Fundamentals of Soil Nailing Technique

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Soil nailing is a technique in which soil slopes, excavations or retaining walls are passively reinforced by the insertion of relatively slender elements - normally steel reinforcing bars. Such structural element which provides load transfer to the ground in excavation reinforcement application is called nail (Refer Figure 1). Soil nails are usually installed at an inclination of 10 to 20 degrees with horizontal and are primarily subjected to tensile stress. Tensile stress is applied passively to the nails in response to the deformation of the retained materials during subsequent excavation process. Soil nailing is typically used to stabilize existing slopes or excavations where top-to-bottom construction is advantageous compared to the other retaining wall systems. As construction proceeds from the top to bottom, shotcrete or concrete is also applied on the excavation face to provide continuity. In short Soil Nailing increases the shearing resistance of soil by acting in tension.

In the present era, soil nailing is being carried out at large in railway construction work for the stabilization of side lopes in existing track-road or laying of new tracks adjoining to an existing one (Refer Figure 4).

Development Of The Soil Nailing Technique

The soil nailing technique was developed in the early 1960s, partly from the techniques for rock bolting and multi-anchorage systems, and partly from reinforced fill technique (Clouterre, 1991; FHWA, 1998). The New Austrian Tunnelling Method introduced in the early 1960s was the premier prototype to use steel bars and shotcrete to reinforce the ground. With the increasing use of the technique, semi-empirical designs for soil nailing began to evolve in the early 1970s. The first systematic research on soil nailing, involving both model tests and full-scale field tests, was carried out in Germany in the mid-1970s. Subsequent development work was initiated in France and the United States in the early 1990s. The result of this research and development work formed the basis for the formulation of the design and construction approach for the soil nailing technique in the subsequent decades.
Various types of soil nailing

Various types of soil nailing methods that are employed in the field is listed below:

**Grouted Nail:** After excavation, first holes are drilled in the wall/slope face and then the nails are placed in the pre-drilled holes. Finally, the drill hole is then filled with cement grout.

**Driven Nail:** In this type, nails are mechanically driven to the wall during excavation. Installation of this type of soil nailing is very fast; however, it does not provide a good corrosion protection. This is generally used as temporary nailing.

**Self-Drilling Soil Nail:** Hollow bars are driven and grout is injected through the hollow bar simultaneously during the drilling. This method is faster than the grouted nailing and it exhibits more corrosion protection than driven nail.

**Jet-Grouted Soil Nail:** Jet grouting is used to erode the ground and for creating the hole to install the steel bars. The grout provides corrosion protection for the nail.

**Launched Soil Nail:** Bars are “launched” into the soil with very high speed using firing mechanism involving compressed air. This method of installation is very fast; however, it is difficult to control the length of the bar penetrating the ground.

**Basic Elements of a Soil-nailed System**

Figure 5 shows the cross-section of a typical soil-nailed cut slope. A soil-nailed system formed by the drill-and-grout method comprises the following basic elements:

**Soil-Nail Reinforcement:** A soil-nail reinforcement is the main element of a soil-nailed system. Its primary function is to provide tensile resistance. The reinforcement is typically a solid high yield deformed steel bar. Other types of materials, such as fibre reinforced polymer, can also be used as a soil-nail reinforcement.

**Reinforcement Connector (Coupler):** Couplers are used for joining sections of soil-nail reinforcing bars.

**Cement Grout Sleeve:** Cement grout, made of Portland cement and water, is placed in a pre-drilled hole after the insertion of a soil-nail reinforcement. The cement grout sleeve serves the primary function of transferring stresses between the ground and the soil-nail reinforcement. It also provides a nominal level of corrosion protection to the reinforcement.

**Corrosion Protection Measures:** Different types of corrosion protection measures are required depending on the design life and soil aggressivity. Common types of corrosion protection measures are hot-dip galvanising and corrugated plastic sheathing. Heat-shrinkable sleeves made of polyethylene and anti-corrosion mastic sealant material are commonly used to protect couplers.

**Soil-Nail Head:** A soil-nail head typically comprises a reinforced concrete pad, a steel bearing plate and nuts. Its primary function is to provide a reaction for individual soil nails to mobilise tensile force. It also promotes local stability of the ground near the slope surface and between soil nails.

**Slope Facing:** A slope facing generally serves to provide the slope with surface protection, and to minimise erosion and other adverse effects of surface water on the slope. It may be soft, flexible, hard, or a combination of the three (CIRIA, 2005). A soft slope facing can enhance the stability of a soil-nailed system by the transfer of loads from the free surface in between the soil-nail heads to the soil nails and redistribution of forces between soil nails. The
most common type of soft facing is vegetation cover, often in association with an erosion control mat and a steel wire mesh.

**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 these. 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 cohesionless soils, soils with cobbles and boulder (difficult to drill and increases construction cost), highly corrosive soil (involves expensive corrosion protection), soft to very finegrained soils, and organic soil (very low bond stress or soil nail interaction force leading to excess nail length). 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.
- Performing in-situ test for soil nail interaction and nail strength.

![Schematic Diagram of a Soil-nailed Cut Slope](image)

![Figure 5: Schematic Diagram of a Soil-nailed Cut Slope](image)

![Figure 6: Construction of soil nailing](image)

(a) Excavation (b) Mobile drilling rig, (c) Steel bar Installation, (d) Grouting Process (e) Stage construction
Effective design of nailed slope system.

Construction procedure of nailed structure

Soil nailed structures are generally constructed in stages and it involves following steps:-

- Excavation till the depth where nails will be installed at a particular level
- Drilling nail holes
- Nail installation and grouting
- Construction of temporary shotcrete facing

Subsequent levels are then constructed and finally permanent facing is placed over the wall. Some of the field photographs of soil nail construction procedure are presented in Figure 6.

Design Requirement

Installation of nailing along the slope face increases the resisting force against the driving force of the soil mass in the failure zone. Hence, it can be regarded as a slope stabilization method. The fundamental principle of soil nailing is the development of tensile force in the soil mass and renders the soil mass stable. Although only tensile force is considered in the analysis and design, soil nail also resist bending and shear force in the slope. Through finite element analysis by Cheng (1998), has demonstrated that the bending and shear contribution to the factor of safety is relatively insignificant and the current practice in soil nail design (of considering only tensile force) should be good enough for the most cases. Nails are usually constructed at an angle of inclination from 10° to 20°. Depending upon the climate of a particular region some sort of thickness of corrosion zone is assumed for an ordinary steel bar soil nail. As in Hong-Kong practice, a thickness of 2 mm is assumed as the corrosion zone so that the design bar diameter is totally 4 mm less than the actual diameter of the bar. The nail is usually protected by galvanization, paint, epoxy and cement grout. Alternatively, fiber reinforced polymer (FRP) and carbon fiber reinforced polymer (CFRP) may be used for soil nails which are currently under consideration. There are several practices in the design of soil nails. The effective nail load is usually taken as the minimum of

- the bond strength between cement grout and soil,
- the tensile strength of the soil nail and
- the bond stress between grout and the nail.

Design Considerations

A soil-nailed system is required to fulfil 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, which rely upon it.
- 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 aggressivity.
- Economic Considerations: The construction cost of a soil-nailed system depends on the material cost, construction method, temporary works requirements, buildability, 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 drillholes when drilling rocks, screening the working platform and installing noise barriers in areas with sensitive receivers, should be provided.

Merits And Limitations

The soil nailing technique offers an alternative design solution to the conventional techniques of cutting back and retaining wall construction.

Merits

(a) It is suitable for cramped sites with difficult access because the construction plant required for soil nail installation is small and mobile.
(b) It can easily cope with site constraints and variations in ground conditions encountered during construction, e.g., by adjusting the location and length of the soil nails to suit the site conditions.
(c) During construction, it causes less environmental impact than cutting back and retaining wall construction as no major earthworks and tree felling are needed.
(d) There could be time and cost savings compared to conventional techniques of cutting back and retaining wall construction which usually involve substantial earthworks and temporary works.
(e) It is less sensitive to undetected adverse geological features, and thus more robust and reliable than unsupported cuts. In addition, it renders higher system redundancy than unsupported cuts or anchored slopes due to the presence of a large number of soil nails.

(f) The failure mode of a soil-nailed system is likely to be ductile, thus providing warning signs before failure.

Demerits

(a) The presence of utilities, underground structures or other buried obstructions poses restrictions to the length and layout of soil nails.

(b) The zone occupied by soil nails is sterilised and the site poses constraints to future development.

(c) Permission has to be obtained from the owners of the adjacent land for the installation of soil nails beyond the lot boundary. This places restrictions on the layout of soil nails.

(d) The presence of high groundwater levels may lead to construction difficulties in hole drilling and grouting, and instability problems of slope surface in the case of soil-nailed excavations.

(e) The effectiveness of soil nails may be compromised at sites with past large landslides involving deep-seated failure due to disturbance of the ground.

(f) The presence of permeable ground, such as ground with many cobbles, boulders, highly fractured rocks, open joints, or voids, presents construction difficulties due to potential grout leakage problems.

(g) The presence of ground with a high content of fines may lead to problems of creeping between the ground and soil nails.

(h) Long soil nails are difficult to install, and thus the soil nailing technique may not be appropriate for deep-seated landslides and large slopes.

(i) Because soil nails are not prestressed, mobilisation of soil-nail forces will be accompanied by ground deformation. The effects on nearby structures, facilities or services may have to be considered, particularly in the case of soil-nailed excavations.

(j) Soil nails are not effective in stabilising localised steep slope profiles, back scarps, overhangs or in areas of high erosion potential. Suitable measures, e.g., local trimming, should be considered prior to soil nail installation.

Conclusion

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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