DESIGN & CONSTRUCTION GUIDELINES FOR A SOIL NAIL WALL SYSTEM

GEOTECHNICAL ENGINEERING MANUAL
GEM-21
Revision #4
AUGUST 2015
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I. DESIGN

A. Consultation

The Designer shall consult with the Regional Geotechnical Engineer (RGE) as early as possible in the design phase to ensure adequate subsurface explorations are progressed to verify the feasibility of installing the soil nail wall system. Subsurface explorations must also provide enough information to define the engineering characteristics of the soil for design purposes. When considering the use of a soil nail wall system, it is recommended that the Designer contact the RGE for the determination of the appropriate subsurface exploration locations and subsequent analysis of the soil for its suitability for soil nailing. The Designer and the RGE shall also discuss the groundwater elevation and its effect on the proposed soil nail wall system and the anticipated construction sequencing with regard to the work zone traffic control to determine if additional subsurface explorations are required.

1. Temporary or Permanent Soil Nail Walls:

   A structure with a service life of 18 months or less qualifies as temporary. A structure with a service life longer than 18 months qualifies as permanent. If a structure is initially intended as temporary (e.g. temporary support of an excavation) but the results of the discussions between the Designer and RGE indicate that substantial construction delays are expected which dictate the excavation remain open much longer than 18 months, the soil nail wall should be characterized as permanent.

B. Feasibility Analysis

Although the details of the soil nail wall system will be designed by the Contractor’s consultant, a feasibility analysis is recommended. The Designer and the RGE shall request the Geotechnical Engineering Bureau (GEB) for a feasibility analysis. This analysis shall include:

1. Investigation of the site to determine if the subsoils are appropriate for soil nailing. Some limitations to soil nails are:

   A. Excavation support: To construct a soil nail wall, the first step is to make a near vertical excavation approximately 3 ft. to 6 ft. (1 m to 2 m) high. Therefore, the soil must be able to stand unsupported for a certain period of time, depending on nail installation progress and the length of the excavated row (length of wall). This would require the soil to have a sufficient degree of cohesion, cementing, or apparent cohesion from moisture. In addition, the anticipated construction sequencing with regard to the work zone traffic control should be reviewed to determine the offset to traffic.

   B. Seepage: If the groundwater exists within the cut face, the unreinforced soil may slump locally upon excavation, or the shotcrete to soil bond may be reduced.

   C. Soft Clays: The low frictional resistance of soft clay would require a very high density, of considerable length, of nails. In addition, soil nails in these soils are susceptible to creep and permanent wall systems may not be practical.
D. Utility Trenches: In addition to the presence of the utility itself, utility trenches are a potential plane of weakness. They may be a source of poorly compacted or unsuitable fill for soil nailing and/or a conduit for groundwater flow.

E. Work Zone: The method of drilling selected by the specialty Contractor will depend on the site and ground conditions and owned drill equipment. Most soil nails are installed using small hydraulic, track-mounted drill rigs. However, adequate working area is required (minimum of 16 ft. to 20 ft. (5 m to 6 m) wide benches). In addition to this, the anticipated construction sequencing with regard to the work zone traffic control should be analyzed. The working area requirements for installing soil nails may potentially impact the projects constraints. Specifically, when constructing a stageline wall for a structure replacement, the Department typically identifies 3 ft. (1 m) offset from the existing substructure and projects a safe slope layback for the excavation. However, in order to install the bottom row of nails, the Contractor’s equipment will require additional area for maneuverability. The Designer shall incorporate this additional area, typically 2 nails or 10 ft. (3 m), in developing excavation limits.

2. Preliminary design of the soil nails for length determinations. The GEB soil nail wall designer is directed to the current applicable design manual, US Department of Transportation, Federal Highway Administration, Publication No. FHWA-IF-03-017: Geotechnical Engineering Circular No. 7 Soil Nail Walls, March 2003. Some topics to study include the following:
   A. Right-of-Way: Permanent underground easements may be required.
   B. Utility Restrictions: Installation of soil nails may conflict with existing utility locations. (Also, see I.B.1.D. Utility Trenches) The GEB soil nail wall designer should work through the RGE to discuss with the Region if future utility installations in the area of the proposed wall are planned.

When performing the feasibility analysis, it is recommended that the GEB soil nail wall designer consult the RGE during the site investigation phase.

C. General Layout

The Designer is responsible for detailing the general layout of the proposed soil nail wall system for bidding purposes. The details are to provide sufficient information for a Contractor to bid the wall and for the Contractor’s Consultant to perform an engineering analysis and final detailing of the soil nail wall system. The following information is to be shown on the Plans:

1. Plan location of the soil nail wall.
2. Elevation view of the soil nail wall including payment limits.
3. Typical section of the soil nail wall.
4. Existing and final grade profiles in front of and behind the wall.
5. Right-of-way, temporary easement limits, potential interferences, utilities, etc.
6. All appropriate item numbers.
7. Quantities.
8. Table identifying the soil parameters used for the design:

<table>
<thead>
<tr>
<th>Location</th>
<th>Elevation (feet (meters))</th>
<th>Unit Weight (pcf (kN/m))</th>
<th>Friction Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Notes:

a. Groundwater is assumed at elevation _____.

b. A surcharge load of _____psf (kPa) is to be assumed at the top of wall.

c. The Contractor’s attention is directed to the subsurface conditions at elevation ______ which indicates (choices: rock, boulders, loose material, obstructions, perched water).

d. Any other pertinent information.

If the soil nailed wall is associated with a structure for which a Foundation Design Report (FDR) has been prepared, the FDR will provide this information. If, however, an FDR has not been prepared or the soil nailed wall is not in the vicinity of a structure, this information is to be provided by the GEB or the RGE for inclusion on the plans.

9. The location of the preproduction verification test nail is to be shown on the Plans. The specification requires a minimum of 2 verification tests in each different soil/rock unit and for each different drilling/grouting method proposed to be used, at each wall location. Verification test nails will be sacrificial and not incorporated as production nails. The preproduction verification test nail location will identify the first nail (sacrificial) to be tested to confirm the assumptions of the Contractor’s Consultant.

The facing details for permanent soil nail walls are left to the Designer. All appropriate item numbers should be identified for the permanent facing components as they are not included under the Basis of Payment in the soil nail specification. The details should include:

1. Connection of the permanent facing to the construction face of the soil nailed wall system.
2. Required reinforcement (if necessary).
3. Extension of internal and external drainage systems.
4. All appropriate item numbers and details pertinent to the chosen facing (barriers, coping, color, finishes, etc.).
II. CONSTRUCTION

A. Consultation

The Engineer-In-Charge (EIC) will consult with the Regional Geotechnical Engineer (RGE) to discuss the anticipated ground conditions at the site prior to the installation of the soil nail wall. The design assumptions may be discussed at a pre-construction meeting between the EIC, Inspector, RGE, Geotechnical Engineering Bureau (GEB), Contractor, and the Contractor’s soil nail wall designer.

B. Design Submittal:

The approval process for the design and installation personnel for the soil nail wall system is directed through the Deputy Chief Engineer Technical Services (DCETS). The EIC will submit the engineering analysis and final detailing of the soil nail wall system performed by the Contractor’s Consultant, and the proof of prior experience of the Contractor slated to perform the work, to the following:

Attn: Highway Design & Construction Section
New York State Department of Transportation
Geotechnical Engineering Bureau, Mail Pod 42
50 Wolf Rd.
Albany, NY 12232

The installation process requires testing a portion of the soil nails. The Contractor shall submit two (2) copies of all test data to the EIC. The EIC will forward one (1) copy to the above listed address for the GEB and retain the other copy in the job records and to be reviewed with the RGE.

C. Materials

The Inspector will check all Mill Test Certificates for compliance with the specification.

The Inspector will ensure that the nail tendons are assembled according the Contractor’s approved procedure. Specifically, the Inspector will check:

- The size of the nail tendon.
- The centralizer spacing and fastening such that they will allow unobstructed grout flow around the centralizers. Openings between the centralizer support arms should not be obstructed by material used to secure the centralizer to the nail tendon.
The nail tendons will be inspected for rust just prior to installation. Loose, powdery rust should be rubbed off, but not sanded. Nail tendons with nicks or pits are to be rejected.

The nail tendon is encapsulated or specified corrosion protection is applied, if required by the contract documents. Bare spots are unacceptable, as even the smallest pinholes can result in severe corrosion in aggressive soils.

The nail tendons shall be covered and stored off the ground, out of the way of construction equipment. Encapsulated or epoxy coated corrosion protected nail tendons shall be stacked with care to prevent damage to the coating or encapsulation.

The Inspector will confirm the mix design of the soil nail grout and facing shotcrete for compliance with the specification. When required, take grout cubes and/or shotcrete test panel and core samples for testing.

The Inspector will verify that the geocomposite drainage materials conform to the requirements of the specification and appear on the Department's Approved List.

D. Monitoring Nail Installation

1. **Excavation:**

Prior to the start of the wall construction, the Inspector will check for any variations between the actual ground elevation along the wall line and those shown on the Approved Shop Drawings.

The Inspector will monitor the excavation operation, frequently scanning the wall’s construction site to ensure the Contractor is maintaining overall stability and no ground deformations have occurred. The Inspector will check the wall neat line excavation and verify that the Contractor is not overexcavating into the next lift.

Typically, tension cracks form in the ground surface located immediately behind the top of the soil nail wall excavation. These cracks should be located and the Contactor and designer notified of their presence. The Inspector will monitor the cracks and provide displacement data to the Contractor and designer. Water should not be allowed to enter tension cracks.
2. **Drilling:**
   - The Inspector will record all appropriate information for each soil nail installation on a copy of the Soil Nail Installation and Summary Forms included in this manual. The Inspector will log the soil and rock cuttings brought up by the drilling operation.
   
   - The Inspector will verify the nail hole location. During drilling, the Inspector will check that the Contractor is utilizing a drill bit that will produce the proper hole diameter and verify that the nail declination angle is the same as shown on the Approved Shop Drawings.
   
   - The Inspector will continue monitoring to ensure no ground deformations have occurred or that there is no interconnection between drillholes.

3. **Nail Installation:**
   - The Inspector will inspect uncased holes with a mirror or flashlight for caving or loose debris. The hole shall be open and clean.
   
   - The Inspector will check the bonded and temporary unbonded lengths of the test nails.
   
   - The Inspector will ensure that the nail tendon is handled carefully to prevent damage. The temperature of the nail tendons must be above 32°F (0°C) to prevent the grout from freezing on contact.
   
   - The Inspector will verify that the nails are inserted to the minimum length shown on the Approved Drawings. If the Contractor is unable to insert the nail tendon to the minimum length, this unacceptable condition points to a caving/sloughing hole and/or insufficient drilled length. Never allow the nail tendon to be driven or pushed beyond the drilled length, or cut off.

4. **Grouting:**
   - The Inspector will verify that the grout is batched in accordance with the approved mix design. The grouting equipment shall be equipped with a working pressure gauge. The Inspector will monitor and record the grout pressure used. The Contractor shall clean the grout pressure gauge at least daily to prevent clogging.
The Inspector will ensure that the grout is pumped at the lowest point of the drill hole so that the hole is filled progressively from bottom to top. The tremie pipe shall remain below the level of the grout as it is extracted. The Contractor shall continue pumping grout until it flows out free of the impurities and lumps. The Contractor shall continue to pump grout as the grout tube, auger, or casing is removed. The Contractor shall not reverse the auger rotation while grouting.

The Inspector will measure and record the grout volume placed in the hole and determine the “grout take”. The “grout take” is the volume of grout actually placed in the drillhole, divided by the estimated hole volume. The estimated hole volume is computed as follows:

\[ \text{Hole Volume} = \frac{\pi D^2}{4} \times \text{grouted length of drillhole} \]

\[ \pi = 3.14 \]

\[ D = \text{drillhole diameter} \]

The Inspector will perform Quality Assurance Testing –

Density of Fluid Grout: Use a Baroid Mud Balance in accordance with the American Petroleum Institute (API) Recommended Practice (RP) 13B-1: Standard Procedure for Testing Water-Based Drilling Fluids to check the density of each batch of mixed grout prior to placement.

If the State elects to test compressive strength, perform the following:

Grout Cubes: Cast a mold set (three (3) grout cubes) for every 50 yd\(^3\) of grout placed in accordance with the procedure contained in Materials Bureau Test Method NY701-19E Grout Cube Molding Procedure

E. Supervising Nail Stressing and Testing:

The Inspector will obtain the nail tendon bar properties (i.e. steel modulus and area) necessary to calculate elongation from the Contractor. Verify the temporary unbonded test length.

The theoretical elastic movement of the unbonded length is computed as:

\[ \text{Deformation} \Delta e = \frac{PL}{AE} \]
\( P = \text{load (maximum applied test load, kips (kN))}. \)
\( L = \text{original length (temporary unbonded length: length from back of reference plate to the top of the bond length, inches (millimeters))}. \)
\( A = \text{cross sectional area of steel (square inches (square millimeters))}. \)
\( E = \text{Young’s modulus of elasticity (typically 29,000 ksi (200 GPa) for steel)}. \)

The measured movement of the soil nail head should exceed 80% of the theoretical elastic movement. This ensures that load is transferred from the soil nail tendon to the soil only in the bonded length and that additional load transfer is not occurring in the temporary unbonded length.

- The Inspector will verify that the nail length is sufficient to accommodate all test equipment (or use a coupler if allowed). The dial gauges shall be in proper working order and have an appropriate travel length (2 in. (50 mm) recommended minimum). The jack shall be in proper working order and the jack and pressure gauge shall be calibrated as a set. The calibration curves for the jack and pressure gauge and the load cell shall be obtained from the Contractor. The jack or pump shall have a bleed-off valve.

- The Inspector will check that the load cell and jack are aligned concentrically with one another and with the soil nail tendon. The dial gauge shall be aligned with the axis line of the anchor and independent of the nail and testing apparatus. Do not allow the jack to drop onto or lay on the anchor.

- The Inspector will ensure that the load in the anchor does not drop below the alignment load (AL) identified in the testing criteria. During a creep test, the load shall be held constant. The load shall be held within 2% of the intended load by use of a load cell.

The creep movement in the verification test is set such that the total movement is less than 0.08 in. (2 mm) between the 6 minute and 60 minute readings. During a proof test, the creep portion may be terminated if less than 0.04 in. (1 mm) of movement has occurred between the 1 minute and 10 minute readings. This criterion has been set to ensure that the nail design loads can be safely carried throughout the structure’s service life.

- The Inspector will continue monitoring the testing equipment to ensure that interference between the jacking set-up and the nail tendon has not occurred due to misalignment.

- The Inspector will record all readings and other pertinent information during testing on a copy of the Soil Nail Test Data Sheet, Elastic Movement, and Test Nail Creep Movement included in this manual.

- At the completion of testing for all test nails, including sacrificial nails, the Inspector will verify that the unbonded test length has been properly filled with grout. No voids shall be left in the ground.
F. Temporary Shotcrete Construction Facing and Drainage Examination:

- The Inspector will check that the geocomposite drainage strips, along with all elements of the wall drainage network, are installed as shown on the Approved Shop Drawings and are interconnected, providing continuous drainage paths. Maintenance of drainage continuity and capacity is critical to the overall stability of the soil nail wall system.

- The Inspector will verify that the welded wire fabric has been installed at the locations and to the dimensions shown on the Approved Shop Drawings.

- The Inspector will verify that the reinforcing steel has been installed at the locations and to the dimensions shown on the Approved Shop Drawings.

- The Inspector will verify that the shotcrete is batched in accordance with the approved mix design.

G. Documentation:

- The Inspector will make copies of all appropriate forms for nail tendon installation and testing. Record and log each nail tendon installation which includes: drilling, subsurface conditions encountered, nail tendon installation, and grouting. Record and plot test results for each nail tendon.

- All forms and calculations shall be complete, accurate and up to date. Log dates, times, and weather conditions on all records. Keep a photographic record along with the written documentation.
REFERENCES

Further information on soil nails may be found in such sources as: US Department of Transportation, Federal Highway Administration. Publications - Geotechnical Engineering - FHWA
APPENDICIES

FORMS:
The following forms were reproduced from:
# Soil Nail Installation and Summary Forms (US Customary Units)

## SOIL NAIL INSTALLATION FORM

Structure ___________________________ Nail Number ___________________________ Date ___________________________

Inspector ___________________________ Contract ___________________________ Location ___________________________ Station ___________________________

Method ___________________________ Rig Type ___________________________

Hole Diameter ___________________________ Inclination ___________________________ Tolerance Deviation ___________________________

Remarks ___________________________

---

## NAIL

Bar Diameter ___________________________ Bar Length ___________________________ Total Steel Area ___________________________

Bond Length ___________________________ Unbonded Length ___________________________ Design Load ___________________________

Remarks ___________________________

---

## GROUTING

Cu. Ft./Stroke ___________________________ Start Time ___________________________ Finish Time ___________________________

Pump Pressure ___________________________

Pumped Volume ___________________________ x ___________________________ = ___________________________

Hole Volume ___________________________ x ___________________________ = ___________________________

Grout Take (Ratio Pump Vol./Hole Vol.) ___________________________

Remarks ___________________________

---

## UNBONDED ZONE BACKFILL

Date ___________________________ Placement Method ___________________________

Start Time ___________________________ Finish Time ___________________________ Estimated Grout Volume ___________________________

Remarks ___________________________

---

Soil Nail Accepted ___________________________ Date ___________________________

Remarks ___________________________
Soil Nail Installation and Summary Forms (US Customary Units)

#SOIL NAIL INSTALLATION SUMMARY#

<table>
<thead>
<tr>
<th>Soil Nail Number</th>
<th>Date</th>
<th>Diameter/Method/Length</th>
<th>Type</th>
<th>Inclination</th>
<th>Soils</th>
<th>Tendon Dia./Grade/Length</th>
<th>Grouting</th>
<th>Remarks</th>
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</tbody>
</table>

**NOTES:**
## Soil Nail Test Data Sheet

<table>
<thead>
<tr>
<th>Time</th>
<th>Load</th>
<th>Movement (in.)</th>
<th>Tendon Dia.</th>
<th>Tendon Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load Increments (%)</td>
<td>Load Increments (kips)</td>
<td>Pressure Gauge (psi)</td>
<td>Dial Gage 1</td>
</tr>
</tbody>
</table>

- **Project:**
- **Station:**
- **Nail No.:**
- **Project No.:**
- **Length:**
- **Bonded Length:**
- **Hole Dia.:**
- **Unbonded Length:**
- **Type Test:**
  - Verification
  - Ultimate
  - Proof

This form is used for recording the data from soil nail tests, including load increments, movement, and tendon details.
Soil Nail Installation and Summary Forms (US Customary Units)

ELASTIC MOVEMENT

Project: ______________________________  Soil Nail No: ______________________________
Project No: __________________________  Bended Length: __________________________
Date: ______________  Unbonded Length: __________________________
Bar Size: ______________  Bar Dia: ______________ (in.)  Cross-sectional Area: ______________ (sq.in.)

Test Load P (kips)

<table>
<thead>
<tr>
<th>0</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td></td>
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<td>0.6</td>
<td></td>
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<tr>
<td>0.8</td>
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<tr>
<td>1.0</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>1.2</td>
<td></td>
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</tbody>
</table>

Movement (inches)

Test Acceptance Criteria:

\[ \text{Meas. Movement} > \frac{0.5 \times P \times UL}{A \times E} \]

Where:

- \( A \) = area of tendon (sq.in.)
- \( UL \) = unbonded length (in.)
- \( P \) = test load (kips)
- \( E = 29,000 \) Ksf
TEST NAIL CREEP MOVEMENT

Project: ____________________________  Soil Nail No.: ______________________

Project No.: ________________________  Date: ____________________________

Creep Movement (inches)

Log Time (minutes)
# Soil Nail Installation and Summary Forms

*International System of Units*

## Soil Nail Installation Form

<table>
<thead>
<tr>
<th>Structure</th>
<th>Nail Number</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspector</td>
<td>Contract</td>
<td>Location</td>
</tr>
<tr>
<td>Method</td>
<td>Rig Type</td>
<td>Hole Diameter</td>
</tr>
<tr>
<td>Remarks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Nail

<table>
<thead>
<tr>
<th>Bar Diameter</th>
<th>Bar Length</th>
<th>Total Steel Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond Length</td>
<td>Un-bonded Length</td>
<td>Design Load</td>
</tr>
<tr>
<td>Remarks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Grouting

<table>
<thead>
<tr>
<th>Cu. m/Stroke</th>
<th>Start Time</th>
<th>Finish Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump Pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumped Volume</td>
<td>x</td>
<td>=</td>
</tr>
<tr>
<td>Hole Volume</td>
<td>x</td>
<td>=</td>
</tr>
<tr>
<td>Grout Take (Ratio Pump Vol./Hole Vol.)</td>
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<td></td>
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<tr>
<td>Remarks</td>
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</tbody>
</table>

## Unbonded Zone Backfill

<table>
<thead>
<tr>
<th>Date</th>
<th>Placement Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Time</td>
<td>Finish Time</td>
</tr>
<tr>
<td>Remarks</td>
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<table>
<thead>
<tr>
<th>Soil Nail Accepted</th>
<th>Date</th>
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<tbody>
<tr>
<td>Remarks</td>
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</table>
Soil Nail Installation and Summary Forms (*International System of Units*)

### Soil Nail Installation Summary

<table>
<thead>
<tr>
<th>Soil Nail Number</th>
<th>Date</th>
<th>Diameter/Method/Length</th>
<th>Rig Type</th>
<th>Inclination</th>
<th>Soils</th>
<th>Tendon Dia./Grade/Length</th>
<th>Grouting</th>
<th>Remarks</th>
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**NOTES:**

SOIL NAIL TEST DATA SHEET

<table>
<thead>
<tr>
<th>Project:</th>
<th>Station:</th>
<th>Nail No.:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project No.:</td>
<td>Length:</td>
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<tr>
<td>Date:</td>
<td>Bonded Length:</td>
<td>Hole Dia.:</td>
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<td>Field Inspector:</td>
<td>Unbonded Length:</td>
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<tr>
<td>Type Test: Verification</td>
<td>Ultimate</td>
<td>Proof:</td>
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<table>
<thead>
<tr>
<th>Time</th>
<th>Load</th>
<th>Movement (mm)</th>
<th>Tendon Dia.</th>
<th>Tendon Grade</th>
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<tbody>
<tr>
<td></td>
<td>Load Increments (%)</td>
<td>Load Increments (% * %)</td>
<td>Pressure Gauge (kPa)</td>
<td>Dial Gage 1</td>
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Comments
ELASTIC MOVEMENT

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<tbody>
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<td>Bonded Length:</td>
</tr>
<tr>
<td>Date:</td>
<td>Unbonded Length:</td>
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Bar Size: Bar Dia.: (mm) Cross-sectional Area: (sq.mm)

Test Load P (kN)

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<th>120</th>
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Test Acceptance Criteria:

\[
\text{Meas. Movement} > \frac{0.8 \times P \times UL}{A \times E}
\]

Where:
- \( A \) = area of tendon (sq.mm)
- \( UL \) = unbonded length (mm)
- \( P \) = test load (kN)
- \( E \) = 500 GPa
TEST NAIL CREEP MOVEMENT

Project: ___________________________ Soil Nail No.: ___________________________

Project No.: ___________________________ Date: ___________________________

Creep Movement (millimeters)

Log Time (minutes)