Soil Nailing

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Historical Background

The insertion and grouting of metallic reinforcement into the ground, in combination with the use of shotcrete facing to provide excavation support, derives from the system developed for rock-excavation support known as the “New Austrian Tunneling Method”.

The passive steel bars are known as rock bolts in the tunnel industry. The concept of combining passive steel reinforcement and shotcrete extended subsequently to rock-slope stabilization projects. The use of this method was later expanded to stabilize slopes and excavations in soil.

In 1972 soil nails were used to stabilize an approximately (18^{m}) high cut-slope in sand for a railroad-widening project near Versailles, France. The method proved to be cost-effective and the construction faster than other conventional support methods.

The use of soil nails became common in France and other European countries since the completion of the Versailles project. The first use of soil nails in earth-retaining systems in Germany took place in 1975.

Introduction

Soil nail walls are constructed using a “top-down” construction sequence, where the ground is excavated in lifts of limited height. Soil nails and an initial shotcrete facing are installed at each excavation lift to provide support. Subsequently, a final shotcrete or cast-in-place- concrete (CIP) facing is installed.

Nails are most often installed at a vertical spacing of (1.2 to 1.8^{m}). The nail vertical spacing is comparable to the typical height of a stable, excavation lift, which is commonly (1 to 1.5^{m}) and could be more in some soils. The horizontal spacing of nails is often also in the range of (1.2 to 1.8^{m}).

Figure below depicts a soil nail wall installed to permit excavation in the right-of-way for a road widening project. Both the soil nails and the initial and final facing contribute to the stability of the excavation. The soil nails support the soil and transfer loads to the soil mass behind the wall. The facing supports the soil between nails and immediately behind the face, provides structural continuity, and enables the soil nail wall to act as a unit.

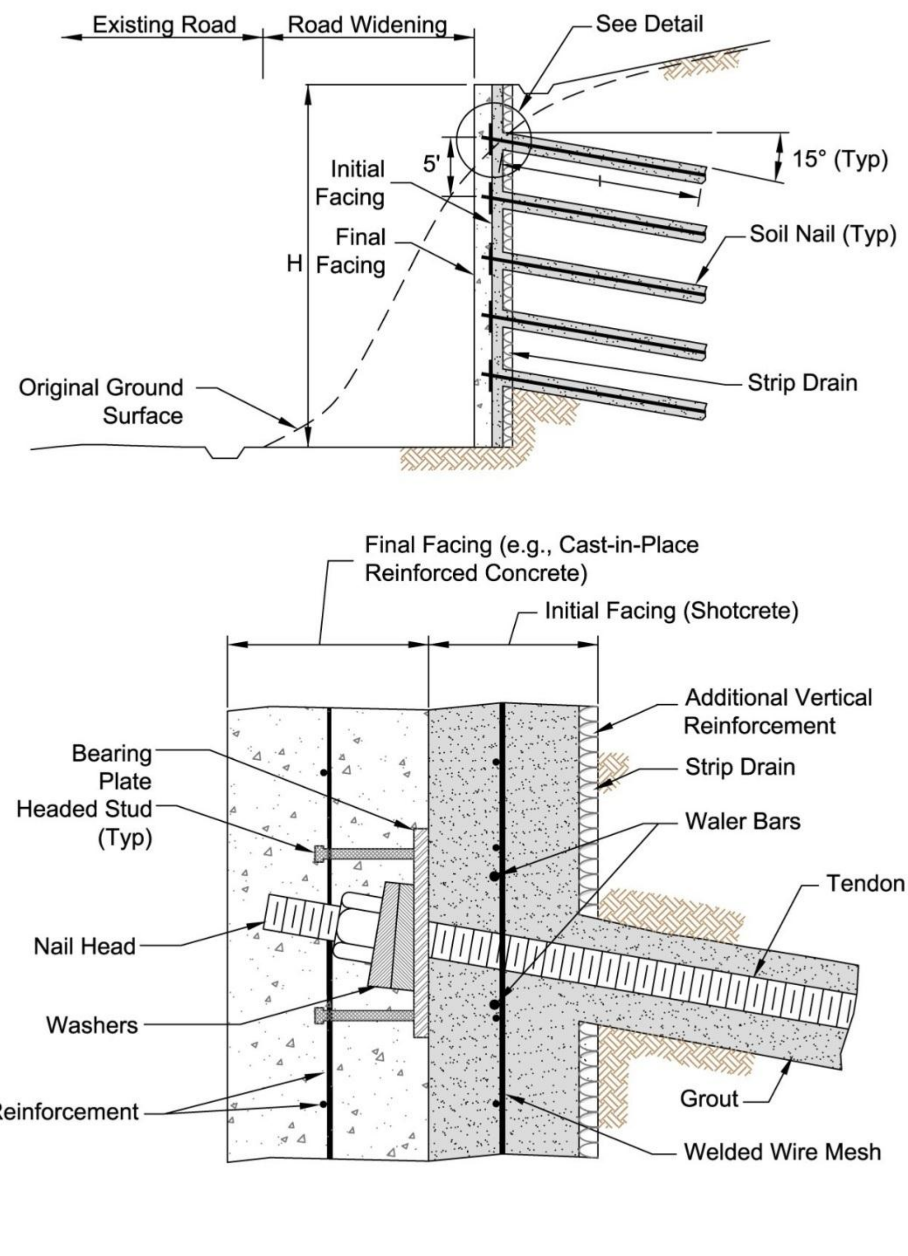

Figure1: Typical cross-section of a soil nail wall

Soil nail walls can be more advantageous than other top-down retaining systems where the ground can temporarily sustain short, vertical or sub-vertical unsupported cuts. Soil nail walls are permanent earth-retaining structures in most roadway projects in the world However, soil nail walls are also constructed as temporary structures (i.e., typical service life of a few months) in roadway work when used as shoring of temporary excavations.

Elements of Soil Nail Wall

The components of soil nail walls used in the World and the U.S. practice are identified in Figure above and are briefly described below:

1. **Soil Nails**
    - **Tendons** – Tendons are the ground reinforcing elements behind a soil nail wall and equivalent to (steel) bars. Tensile stress in each tendon mobilizes in response to lateral movement and deformation of the retained soil. Soil movement can occur during excavation, after excavation in the absence of external loads (as a result of time-dependent deformations), or after excavation when external loads such as surcharge or traffic loads are applied. The tendons can be solid or hollow bars. Solid bars are placed in stable drill holes and grouted in place. Hollow bars are fitted with a sacrificial drill bit and are used to drill the hole to then remain in place as the permanent soil nail reinforcement. Both solid and hollow bars are typically fully threaded.
    - **Grout** – Grout used for soil nails usually consists of Portland cement and water. The grout functions to: (i) transfer shear stresses between the deforming ground and the tendons; (ii) transfer tensile stresses from the tendons to the surrounding stable soil; and (iii) provide some level of

corrosion protection to the tendons. Grout is placed in the drill holes under gravity.

- **Corrosion Protection** – Soil nails used in permanent applications require chemical and/or physical protection against corrosion. The required level of corrosion protection is greater for soils with higher corrosion potential and for projects with lower risk tolerance.

2. Facing

- **Shotcrete** – Facing consists of an initial and a final component. Soon after excavation, the initial facing is applied on the exposed soil at each excavation lift before or after nail installation to provide temporary stability and protection. The initial facing also receives the bearing plate of the soil nail. The final facing is constructed over the initial facing and provides structural continuity throughout the design life. The final facing may also include an aesthetic finish. The initial facing most commonly consists of reinforced shotcrete. The final facing generally consists of (Cast in place) CIP-reinforced concrete, reinforced shotcrete, or precast concrete panels. Reinforcement used in the shotcrete of the initial facing includes the following items: (i) welded-wire mesh (WWM) installed over the entire excavation lift, and effectively over the entire wall using appropriate lap splices; (ii) horizontal bars placed around nail heads to add bending resistance in the horizontal direction; and (iii) vertical bearing bars placed at nail heads to add bending resistance in the vertical direction (see Figure 1 in page 3). Other reinforcement options include the use of steel or synthetic fiber particularly for temporary facing in soft or weathered rock. If the final facing consists of shotcrete, the reinforcement in the final facing is similar to that described for shotcrete in the initial facing. If the final facing consists of CIP or precast concrete, rebar mesh is typical.

3. **Other Components**
    - **Connection Components** – The soil nail is connected to the facing through a number of components including: nuts, washers, bearing plates, and headed-studs. The headed studs are attached to the bearing plate and become embedded within the final facing as depicted in Figure 1 in page 3.
    - **Drainage System** – A drainage system is installed behind soil nail walls to: (i) collect perched groundwater or infiltrated surface water that is present behind the facing; and (ii) direct the collected groundwater away from the wall. The drainage system commonly consists of composite, geo-synthetic drainage strips, also referred to as geo-composite strip drains. The drainage system does not provide full coverage of the wall area, but rather covers commonly 10-20%, or more, of the excavation face, depending on the selected strip drain spacing and commercial widths that are available.

Construction Sequence

The typical sequence of construction of a soil nail wall is described below and illustrated in (Figure 2, page 8):

Step 1. Excavation. The depth of the initial excavation lift (unsupported cut) may range between (0.75 and 2^{m}), but is typically (1 to 1.5^{m}) and reaches slightly below the elevation where the first row of nails will be installed. The feasibility of this step is critical because the excavation face must have the ability to remain unsupported, until the nails and initial face are installed, typically one to two days. The type of soil that is excavated may limit the depth of the excavation lift. The excavated platform must be of sufficient width to provide safe access for the soil nail installation equipment.

Step 2. Drilling of Nail Holes. Drill holes are advanced using specialized drilling equipment operated from the excavated platform. The drill holes typically remain unsupported.

Step 3.
A) Nail Installation and Grouting. Tendons are placed in the drilled hole. A tremie grout pipe is inserted in the drill hole along with the tendon; and the hole is filled with grout, placed under gravity or a nominal, low pressure (less than 5 to 10 psi). If hollow bars are used, the drilling and grouting take place in one operation.

B) Installation of Strip Drains. Strip drains are installed on the excavation face, continuously from the top of the excavation to slightly below the bottom of the excavation. The strip drains are placed between adjacent nails and are unrolled down to the next excavation lift.

Step 4. Construction of Initial Shotcrete Facing. Before the next lift of soil is excavated, an initial facing is applied to the unsupported cut. The initial facing typically consists of a lightly reinforced 10^{cm}. thick shotcrete layer. The reinforcement includes welded-wire mesh (WWM), which is placed in the middle of the facing thickness (Figure 1 page 3). Horizontal and vertical bars are also placed around the nail heads for bending resistance. As the shotcrete starts to cure, a steel bearing plate is placed over the tendon that is protruding from the drill hole. The bearing plate is lightly pressed into the fresh shotcrete. Hex nuts and washers are then installed to engage the nail head against the bearing plate. The hex nut is wrench-tightened within 24 hours of the placement of the initial shotcrete. Testing of some of the installed nails to proof-load their capacity or to verify the load-specified criterion may be performed before proceeding with the next excavation lift. The shotcrete should attain its minimum specified 3-day compressive strength before proceeding with subsequent excavation lifts. For planning purposes, the curing period of the shotcrete should be considered 72 hours.

Step 5. Construction of Subsequent Levels. Steps 1 through 4 are repeated for the remaining excavation lifts. At each excavation lift, the strip drain is unrolled downward to the subsequent lift. A new panel of WWM is then placed overlapping at least one full mesh cell with the WWM panel above. The temporary shotcrete is continued with the previous shotcrete lift.

Step 6. Construction of Final Facing. After the bottom of the excavation is reached and nails are installed and tested, the final facing is constructed. Final facing may consist of (cast in place) CIP reinforced concrete, reinforced shotcrete, or prefabricated panels. Weep holes, a foot drain, and drainage ditches are then installed to discharge water that may collect in the continuous strip drain.

Variations of the steps described above may be necessary to accommodate specific project conditions. For example, shotcrete may be applied at each lift immediately after excavation and before drilling of the holes and nail installation, particularly where stability of the excavation face is a concern. Another variation may be grouting the drill hole before placement of the tendon in the wet grout.

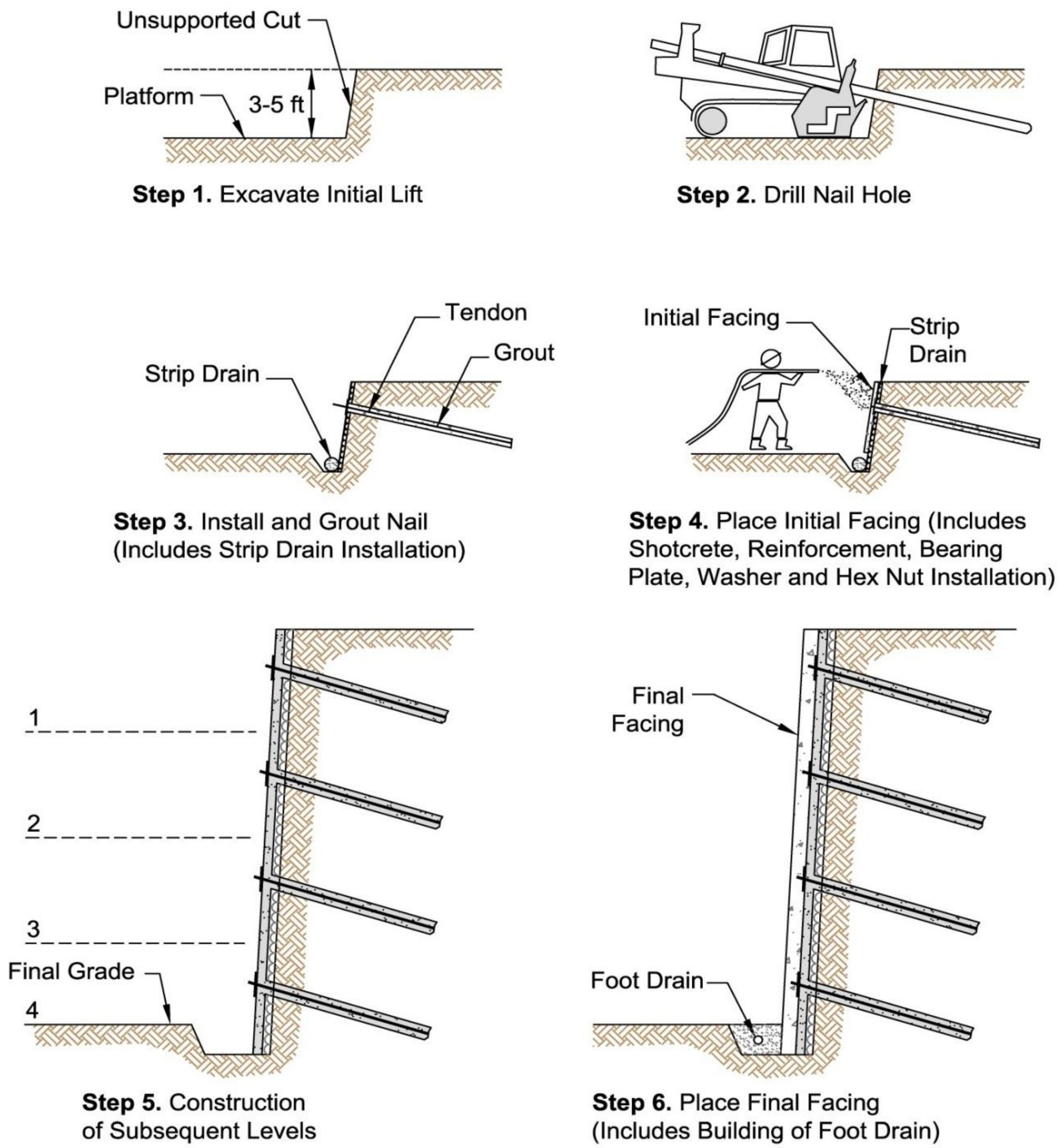

Figure 2: Illustration. Typical Soil-Nail Wall Construction Sequence

Applications of Soil Nail Walls

Soil nail walls can be used in the following roadway applications:

- Roadway cuts
- Road widening under existing bridge abutments
- Tunnel portals
- Repair and reconstruction of existing retaining structures
- Hybrid soil nail systems
- Shored Mechanically Stabilized Earth (SMSE) walls

Figure 3: Photo. Construction of Soil Nail Wall

- **Roadway Cuts**

Soil nailing is attractive in roadway cuts because a limited excavation and reasonable right- of-way (ROW) and clearing limits are required (See Figure 4 page 11). These factors help to reduce the environmental impacts along the transportation corridor. The impact to traffic may also be reduced because the equipment for installing soil nails is relatively small.

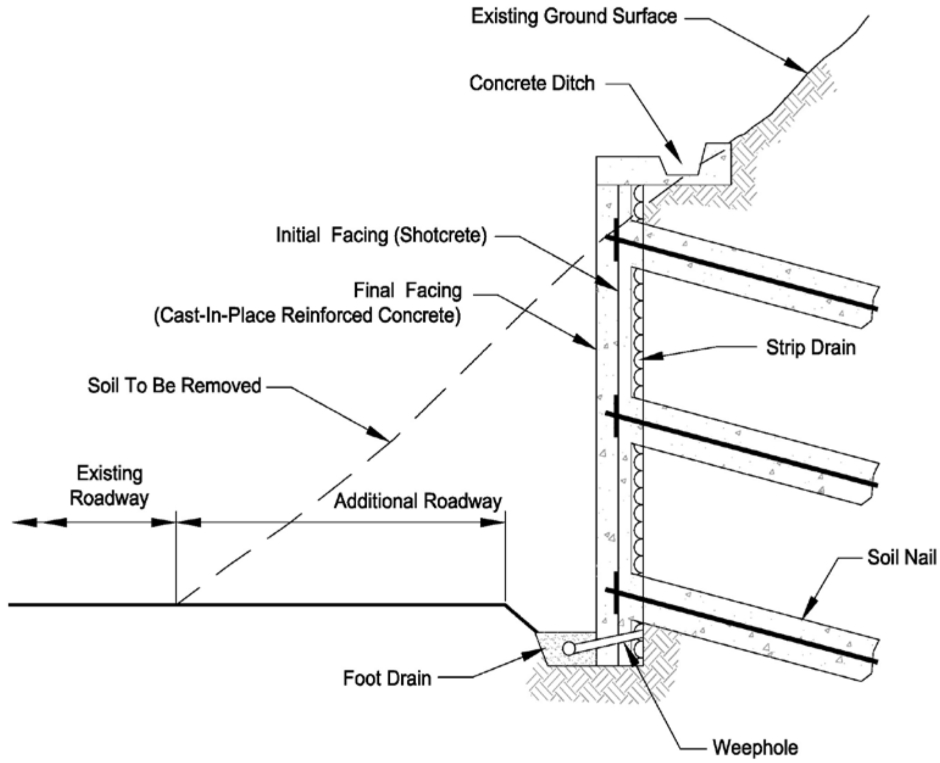

Figure 4: Illustration. Roadway Cut Supported with Soil Nails

Variations in the details shown schematically in Figure 4 may exist, particularly to those details related to runoff control

- **Road Widening Under Existing Bridge Abutments**

Soil nail walls can be advantageous for underpass widening when the removal of an existing bridge abutment slope is necessary. While the cost of installing a soil nail wall under a bridge abutment may be comparable to that of other applicable systems, the advantage of soil nailing is that the size of the soil nail drill rig is relatively small. Soil nailing equipment can operate within limited overhead, and traffic flow along the underpass road may not need to be totally interrupted during the widening. The location, length, and inclination of soil nails need to be carefully planned so that the nails do not interfere with the existing bridge girders and do not intersect the existing abutment foundation. The upper soil nails must be positioned within the clear space between bridge girders and must be parallel to them. The remaining, lower rows of soil nails must be positioned and oriented to avoid hitting the foundation elements below. Figure 5 depicts an example of road widening under an existing bridge.

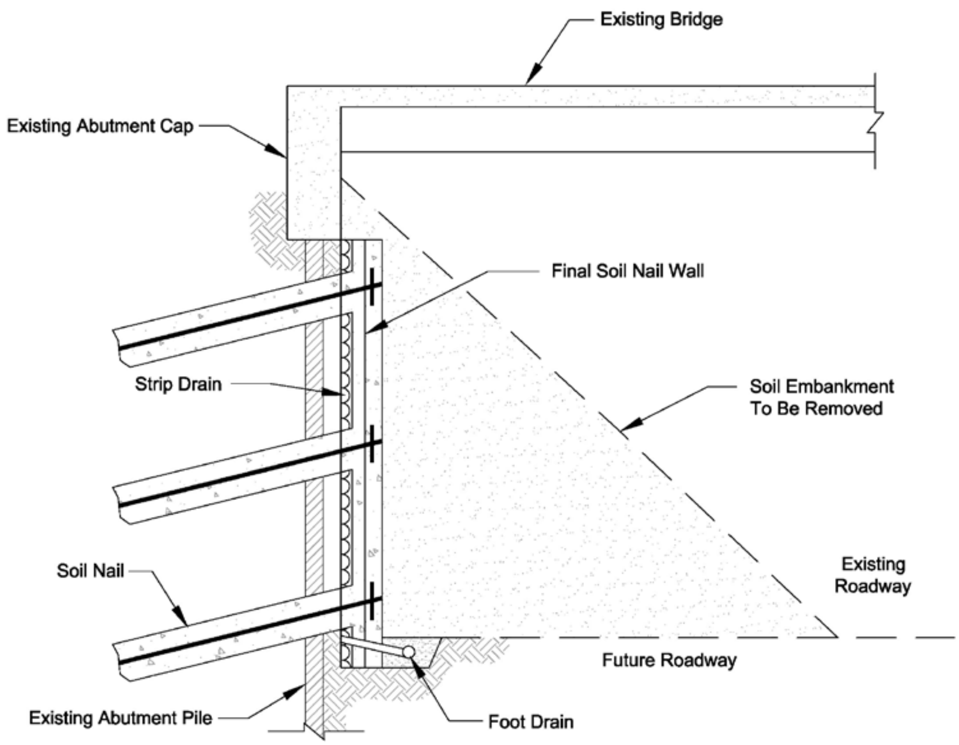

Figure 5: Illustration. Road widening under existing bridge.

Vertical micropiles and soil nails have also been used in modified abutments for road widening projects where an existing bridge was originally supported on shallow foundations constructed on top of an existing embankment. The micropiles support the modified abutment and prevent settlements, as they transfer bridge loads below the new road grades. At the same time, the added soil nail wall retains the excavated soil. Because overhead clearances are small in most roadway widening projects, the combined use of soil nails and micropiles is attractive in these applications as they can help expedite construction by allowing the bridge to remain operational during widening of the underpass lane.

- **Tunnel Portals**

Tunnel portals can also be stabilized using soil nails. Although the principle behind the use of soil nails in tunnel portals is similar to that for road cuts, other aspects must be considered in the design and construction of this application. First, the vertical stability of the shotcrete facing above the tunnel must be considered. The potential transfer of soil nail loads to the tunnel structure at the portal must also be taken into account. The interaction between soil nails and the initial shotcrete support and lining of the tunnel near the portal need to be fully evaluated. In addition, the layout of soil nails may be different than that in the conventional use in roadway applications. Soil nails must be installed with an appropriate horizontal splay and a suitable vertical orientation to avoid interfering with the tunnel support components.

- **Repair and Reconstruction of Existing Retaining Structures**

Soil nails can be used to stabilize and/or strengthen failing or distressed retaining structures. For example, some mechanically stabilized earth (MSE) walls may exhibit excessive deformation due to poor design, poor construction, or both. Soil nails can be installed directly through the face of an MSE wall if the existing face is sufficiently stable to resist drilling. As the MSE wall continues to deform, the backfill of the MSE wall and its facing would transfer loads to the installed soil nails, and these would transfer loads to stable soils lying behind the MSE-reinforced block of soil.

- **Hybrid Soil Nail Walls**

Soil nail walls can be used with other types of wall systems such as ground anchor walls and MSE walls to combine the advantage of each method. This situation may arise for walls with a complex layout or when the costs associated with other earth-retaining systems are too high. The combination of MSE and soil nail walls may provide a more economical design in cut/fill situations than the traditionally used full-height MSE walls or drilled shaft retaining walls. Figure 6 shows an example of a hybrid soil nail/MSE wall.

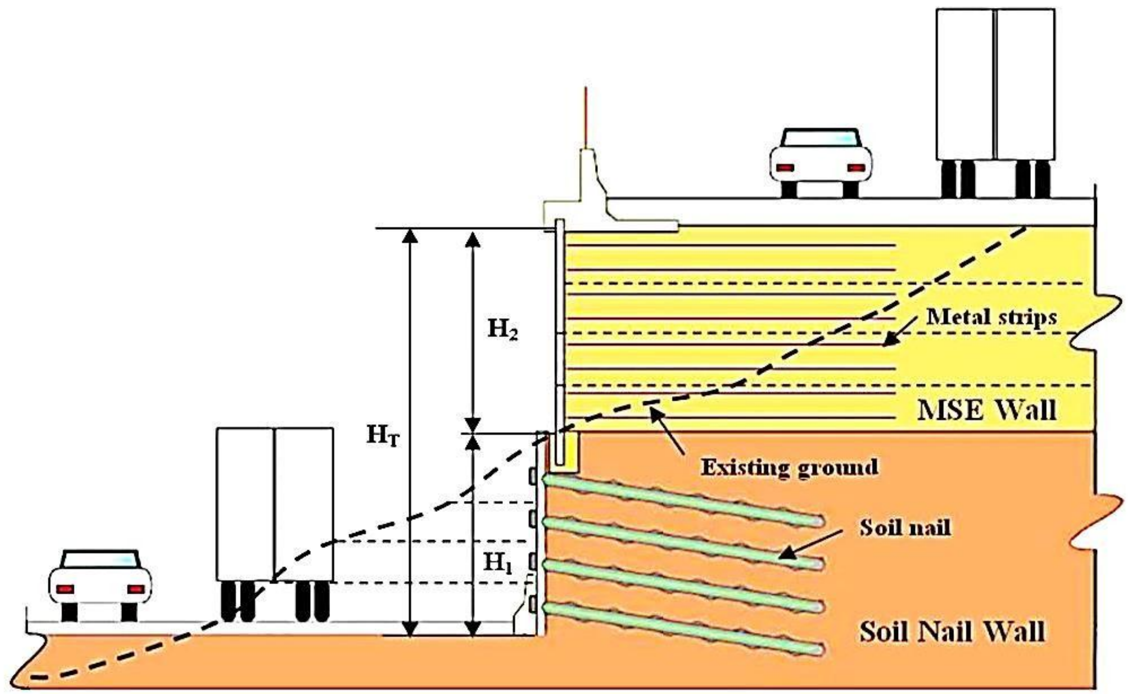

Figure 6: Illustration. Hybrid soil nail / MSE wall.

- **Shored Mechanically Stabilized Earth (SMSE) Walls**

Soil nail walls have been increasingly used in combination with MSE walls for widening low-volume roads by fill placement in steep terrain. MSE wall construction in steep terrain requires excavation to establish a flat bench to place the soil reinforcement. The required depths of embedment increase with the steepness of the slope below the wall toe. If the slope is too steep, the excavation for the MSE wall becomes impractical, particularly in situations where traffic must be maintained during construction of the widening. Soil nail walls can be used as shoring to stabilize the back slope (or back-cut) first, and then allow the construction of a conventional MSE wall in front of the soil nail wall. Figure 7 shows a generic cross- section of this combination.

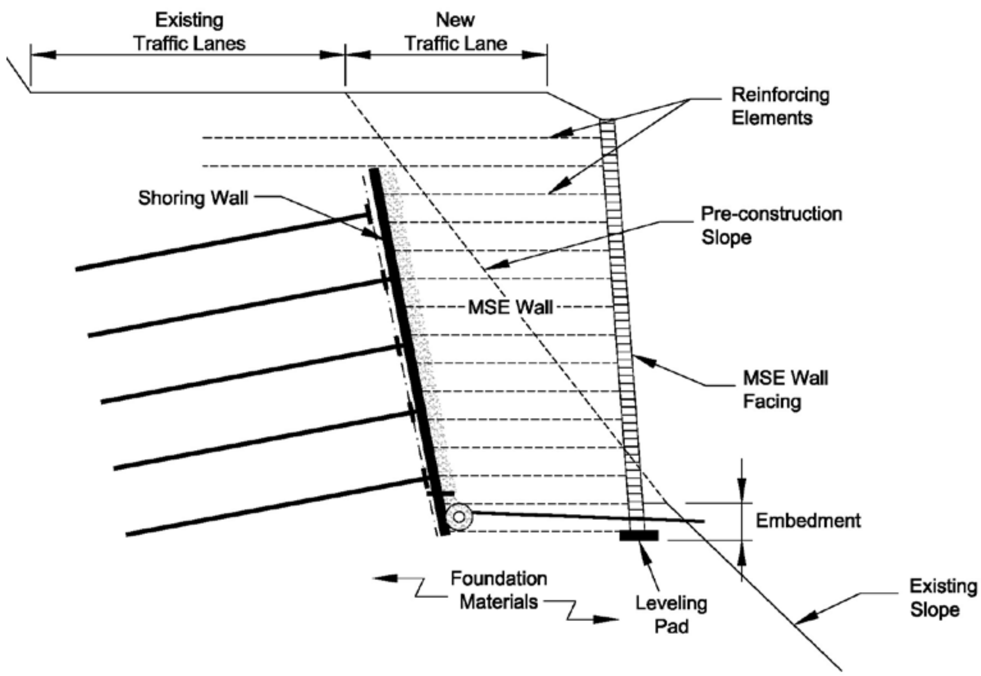

Figure 7: Illustration. SMSE wall for steep terrain.

Advantages and Limitations of Soil Nailing

1. **Advantages:** Advantages associated with soil nailing fall into three main categories: Construction, Performance, and Cost.

Construction

- Soil nail walls require smaller ROWs than most other competing systems. This is also true for ground anchors as soil nails are typically shorter.
- Soil nail walls are less disruptive to traffic and cause less environmental impact compared to other construction techniques such as drilled shafts or soldier pile walls, which require relatively large equipment.
- Soil nailing causes less congestion in the excavation when compared to braced excavations.
- The installation of soil nail walls is relatively fast.
- Easy adjustments to nail inclination and location can be made when obstructions are encountered, such as boulders, piles or underground utilities.
- Soil nail wall installation is not as restricted by overhead limitation as in the case of soldier pile installation.
- Soil nailing may be more cost-effective at sites with remote access because the smaller equipment is more readily mobilized.
- Soil nails are installed using equipment that is multipurpose and can be used for other substructure elements such as underpinning or protection of adjacent, movement- sensitive structures.
- Soil nail walls can accommodate curves and “bends” more easily than other top-down construction wall systems, which would otherwise require straight wall segments.

Performance

- Soil nail walls are relatively flexible and can accommodate comparatively large total and differential movements.
- Soil nail walls have performed well during seismic events.
- Soil nail walls have more redundancy than anchored walls because the number of reinforcing elements per unit area of wall is larger than for anchored walls.
- Sculpted facings, which can be applied to soil nail walls, give a more natural appearance than other finishes, to fit in with the surrounding environment.

Cost

- Conventional soil nail walls tend to be more economical than conventional concrete gravity walls taller than approximately (3.5 to 4.5^{m}).
- Soil nail walls are typically equivalent in cost or more cost-effective than ground anchor walls when conventional soil nailing construction procedures are used.

2. **Limitations**

The main limitations associated with soil nailing are:

- In projects where strict wall movement criteria exist, additional measures to limit deflections may be required. These requirements would add cost. If very strict movement criteria exist, soil nails may not be a feasible option for the project.
- The existence of utilities behind the wall will likely create restrictions to the location, inclination, and length of soil nails, particularly in the upper rows.
- Soil nail walls are not well-suited where large amounts of groundwater seep into the excavation. Soil nail walls

require maintaining a temporary unsupported excavation face during construction.

- Permanent soil nail walls require permanent underground easements.
- Soil nail tendons may interfere with certain types of communication lines (e.g., optic fiber) running immediately adjacent to soil nail walls.

Figure 8: Photo. Excavation of soil lift during construction of soil nail wall.

Figure 9: Photo. Drilling Nail Holes.

Similar Technologies

1. **Launched Nails**

- Launched nails are bars "launched" into the soil at high speeds approaching 300 Km per hour using a firing mechanism involving compressed air. Bars can be perforated galvanized steel tube, perforated fiberglass, or bare steel tubes. Bars are typically 1.5 in. in diameter and can be 2 in. in diameter. They can be up to 6^{m} in length. An epoxy-coated, small-diameter threaded bar can be inserted into the tube after pressure grouting is applied to increase structural capacities.

  Launched nails allow for a fast installation with little impact to the project site; however, it may be difficult to control the length of nail that penetrates the ground. Advantages include rapid construction, easy monitoring and testing, construction with limited headroom and right-of-way, and ability to withstand large deformations. Potential disadvantages with launched nails include: (i) this is a proprietary and licensed technology; (ii) specialized contractor and equipment are required; and (iii) lack of simple, comprehensive design procedures.

  This technique is applicable to landslide repairs, and to roadway and embankment widening. A launched nail acts as a dowel in the soil, and the contribution to stability is primarily by shear and associated, localized bending, and not primarily by tension as with a drilled and grouted nail. Launched nails develop limited axial capacity without grout. However, the technique mentioned above includes inserting a threaded bar for some to allow pressure grouting, and some increased capacity is possible. Figure 10 shows a launched nail installation.

Figure 10: Photo. Launched nail installation.

2. Screw-in Nails

- Screw-in soil nailing consists of helical soil nails that stabilize retained soils. These nails typically comprise a 1.5-in. square solid steel shaft on which steel helices are welded at regular intervals. Helical soil nails are installed using drilling equipment with sufficient torque output to penetrate the native soils. The spacing of the helices is a function of the helix diameter and is typically about 3.6 times the diameter. Screw-in nails are typically used in places difficult to access or for small areas. The bars are not grouted. A screw-in nail acts as an anchor in the soil, and the contribution to stability is by bearing resistance of the helices, not by bond stresses developed along the reinforcement as is the case with a drilled and grouted soil nail. Figure 11 shows the installation of a screw- in nail.

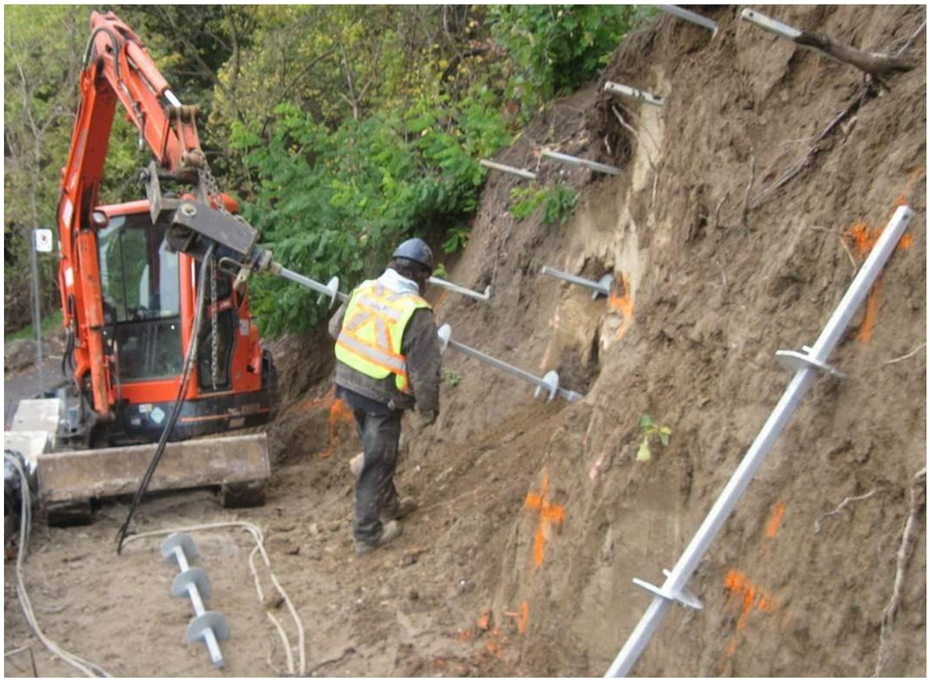

Figure 11: Photo. Screw-in nail installation.

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