THEORETICAL ANALYSIS OF SOIL NAILING: DESIGN, PERFORMANCE AND FUTURE ASPECTS

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Abstract- Soil stabilization is a general term for any physical, chemical, biological, or combined method of changing a natural soil to meet an engineering purpose. This process includes increasing the weight bearing capabilities and performance of in-situ soil and sand. Soil nailing is a construction technique that can be used as a remedial measure to treat unstable natural soil slopes or as a construction technique that allows the safe over-steepening of new or existing soil slopes. The technique involves the insertion of relatively slender reinforcing elements into the slope – often general purpose reinforcing bars (rebar) although solid or hollow-system bars are also available. Kinetic methods of firing relatively short bars into soil slopes have also been developed. Bars installed using drilling techniques are usually fully grouted and installed at a slight downward inclination. Soil nail components may also be used to stabilize retaining walls or existing fill slopes like embankments and levees and this is normally undertaken as a remedial measure. Since the first application of soil nailing was implemented in 1972 for a railroad widening project in France, soil nailing is now a well-established technique around the world.

Keywords- soil stabilization, soil nailing, design aspects, necessity, performance of soil, soil properties. applications.

1. INTRODUCTION

1.1. General Analysis

The main points to be considered in determining if soil nailing would be an effective retention technique are as follows:-

First, the existing ground conditions should be examined. Next, the advantages and disadvantages for a soil nail wall should be assessed for the particular application being considered. Then other systems should be considered for the particular application. Finally, cost of the soil nail wall should be considered.

Soil nail walls can be used for a variety of soil types and conditions. The most favorable conditions for soil nailing should be follow before starting any operation of soil nailing and they are:

- The soil should be able to stand unsupported one to two meters high for a minimum of two days when cut vertical or nearly vertical.
- Also all soil nails within a cross section should be located above the groundwater table. If the soil nails are not located above the groundwater table, the groundwater would negatively affect the face of the excavation i.e. the bond between the ground and the soil nail itself.

Based upon these “favorable conditions” for soil nailing stiff to hard fine-grained soils which include stiff to hard clays, clayey silts, silty clays, sandy clays, and sandy silts are preferred soils. Sand and gravels which are dense to very dense soils with some apparent cohesion also work well for soil nailing. Weathered rock is also acceptable as long as the rock is weathered evenly throughout. Finally, glacial soils work well for soil nailing.

A list of “unfavorable or difficult soil conditions” for soil nailing can include dry, poorly graded cohesion-less soils, soils with a high groundwater table, soils with cobbles and boulders, soft to very soft fine-grained soils, highly corrosive soils, weathered rock with unfavorable weakness planes, and loess. Other difficult conditions include prolonged exposure to freezing temperatures, a climate that has a repeated freeze-and-thaw cycle and granular soils that are very loose.

1.2 Design Philosophies

After a preliminary analysis of the site, initial designs of the soil nail wall can be begin. This begins with a selection of limit states and design approaches. The two most common limit states used in soil nail wall design is strength limit and service limit states. The strength limit state is the limit state that addresses potential failure mechanisms or collapse states of the soil nail wall system. The service limit state is the limit state that addresses loss of service function resulting from excessive wall deformation and is defined by restrictions in stress, deformation and facing crack width under regular service conditions. The two most common design approaches for soil nail walls are limit state design and service load design.

Initial design considerations include wall layout (wall height and length), soil nail vertical and horizontal spacing, soil nail pattern on wall face, soil nail inclination, soil nail length and distribution, soil nail material and relevant ground properties. With all these variables in the mind of the design engineer the next step is to use simplified charts to preliminarily evaluate nail length and maximum nail force. Nail length, diameter and spacing typically control external and internal stability of the wall. These parameters can be adjusted during design until all external and internal stability requirements are met. After the initial design is completed, final design progresses where the soil nail wall has to be tested for external and internal failure modes, seismic considerations and aesthetic qualities. Drainage, frost penetration and external loads such as wind and hydrostatic forces also have to be determined and included in the final examination of the design. Soil nail walls are not ideal in locations with highly plastic clay soils. Soils with high plasticity, a high liquid limit and low undrained shear strengths are at risk of long-term deformation (creep).

1.3 Construction Procedure

With the design complete, construction is the next step. Most soil nail wall construction follows a specific procedure. First a cut is excavated and temporary bracing is put in place if necessary. This is done with conventional earth moving equipment and hydraulic drills. Next, holes for the soil nails are drilled at predetermined locations as specified by the design engineer. The equipment used for this step is dependent on the stability of the material in which the soil nail wall is supporting. Rotary or rotary percussive methods using air flush or dry auger methods can be used with stable ground. For unstable ground, single tube and duplex rotary methods with air and water flush or hollow stem auger methods are used. With the holes drilled, the next step is to install and grout the nails into place. After all nails are inserted, a drainage system is put into place. Synthetic drainage mat is placed vertically between the nail heads, which are extended down to the base of the wall where they are most commonly connected to a footing drain. A layer of shotcrete is applied and bearing plates are installed before a final facing is put in place to complete the soil nail wall. Variations of the steps described above may be necessary to accommodate additional preparation tasks or supplementary activities for specific project conditions.

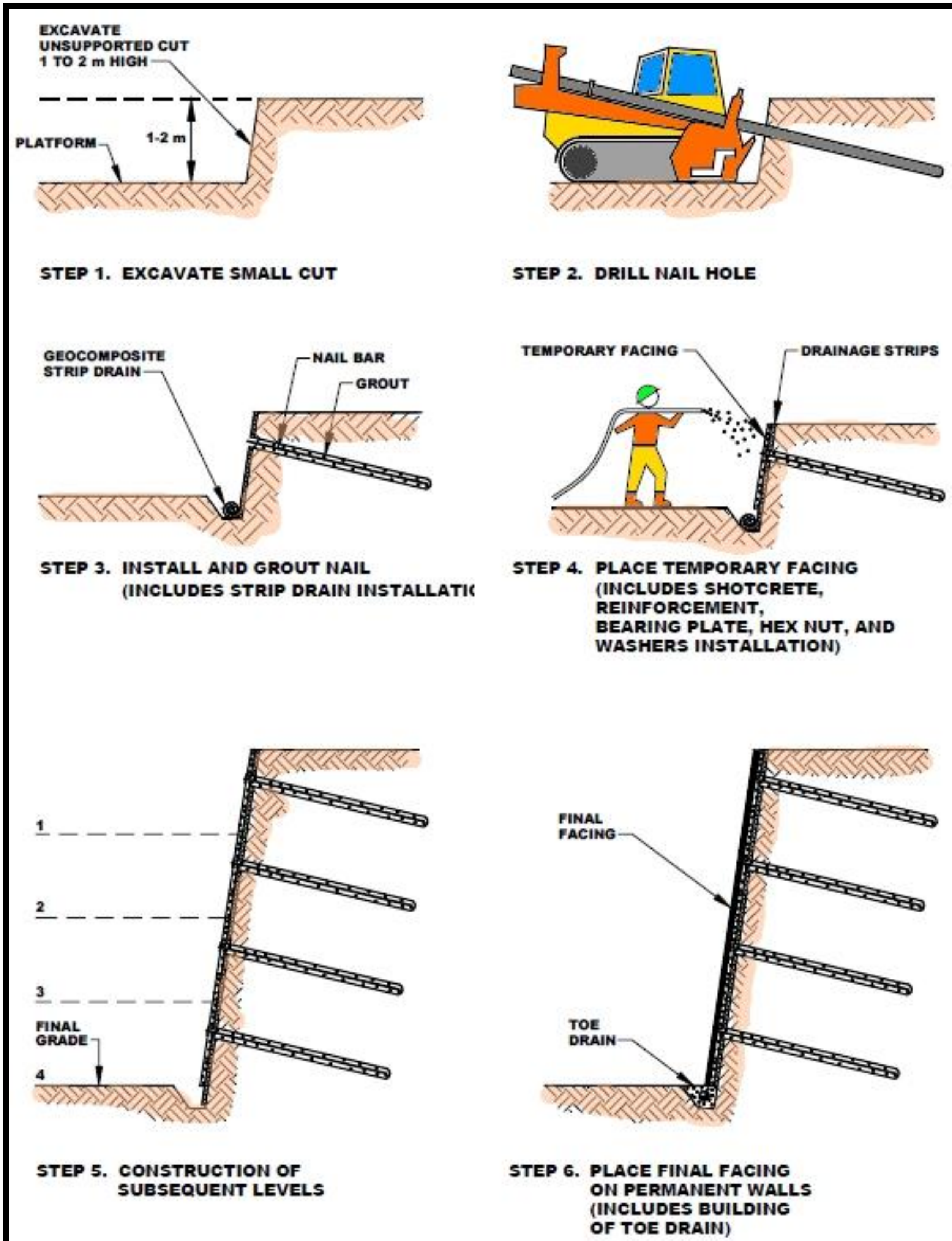

Figure1: Step by step procedure of soil nailing

1.4 Performance Evaluation

Inspection activities play a vital role in the production of high-quality soil nail walls because conformance to project plans and specifications should result in a soil nail wall that will perform its intended duty for its designed duration. Inspections usually involve evaluation of the following: conformance of system components to material specification, conformance of construction methods to execution specifications, conformance to short-term performance specifications, and long-term monitoring. Short-term performance specifications are checked with loads tests, which utilize hydraulic jacks and pumps to perform several load applications. Three common load tests for short-term performance are verification or ultimate load tests, proof tests and creep tests. Verification or ultimate load tests are conducted to verify the compliance of the soil nails with pullout capacity and strengths resulting from the contractor's installation method. Proof tests are intended to verify that the contractor's construction procedure has been consistent and that the nails have not been drilled and grouted in a soil zone not tested in the verification stage. Creep tests are performed to ensure that the nail design loads can be safely carried throughout the structure's service life.

Long-term performance monitoring is used to collect data to ensure adequate performance and refine future design practices. Parameters to be measured include vertical and horizontal movement of the wall face, local movements or deterioration of facing elements, drainage to the ground, loads, load distribution and load changes in the nails, temperature and rainfall. These parameters are measured using several specific tools including inclinometers, load cells and strain gauges.

1.5 Soil Nail Installation Process

Soil nail provides a resisting force against slope failures. Its construction process is faster than other similar methods. The construction procedure starts, drilling into the soil, where the nail, steel bar, is going to be placed. After the drilling has been completed, exact depth must be provided by the geotechnical engineer, the nail must be inserted into the drilled hole. Then, it must be grouted into the soil to create a structure similar to a gravity wall. After placing the nail, a shot-Crete layer is usually placed as a facing material, to protect the exposed nail, and then other architectural options are placed over the shot-Crete, creating an aesthetic finish to the project. Steel tendons typically used for drill-and-grout soil nails usually consist of 0.8 to 2.0 inch bars with yield strength in the range of 60 to 72 Ksi. Drainage is a critical aspect of soil nail wall construction. Face drainage is virtually always used with permanent walls, and very commonly used with temporary walls. Face drainage usually consists of synthetic drainage elements placed between the shot-Crete and the retained soil, and may be typically 8 to 12 inches wide synthetic strips or perforated pipes. The grouted soil nail hole typically has minimum diameter of 4 inches. Centralizers are placed around the soil nail to maintain an even thickness of grout around the bar. For permanent applications, nails may be epoxy-coated or provided with a protective sheath for corrosion protection. Soil Nailing is not recommended to use on clayey soils, and or clean sands where the cohesion of the soil is minimum.

Figure 2: Actual picture of soil nailing in hill slope

1.6 Advantages

Soil nailing has been used regularly over the last few years over traditional cut retaining walls due to several reasons:-

1. It is ideal for tight spaces.
2. It can be used in irregular shapes.
3. Less noise and fewer traffic obstructions.
4. Less impact on surrounding areas.
5. Minimum shoring is required.
6. Lower load requirements than tieback anchors systems.
7. Eliminates the time and expense of placing steel piles.
8. Can be used to repair other existing wall systems.
9. It can be used on new constructions, as temporary structures or on remodeling process.
10. Wall height is not restricted.
11. Reduce right-of-way requirements.

1.7 Limitations

1. In some instances soil might be overexposed prior to the installation of nail.
2. Sand and gravels might not be compatible with soil nailing.
3. Not recommended to use in high water table areas.
4. Soil nailing in very low shear strength soil may require a very high soil nail density.
5. Soil nailing in expansive soils and sensitive soils for permanent long term applications is not recommended.

2.0 SOIL NAILING TECHNIQUES AND TYPES

Soil nailing is a construction technique used to reinforce soil to make it more stable. Soil nailing is used for slopes, excavations, retaining walls etc. to make it more stable. In this technique, soil is reinforced with slender elements such as reinforcing bars which are called as nails. These reinforcing bars are installed into pre-drilled holes and then grouted. These nails are installed at an inclination of 10 to 20 degrees with vertical. Soil nailing is used to stabilize the slopes or excavations where required slopes for excavation cannot be provided due to space constraints and construction of retaining wall is not feasible. It is just an alternate to retaining wall structures. As the excavation precedes, the shotcrete, concrete or other grouting materials are applied on the excavation face to grout the reinforcing steel or nails. These provide stability to the steep soil slope. Soil nailing technique is used for slopes or excavations alongside highways, railway lines etc.

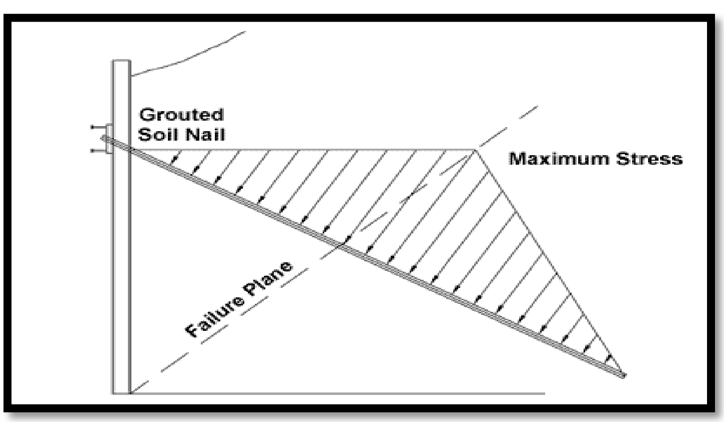

Figure 3: Stress distribution of soil nail

Types of Soil Nailing

There are various types of soil nailing techniques:

1. Grouted Soil Nailing

In this type of soil nailing, the holes are drilled in walls or slope face and then nails are inserted in the pre-drilled holes. Then the hole is filled with grouting materials such as concrete, shotcrete etc.

2. Driven Nails

Driven nailing is used for temporary stabilization of soil slopes. In this method, the nails are driven in the slope face during excavation. This method is very fast, but does not provide corrosion protection to the reinforcement steel or nails.

3. Self drilling Soil Nail

In this method, the hollow bars are used. Hollow bars are drilled into the slope surface and grout is injected simultaneously during the drilling process. This method of soil nailing is faster than grouted nailing. This method provides more corrosion resistance to nails than driven nails.

4. Jet Grouted Soil Nail

In this method, jets are used for eroding the soil for creating holes in the slope surface. Steel bars are then installed in this hole and grouted with concrete. It provides good corrosion protection for the steel bars (nails).

5. Launched Soil Nail

In this method of soil nailing, the steel bars are forced into the soil with very high speed using compressed air mechanism. The installation of soil nails are fast, but control over length of bar penetrating the ground is difficult.

These points must be noted for installation of soil nails

1. Soil Nails must penetrate beyond the slip plane into the passive zone typically for 4 to 5m.
2. The spacing of soil nails in horizontal or vertical direction must be related to strength of the soil. Extra soil nails should be installed at the edge of any surface being stabilized.
3. Soil nailing should start immediately after excavation.
4. Any delay in nailing may lead to collapse of soil slope.

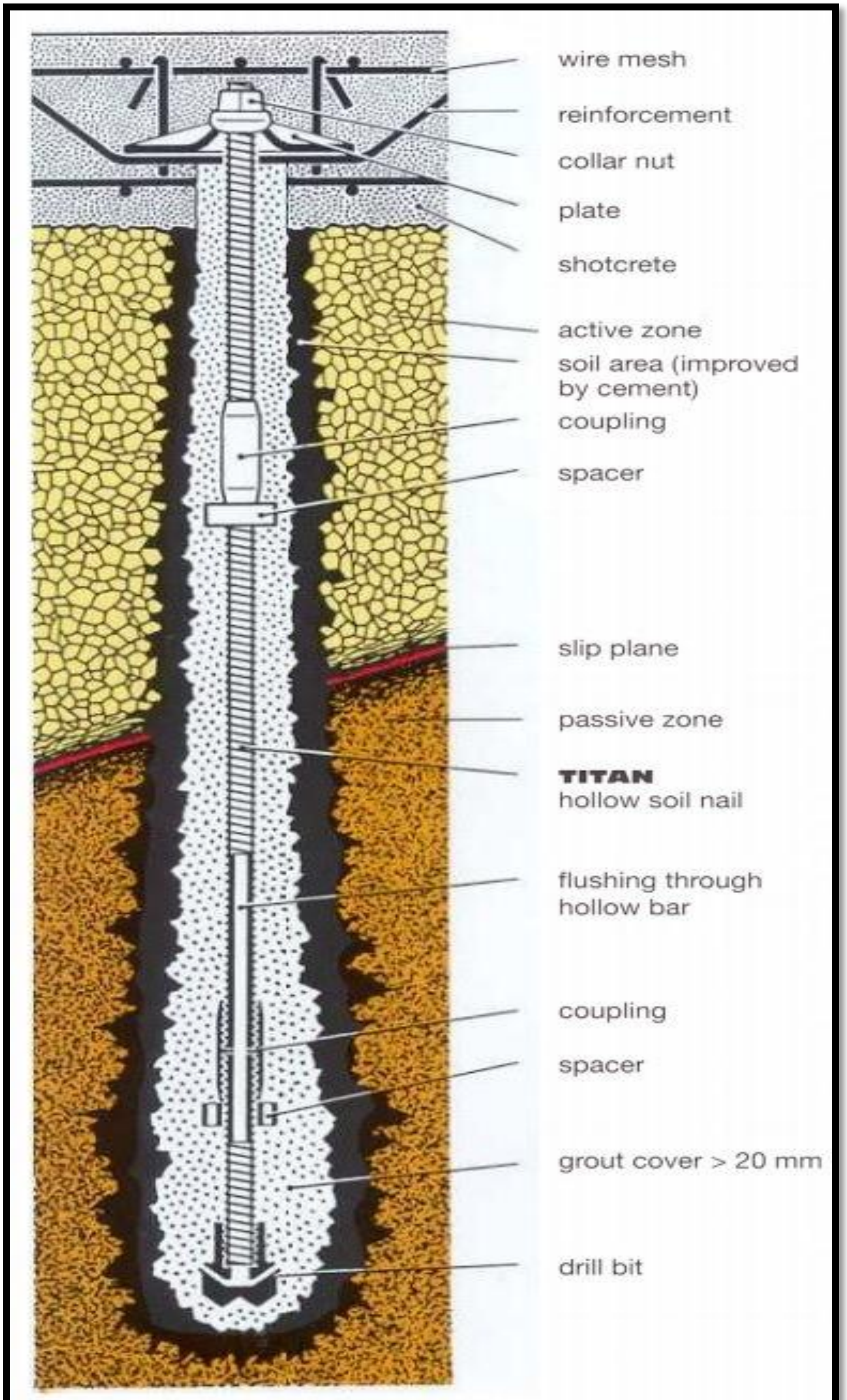

Figure 4: Soil nailing details

2.1 Protection of Nailed Structure

1) Corrosion Protection

Soil nails can be protected against corrosion in a variety of ways suitable for both temporary (24 months) and permanent (>24 months) applications.

2) Bare bar in cement grout

Cement grout alone can be used for corrosion protection of temporary soil nails and permanent nails in non-aggressive ground, provided the thickness of the grout cover exceeds 1-1/2" (38 mm).

The Drill bar system is ideally suited for temporary soil nails, particularly in non-cohesive soils.

3) Sacrificial steel

Steel elements of the soil nail system can be oversized to allow for loss of cross sectional area due to corrosion. The rate of corrosion shall be based on historical data for ground conditions with the same or lower level of aggressiveness. Additional factors of safety are recommended.

4) Hot Dip Galvanizing

Permanent soil nails in non-aggressive ground can be protected against corrosion by hot dip galvanizing in accordance with ASTM A-153. Hot dip galvanizing of GR150 bars requires specialized procedures to avoid hydrogen embrittlement.

5) Epoxy coating

Soil nails in non aggressive ground and temporary nails in aggressive ground can be protected against corrosion by epoxy coating in accordance with ASTM A-934 or ASTM A-775. Although ASTM A-934 has shown better performance than A-775 coating, it is not available in all areas. With this system, it is possible to epoxy coat the entire length of the bar. Oversized hardware is available to thread over a coating up to 40 mm thick. ASTM A-934 is usually purple or gray in color while ASTM A-775 is green in color.

6) Epoxy coated bar with partial or full DCP

Partial Double Corrosion Protection (DCP) protection over epoxy-coated bar provides additional protection in areas considered most corrosive. A bar that is epoxy coated over its entire length with a pregrouted plastic sheathing is often referred to as a triple corrosion protected soil nail. This type of corrosion protection is used in extremely aggressive environments.

7) Double Corrosion Protection - DCP

The most reliable corrosion protection for soil nails in permanent applications or for nails used in critical structures is to pregrout the nail in corrugated PVC or HDPE sheathing. The sheathing provides a watertight barrier. Tests have proven that the deformations of the THREADBAR limit crack width to 0.1 mm.

2.2 Various Issues Affecting Soil Nailed Slope

There are several factors that affect the feasibility and stability of soil nailing in slopes or excavations. As mentioned earlier, construction of soil nailing is subjected to favorable ground conditions. There are also various internal and global stability factors for soil nailed slopes.

Favorable Ground Condition: Soil nailing is well suited for Stiff to hard fine-grained soils which includes stiff to hard clays, clayey silts, silty clays, sandy clays, sandy silts, and combinations of theses. It is also applicable for dense to very dense granular soils with some apparent cohesion (some fine contents with percentage of fines not more than 10-15%). Nailing is not suitable for dry, poorly graded cohesion less soils, soils with cobbles and boulder (difficult to drill and increases construction cost), highly corrosive soil (involves expensive corrosion protection), soft to very soft fine grained soils, and organic soil. Soil nailing is also not recommended for soils with high ground water table.

External Stability: The external or global stability of nailed slope includes stability of nailed slope, overturning and sliding of soil-nail system, bearing capacity failure against basal heave due to excavation. Sometimes long-term stability problem also come into picture, e.g., seasonal raining. In such cases, though ground water table may be low, the seeping water may affect the stability of nailed slope without facing or proper drainage system.

Internal Stability: It comprises of various failure modes of nailed structure e.g. nail soil pull-out failure, nail tensile failure, and facing flexural or punching shear failure. Such issues may be overcome by conducting adequate ground investigation and geotechnical testing for identification of soil parameters and ground characterization and by performing in-situ test for soil nail interaction and nail strength.

2.3 Design Considerations

A soil-nailed system is required to fulfill fundamental requirements of stability, serviceability and durability during construction and throughout its design life. Other issues such as cost and environmental impact are also important design considerations.

Stability: The stability of a soil-nailed system throughout its design life should be assessed. The design of a soil-nailed system should ensure that there is an adequate safety margin against all the perceived potential modes of failure.

Serviceability: The performance of a soil-nailed system should not exceed a state at which the movement of the system affects its appearance or the efficient use of nearby structures, facilities or services.

Durability: The environmental conditions should be investigated at the design stage to assess their significance in relation to the durability of soil nails. The durability of a steel soil-nailed system is governed primarily by the resistance to corrosion under different soil aggressively.

Economic Considerations: The construction cost of a soil-nailed system depends on the material cost, construction method, temporary works requirements, build ability, corrosion protection requirements, soil-nail layout, type of facing, etc.

Environmental Considerations: The construction of a soil-nailed system may disturb the ground ecosystem, induce nuisance and pollution during construction, and cause visual impact to the existing environment. Appropriate pollution control measures, such as providing water sprays and dust traps at the mouths of drill holes when drilling rocks, screening the working platform and installing noise barriers in areas with sensitive receivers, should be provided.

CONCLUSIONS

Soil nailing is embraced by practicing engineers as a highly competitive well proven technique. Soil nailing has certain similarities to both reinforced earth and anchoring, although its particular operating principles and construction methods give it a firm and distinct identity. Similar considerations distinguish it from allied insitu soil reinforcing techniques such as reticulated root piles and soil dwelling. Most applications of soil nailing to date have been associated with new construction projects such as foundation excavations and slope stabilization, for both temporary and permanent works. The system has equal facility in a wide range of remedial projects, and indeed it is most likely that nailing will find its wide applications in the India in this field, bearing in mind the prevailing economic trends. It is to be hoped that the growth of the technique in India can be fostered by practical research collaborations between industry, the universities and government, in the manner of developed countries like France, Germany, United States of America and United Kingdom, who are the current leaders in this field.

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