the Contractor demonstrates, to the satisfaction of the Engineer, that the test nails will be bonded into ground that is representative of the ground at the sacrificial verification test nail locations designated in the Contract Documents. Install the production soil nails before the construction of the permanent shotcrete facing.

The Contractor shall place a sealing layer (flashcoat) of shotcrete or fiber reinforced shotcrete to protect and stabilize the face of the excavation as shown in the Contract Documents. Cost of the sealing layer (flashcoat) of shotcrete or fiber reinforced shotcrete shall be measured and paid for under Section 628 - Shotcrete.

The Engineer may add, eliminate, or relocate nails to accommodate actual field conditions. Cost adjustments associated with these modifications shall be made in accordance with the Contract Documents.

The cost of any redesign, additional material, or installation modifications resulting from actions of the Contractor shall be borne by the Contractor.

(J) Drilling. The specified size drill holes for the soil nails shall be made at the locations, orientations, and lengths shown on the plans or as directed by the Engineer. The Contractor has the option to make adjustments in the diameter of the drill holes, upon written acceptance of the Engineer, at no additional cost provided that the resulting change in the drill hole size will achieve the nail pullout resistance(s) specified herein and in the Contract Documents. The adjusted soil nail shall be capable of sustaining a **minimum load of 1.4 kips per lineal foot of the soil nail length** or otherwise specified in the Contract Documents and the diameter of the drilled hole shall not be less than 8 inches.

Subsurface exploration at the locations of the soil nail retaining walls was conducted at selected locations as part of the project. The Contractor may assume that the subsurface materials to be encountered at the soil nail retaining wall locations will consist of the geologic formations identified in the boring logs shown in the Contract Documents, referred to the report by Ernest K. Hirata & Associates, Inc., entitled as "Soils Investigation, Kuhio Highway Improvements at Lumahai and Wainiha, Lumahai, Kauai", dated August 30, 1999. It shall be noted that highly weathered basalt rock stratum shown on the Contract Documents may include core stones of relatively hard, less weathered rock (possible spheroidal weathering). The Contractor shall anticipate the presence of cobbles, boulders, and hard rock at the site.

Thoroughly investigate the site and select the appropriate drilling equipment and methods for the drilling. Use of drilling muds such as bentonite slurry to assist in drill cutting removal is not allowed but compressed air may be used. Care shall be exercised by the Contractor to avoid disturbing the existing structures and features behind the soil nail retaining wall when compressed air is used for the drilling. Where hard drilling conditions such as rock, cobbles, boulders, or obstructions are encountered, percussion or other suitable drilling equipment capable of drilling and maintaining stable drill holes through such materials shall be used. The Engineer will not make separate payment for excavation of materials of different densities and character (hardness) or employment of special tools and procedures necessary to install the soil nails.

Immediately suspend or modify the drilling operations if ground subsidence is observed, if the soil nail wall is adversely affected, or if adjacent structures and/or features are damaged from the drilling operation. Immediately stabilize the adverse conditions at no additional cost to the State.

(K) Nail Bar Installation. Provide fully encapsulated nail bars in accordance with the schedules included in the Plans. Provide centralizers sized to position the bar within 1 inch of the center of the drill hole. Position centralizers as shown in the Contract Documents so that the maximum center-to-center spacing does not exceed 10 feet. Also, locate centralizers within 2 feet from the top and bottom of the drill hole. Securely attach centralizers to the fully encapsulated bar so that they will not shift during handling or insertion into the drill hole, will still allow grout tremie pipe insertion to the bottom of drill hole, and will allow grout to flow freely up the hole.

Inspect each fully encapsulated nail bar before installation and repair or replace damaged bars. Check uncased drill holes for cleanliness prior to insertion of the soil nail bar. Insert fully encapsulated nail bars with centralizers into the drill hole to the required length without difficulty and in a way that prevents damage to the drill hole, bar, or corrosion protection. **Do not drive or force partially inserted soil nails into the hole. Remove nails that cannot be fully inserted to the design depth and clean the drill hole to allow unobstructed installation.**

When using cased or hollow stem auger drilling equipment, which does not allow for the centralizers to pass through the casing or auger stem, the Contractor may delete the centralizers if the neat cement grout pumped through the casing is placed using grout pressures greater than 150 psi or if the sand-cement grout placed through the stem of the auger has a slump of 9 inches or less.

(L) Nail Installation Tolerance.

(1) Nail location and orientation tolerances are as follows:

(a) Nail head location, deviation from plan design location: 6 inches in any direction.

(b) Nail inclination, deviation from plan: + or - 3 degrees.

(c) Location tolerances are applicable to only one nail and not cumulative over the large wall area. Center nail bars within 1 inch of the center of the drill hole.

(2) Soil nails that do not satisfy the specified tolerances, due to the Contractor's installation methods, shall be replaced at no additional cost to the State. Backfill abandoned nail drill holes with tremied grout. Nails that encounter unanticipated obstructions during drilling shall be relocated, as accepted by the Engineer. Cost of drilling and backfilling drill holes abandoned due to unanticipated

obstructions will be paid as Extra Work. Drilling through cobbles, boulders, and hard basalt rock formation shall be anticipated by the Contractor and shall not be considered unanticipated obstructions by the Contractor.

(M) Grout Mix Design. Submit the proposed nail grout mix design to the Engineer for review and acceptance in accordance with the submittal section.

(N) Grout Testing. Previous test results for the proposed grout mix completed within one year of the start of work may be submitted for initial verification of the required compressive strengths for installation of pre-production verification test nails and initial production nails. During production, test nail grout in accordance with ASTM C109 at a frequency of no less than one test for each day of grout placement or every 10 cubic yards of grout placed whichever is more frequent. **Provide grout cube test results for 3-day and 28-day compressive strength** in accordance with ASTM C109 to the Engineer within 24 hours of testing.

(O) Grouting Equipment. Grout equipment shall produce a uniformly mixed grout free of lumps and undispersed cement, and shall be capable of continuously agitating the mix. Use a positive displacement grout pump equipped with a pressure gauge, which can measure at least twice but no more than three times the intended grout pressure. Size the grouting equipment to enable the entire nail to be grouted in one continuous operation. Place the grout within 60 minutes after mixing or within the time recommended by the admixture manufacturer, if admixtures are used. Grout not placed in the allowed time limit shall not be used. Soil nails using such grout will be rejected.

(P) Grouting Methods. Grout the drill hole after installation of the nail bar. Each drill hole shall be grouted within 24 hours of completion of drilling, unless otherwise accepted by the Engineer. Inject the grout at the lowest point of each drill hole through a grout tube, casing, hollow-stem auger, or drill rods. Keep the outlet end of the conduit delivering the grout below the surface of the grout as the conduit is withdrawn to prevent the creation of voids. Completely fill the drill hole in one continuous operation. Cold joints in the grout column are not allowed except at the top of the test bond length of tested production nails and the initial grout line at the top of drilled holes.

During casing removal for drill holes advanced by either cased or hollow-stem auger methods, maintain sufficient grout level within the casing to offset the external groundwater/soil pressure and prevent hole caving. Maintain grout head or grout pressures sufficient to ensure that the

drill hole will be completely filled with grout and to prevent unstable soil or groundwater from contaminating or diluting the grout. Record the grout pressures for soil nails installed using pressure grouting techniques. Control grout pressures to prevent excessive ground heave or fracturing.

Remove the grout and nail if grouting is suspended for more than 30 minutes or does not satisfy the requirements of this specification or the Plans, and replace with fresh grout and undamaged nail bar at no additional cost to the State.

(Q) Nail Testing. Perform both verification and proof testing of designated test nails. Perform pre-production verification tests on sacrificial test nails at locations shown in the Contract Documents. Perform verification and proof tests on production nails at locations selected by the Engineer after complete installation based on the drilling and grouting records.

A minimum of 4 verification tests (not including pre-production verification tests on sacrificial test nails) shall be conducted for each type of soil nail during the production work in accordance with the Contract Documents. Verification testing on production nails shall be conducted in accordance with the procedures and loading schedule provided in the "Pre-Production Verification Testing on Sacrificial Test Nails."

Perform proof testing on at least 10 percent of the production nails in the presence of the Engineer at the locations selected by the Engineer. A verification test nail successfully completed during production work shall be considered equivalent to a proof test nail and shall be accounted for in determining the number of proof tests required.

Do not perform nail testing until the nail grout and initial shotcrete facing have cured for at least 72 hours and attained at least their specified 3-day compressive strength. Testing in less than 72 hours will only be allowed if the Contractor submits compressive strength test results, for tests performed by a qualified independent test laboratory, verifying that the nail grout and shotcrete mixes have provided the specified 3-day compressive strengths in the lesser time.

(R) Test Nail Unbonded Length. Provide temporary unbonded lengths for all soil nails installed. Isolate the test nail bar from the initial shotcrete facing and/or the reaction frame used during testing. Isolation of a test nail through the initial shotcrete facing shall not affect the location of the reinforcing steel under the bearing plate. Accepted test nails may be incorporated as production nails provided the temporary test unbonded length is fully grouted subsequent to testing. Submit the proposed test nail isolation methods, methods for providing an unbonded test length, and

methods for grouting the unbonded length subsequent to testing to the Engineer for review and acceptance in accordance with the Submittal section. Where temporary casing of the unbonded length of test nails is provided, install the casing in a way that prevents any reaction between the casing and the grouted bond length of the nail and/or stressing apparatus.

(S) Testing Equipment. Testing equipment shall include dial gauges, dial gauge support, jack and pressure gauge, electronic load cell, and a reaction frame. The load cell is required for the creep test portion of the test. Provide description of test setup and jack, pressure gauge, and load cell calibration curves in accordance with Submittals section.

Design the testing reaction frame to be sufficiently rigid and of adequate dimensions such that excessive deformation of the testing equipment does not occur. If the reaction frame will bear directly on the initial shotcrete facing, design it to prevent cracking of the shotcrete. Independently support and center the jack over the nail bar so that the bar does not carry the weight of the testing equipment. Align the jack, bearing plates, and stressing anchorage with the bar such that unloading and repositioning of the equipment will not be required during the test.

Apply and measure the test load with an electric load cell and digital readout device associated with a hydraulic jack pressure gauge. The pressure gauge shall be graduated in 50 psi increments or less. The jack and pressure gauge shall have a pressure range not exceeding twice the anticipated maximum test pressure. Jack ram travel shall be sufficient to allow the test to be done without resetting the equipment.

Monitor the nail load during verification and proof tests with both the load cell and the pressure gauge. Use the load cell to maintain constant load hold during the creep test load hold increment of the test.

Measure the nail head movement with a dial gauge capable of measuring up to 0.001 inches. The dial gauge shall have a travel sufficient to allow the test to be done without having to reset the gauge. Visually align the gauge to be parallel with the axis of the nail and support the gauge independently from the jack, wall or reaction frame. Use two dial gauges when the test setup requires reaction against a soil cut face.

(T) Pre-Production Verification Testing of Sacrificial Test Nails. Pre-production verification testing shall be performed in the presence of the Engineer prior to installation of production nails to verify the Contractor's installation methods and nail pullout resistance. Perform pre-production verification test at the locations and elevations shown in the Contract Documents, unless otherwise accepted by the Engineer. Perform a minimum of two sacrificial verification tests for each different

drilling/grouting method proposed to be used by the Contractor. Verification test nails will be sacrificial with full-scale strain gage instrumentation. Pre-production verification testing nails shall not be incorporated as production nails.

The full-scale instrumentation consists of vibrating wire embedment strain gages attached on the reinforcing bar at each level, starting from about 2 feet above bottom of drilled hole and subsequently at about 5-foot intervals. The Engineer will install and monitor the strain gages. The Contractor shall provide access and assistance to the Engineer during the installation and monitoring.

Changes in the drilling or installation method by the Contractor may require additional verification testing as determined by the Engineer and shall be provided at no additional cost to the State. Construct verification test nails using the same equipment, installation methods, nail inclination, and drill hole diameter as planned for the production nails. Payment for additional verification tests required due to differing site conditions, if determined by the Engineer, will be paid as Extra Work.

Test nails shall have both bonded and temporary unbonded lengths. Prior to testing, only the bonded length of the test nail shall be grouted. The temporary unbonded length of the test nail shall be at least 3 feet. The bonded length of the test nail shall be determined based on the production nail bar grade and size such that the allowable bar structural load is not exceeded during testing, but shall not be less than 10 feet. The allowable bar structural load during testing shall not be greater than 90 percent of the yield strength for Grade 75. The Contractor shall provide larger verification test bar sizes, if required to safely accommodate the 10 feet minimum test bond length and testing to 2 times the allowable pullout resistance requirements, at no additional cost to the State.

The verification test bonded length (LBV) shall not exceed the test allowable bar structural load divided by 2 times the allowable pullout resistance value. The following equation shall be used for determining the verification test nail maximum bonded length to be used to avoid structurally over-stressing the verification test nail bar size:

$LBV = C \times f_Y \times A_s / 2 \times Q_d$, or 10 feet, whichever is greater.

LBV = Maximum Verification Test Nail Bonded Length (feet)
C = 0.9
f_Y = Bar Yield (75 ksi)
A_s = Bar Steel Area (square inches)
2 = Pullout resistance safety factor
Q_d = Allowable pullout resistance (1.4 kips/lineal foot of grouted nail length, or otherwise specified in the Contract Documents)

The Design Test Load (DTL) during verification testing shall be determined by the following equation:

DTL = Design Test Load (kips) = L_{BV} X Q_d

L_{BV} = As-built bonded test length (feet)
Q_d = Allowable pullout resistance (1.4 kips/lineal foot of grouted nail length or otherwise specified in the Contract Documents)

The Maximum Test Load (MTL) during verification testing shall be determined by the following equation:

MTL = Maximum Test Load (kip) = 2.0 X DTL

Except for the pre-production sacrificial test nails, verification test nails shall be incrementally loaded to a maximum test load of 200 percent of the Design Test Load (DTL) in accordance with the following loading schedule. The pre-production sacrificial test nails shall be tested to failure or reinforcing bar yield strength, whichever is achieved first, in 25 percent of design load increment. The soil nail movements shall be recorded at each load increment.

VERIFICATION TEST LOADING SCHEDULE	
LOAD	HOLD TIME
AL (0.05-DTL maximum)	1 minute
0.25 DTL	10 minutes
0.50 DTL	10 minutes
0.75 DTL	10 minutes
1.00 DTL	10 minutes
1.25 DTL	10 minutes
1.50 DTL (Creep Test)	60 minutes
1.75 DTL	10 minutes
2.00 DTL (Maximum Test Load)	10 minutes

The alignment load (AL) shall be the minimum load required to align the testing apparatus and shall not exceed 5 percent of the Design Test

Load (DTL). Dial gauges shall be set to "zero" after the alignment load has been applied.

Each load increment shall be held for at least 10 minutes with the exception of the alignment load (AL). The verification test nail shall be monitored for creep at the 1.50 DTL load increment. Nail movements during the creep portion of the test shall be measured and recorded at 1 minute, 2, 3, 5, 6, 10, 20, 30, 50, and 60 minutes. The load, during the creep test, shall be maintained at a minimum the load stated in the table above and not exceed 2 percent of the intended load by use of the load cell.

(U) Proof Testing of Production Nails. Perform proof testing on at least 10 percent of the production nails in the presence of the Engineer at the locations selected by the Engineer in the field during construction. A verification test nail successfully completed during production work shall be considered equivalent to a proof test nail and shall be accounted for in determining the number of proof tests required.

Production proof test nails shall have both bonded and temporary unbonded lengths. Prior to testing, only the bonded length of the test nail shall be grouted. The temporary unbonded length of the test nail shall be at least 3 feet. The bonded length of the test nail shall be determined based on the production nail bar grade and size such that the allowable bar structural load is not exceeded during testing, but shall not be less than 10 feet. The allowable bar structural load during testing shall not be greater than 90 percent of the yield strength for Grade 75 bars.

The proof test nail bonded length (L_{BP}) shall not exceed the test allowable bar load divided by 1.5 times the allowable pullout resistance value, or minimum lengths, whichever is greater. The following equation shall be used for sizing the proof test nail bonded length to avoid over-stressing the production nail bar size.

$L_{BP} = C \times f_y \times A_s / 1.5 \times Q_d$, or minimum lengths, whichever is greater.

L_{BP} = Maximum Proof Test Nail Bonded Length (feet)
C = 0.9 for Grade 75 bars
f_Y = Bar Yield Stress (75 ksi)
A_s = Bar Steel Area (square inches)
1.5 = Pullout resistance safety factor
Q_d = Allowable pullout resistance (1.4 kips/lineal foot of grouted nail length or otherwise specified in the Contract Documents)

The Design Test Load (DTL) during proof testing shall be determined by the following equation:

DTL = Design Test Load (kip) = L_{BP} X Q_d

L_{BP} = As-built bonded test length (feet)
Q_d = Allowable pullout resistance (1.4 kips/lineal foot of grouted nail length or otherwise specified in the Contract Documents)

The Maximum Test Load (MTL) during proof testing shall be determined by the following equation:

MTL = Maximum Test Load (kip) = 1.5 X DTL

Proof test shall be performed by incrementally loading the proof test nail to a maximum test load of 150 percent of the Design Test Load (DTL). The nail movement at each load shall be measured and recorded by the Engineer in the same manner as for verification tests. The test load shall be monitored by a load cell and a jack pressure gauge with a sensitivity range meeting the requirements of pressure gauges used for verification test nails. At load increments other than the maximum test load, the load shall be held long enough to obtain a stable reading. The Engineer will determine when the load has stabilized and a stable reading can be made. Incremental loading for proof tests shall be in accordance with the following load schedule. The soil nail movements shall be recorded at each load increment.

PROOF TEST LOADING SCHEDULE	
LOAD	**HOLD TIME**
AL (0.05-DTL maximum)	Until Stable
0.25 DTL	Until Stable
0.50 DTL	Until Stable
0.75 DTL	Until Stable
1.00 DTL	Until Stable
1.25 DTL	Until Stable
1.50 DTL (Maximum Test Load)	See Below

The alignment load (AL) shall be the minimum load required to align the testing apparatus and shall not exceed 5 percent of the Design Test Load (DTL). Dial gauges shall be set to "zero" after the alignment load has been applied.

All load increments shall be maintained at minimum the load stated in the table above and not exceed 5 percent of the intended load. Depending on performance, either 10 minute or 60 minute creep tests shall be performed at the maximum test load (1.50 DTL). The creep period shall start as soon as the maximum test load is applied and the nail movement shall be measured and recorded at 1 minute, 2, 3, 5, 6, and 10 minutes. Where the nail movement between 1 minute and 10 minutes exceeds 0.04 inches, the maximum test load shall be maintained an additional 50 minutes and movements shall be recorded at 20, 30, 50, and 60 minutes.

(V) Test Nail Acceptance Criteria. A test nail will be considered acceptable by the Engineer when:

(1) For the verification tests, a total creep movement of less than 0.08 inch per log cycle of time between the 6 and 60 minute readings is measured during creep testing and the creep rate is linear or decreasing throughout the creep test load hold period.

(2) For the proof tests, a total creep movement of less than 0.04 inch is measured between the 1 and 10 minute readings or a total creep movement of less than 0.08 inch is measured between the 6 and 60 minute readings and the creep rate is linear or decreasing throughout the creep test load hold period.

(3) The total measured movement at the maximum test load exceeds 80 percent of the theoretical elastic elongation of the test nail unbonded length.

(4) A pullout failure does not occur at any load increment. Pullout failure is defined as the load at which attempts to further increase the test load simply result in continued pullout movement of the test nail. The pullout failure load shall be recorded as part of the test data.

Successful verification and proof tested production nails meeting the above test acceptance criteria may be incorporated as production nails, provided that:

(a) the unbonded length of the test nail drill hole has not collapsed during testing,

(b) the minimum required drill hole diameter has been maintained,

(c) the specified corrosion protection is provided, and

(d) the test nail length is equal to or greater than the scheduled production nail length.

Test production nails meeting these requirements shall be completed by satisfactorily grouting up the unbonded test length. Maintaining the temporary unbonded test length for subsequent grouting is the Contractor's responsibility. If the unbonded test length of production test nails cannot be satisfactorily grouted subsequent to testing, the test nail shall become sacrificial and shall be replaced with an additional production nail installed at no additional cost to the State.

(W) Test Nail Rejection. If a test nail does not satisfy the acceptance criterion, the Contractor shall determine the cause. Such nails shall be considered not compliant and rejected.

(X) Verification Test Nails. The Engineer will evaluate the results of each verification test. Installation methods that do not satisfy the nail testing requirements will be rejected. The Contractor shall propose alternative methods and install replacement verification test nails. Replacement test nails shall be installed and tested at no additional cost to the State.

(Y) Proof Test Nails. The Engineer may require the Contractor to replace some or all of the installed production nails between a failed proof test nail and the adjacent passing proof test nail. Alternatively, the Engineer may require the installation and testing of additional proof test nails to verify that adjacent previously installed production nails have sufficient load carrying capacity. Contractor modifications may include, but are not limited to, the installation of additional proof test nails; increasing the drill hole diameter to provide increased capacity; modifying the installation or grouting methods; reducing the production nail spacing from that shown in the Contract Documents and installing more production nails at a reduced capacity; or installing longer production nails if the pullout capacity behind the failure surface controls the allowable nail design capacity. Installation and testing of additional proof test nails or installation of additional or modified nails as a result of proof test nail failure(s) will be at no additional cost to the State.

(Z) Nail Installation Record. Records documenting the soil nail wall construction will be maintained by the Contractor, unless specified otherwise. The Contractor shall provide the Engineer with as-built drawings showing as-built nail locations and as-built shotcrete construction facing line and grade within 5 days after completion of the shotcrete facing.

657.07 Method of Measurement.

(A) Furnishing Specialty Equipment. The Engineer will not measure furnishing specialty equipment for payment. The cost for furnishing specialty equipment shall be incidental to the soil nail installation.

(B) The Engineer will measure soil nails per linear foot in accordance with the contract documents including the pre-production verification tests on sacrificial test nails. The length to be paid will be the length measured along the bar centerline from the back face of the shotcrete facing to the bottom tip end of nail bar as shown on the plans. No separate measurement will be made for pre-production full-scale strain gage instrumentation tests, verification test and proof tests, which shall be considered incidental to soil nail installation.

(C) The Engineer will measure structure excavation for soil nail wall under Section 205 –Excavation and Backfill for Bridge and Retaining Structures.

(D) The Engineer will measure shotcrete facing and wall drainage under Section 628 - Shotcrete.

657.08 Basis of Payment.

(A) The Engineer will pay for the accepted soil nails including furnishing specialty equipment and the pre-production verification tests on sacrificial test nails with full-scale strain gage, installing the production soil nails shown on the plans, performing verification and/or proof testing on the selected production soil nails instrumentation at the contract unit price per linear foot, as shown in the proposal schedule. Payment will be full compensation for all labor, equipment, materials, shop drawings and calculations, field tests and incidentals necessary to perform the wall alignment survey control and construct the soil nails in accordance with the contract.

The Engineer will make payment under:

Pay Item	**Pay Unit**
Soil Nail Installation	Linear Foot

The Engineer will not pay for furnishing specialty equipment for soil nail wall as a separate item.

The Engineer will pay for structure excavation for soil nail wall under Section 205 – Excavation and Backfill for Bridge and Retaining Structures.

The Engineer will pay for shotcrete construction facing and wall drainage under Section 628 – Shotcrete."

END OF SECTION 657