Soil Nailing: An Innovative Ground Improvement Technology

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A soil-nailed system is considered as a soil-nailed retaining wall if the facing of the system is sub-vertical, and it is designed to perform as a structural member that provides retention action to the ground by virtue of its self-weight, bending strength or stiffness. For example, if soil nails are installed into a gravity, reinforced concrete or cantilevered retaining wall, the system is considered as a soil-nailed retaining wall. On the contrary, if the facing serves mainly the function of surface protection or connection between individual soil nails, such as a sprayed concrete facing, the system should be regarded as a soil-nailed slope. Also, in this document, a soil-nailed system is considered to be a soil-nailed excavation if the reinforcing bars in an excavation, which carry either transient or sustained loads, are designed to perform as soil nails. Refer Figure 1 for Soil Nail Wall.

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. 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.

The soil nailing technique was introduced to Hong Kong in the 1980s. Soil nailing was first used in Hong Kong as a prescriptive method to provide support to deeply weathered zones in otherwise sound material. This was followed by a few cases where passive anchors or tie-back systems were used. Some of the impetus for these early cases came no doubt from the desire to find an alternative to prestressed ground anchors, which require long-term monitoring. In the mid-1980s a small number of soil-nailed supports to temporary cuts were made. In the early 1990s, the experience of design and construction of soil nails was summarised by Watkins & Powell (1992), which soon became the standard practice in Hong Kong.

Along with the increasing number of existing slopes and retaining walls upgraded by the Government and private owners, the soil nailing technique has gained popularity since the mid-1990s.

Areas of Application

Given that some subtle adverse geological features could be missed by ground investigation, robust design solutions that are less sensitive to local adverse ground and groundwater conditions are recommended. Large unsupported cuts, particularly those with significant consequence-to-life or major economic consequence in the event of slope failure, should be avoided as far as practicable. Due to lack of robustness, such cut slopes are especially vulnerable to undetected adverse ground and groundwater conditions. Positive slope support or reinforcement systems, supplemented with surface and subsurface drainage measures where necessary, are generally preferred to cutting back alone even though the calculated factors of safety of different schemes based on conventional limit equilibrium analysis may be the same. A soil-nailed system can override local weaknesses in the ground through stress redistribution and is less vulnerable than unsupported cuts to undetected adverse ground and groundwater conditions that have not been accounted for in the slope stability analysis. In Hong Kong, most soil nailing works are associated with the stabilisation of existing cut slopes and retaining walls. They are also used for reinforcing new cut slopes, existing fill slopes, disturbed terrain and natural hill-sides. The use of soil nails in new retaining walls and new fill slopes is rare in Hong Kong. Apart from permanent works, soil nails may be used in temporary excavations. Refer Figure 2 for application of solar nail.

Installation Methods

There are a variety of soil nail installation methods. The choice of installation method depends on a number of factors such as cost, site access, working space, and ground and groundwater conditions. A brief description of the commonly available soil nail installation methods is given below.

(1) Drill-and-grout. This is the most common installation method, both in Hong Kong and overseas. In this method, soil-nail reinforcement is inserted into a pre-drilled hole, which is then cement-grouted under gravity or low pressure. Various drilling techniques, e.g., rotary, rotary percussive and down-the-hole hammer, are available to suit different ground conditions. The advantage of this method is that it can overcome underground obstructions, e.g., corestones, and the drilling spoil can provide information about the ground. In addition, long soil nails can be installed using the method. The size and alignment of the drillholes can be checked before the insertion of reinforcement, if needed. However, the drill-and-grout method
may result in a hole collapse. To overcome this problem, casing is required. The drilling and grouting process may also cause disturbance to the ground.

(2) Self-drilling. This is a relatively new method when compared with the drill-and-grout method. The soil-nail reinforcement is directly drilled into the ground using a sacrificial drill bit. The reinforcement, which is hollow, serves as both the drill rod and the grout pipe. The installation process is rapid as the drilling and grouting are carried out simultaneously. Instead of using air or water, cement grout is used as the flushing medium, which has the benefit of maintaining hole stability. Centralisers and grout pipes are not needed, and casing is usually not required. However, self-drilling soil nails may not be suitable for the ground containing corestones as they cannot penetrate through rock efficiently. It may be difficult to ensure the alignment of long soil nails due to the flexibility of reinforcement. Durability may also be a concern if it relies on the integrity of the corrosion protection measures in the form of grout cover and corrosion protective coatings to steel reinforcement. This is because the specified minimum grout cover may not be achieved in the absence of centralisers and the corrosion protective coatings could be damaged during installation. Non-corrodible reinforcement may be explored to overcome the durability problem.

(3) Driven. Soil-nail reinforcement is directly driven into the ground by the ballistic method using a compressed air launcher, by the percussive method using hammering equipment, or by the vibratory method using a vibrator. During the driving process, the ground around the reinforcement will be displaced and compressed. The installation process is rapid and it causes minimal ground disruption. However, due to the limited power of the equipment, this method can only be used to install soil nails of relatively short length. Moreover, the soil-nail reinforcement may be damaged by the excessive buckling stress induced during the installation process, and hence it is not suitable for sites that contain stiff soil or corestones. As the soil-nail reinforcement is in direct contact with the ground, it is susceptible to corrosion unless non-corrodible reinforcement is used.

Basic Elements of a Soil-nailed System:

A soil-nailed system formed by the drill-and-grout method comprises the following basic elements:

(1) Soil-nail Reinforcement. 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 soil-nail reinforcement.

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

(3) 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.

(4) 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.

(5) 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.

(6) 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. A soft slope facing is non-structural, whereas a flexible or hard slope facing can be either structural or non-structural. A structural 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. Some proprietary products of flexible facing are available. Hard facing includes sprayed concrete, reinforced concrete and stone pitching. Structural beams and grillages can also be constructed on the slope surface to connect the soil-nail heads together to promote the

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Figure 3: Basic elements of a Soil Nail
integral action of the soil-nailed system. Refer Figure 3 for basics of a soil nail. Refer Figure 4 for Soil Nailing Process.

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.

(1) Stability. The stability of a soil-nailed system throughout its design life should be assessed. Its performance should not exceed a state at which failure mechanisms can form in the ground or within the soil-nailed system, or when movement of the soil-nailed system can lead to severe damage to its structural elements or nearby structures, facilities or services.

(2) 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.

(3) Durability. The environmental conditions should be investigated at the design stage to assess their significance in relation to the durability of soil nails.

(4) 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.

(5) 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.

Merits And Limitations

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

The following are typical merits of adopting the soil nailing technique in respect of construction, cost and performance:

(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.

The soil nailing technique has the following main limitations

(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 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 localized steep slope profiles, back scarpers, overhangs or in areas of high erosion potential. Suitable measures, e.g., local trimming, should be considered prior to soil nail installation.

Conclusion

The soil nailing technique improves the stability of slopes, retaining walls and excavations principally through the mobilisation of tension in the soil nails. The tensile forces are developed in the soil nails primarily through the frictional interaction between the soil nails and the ground as well as the reactions provided by soil-nail heads/facing. The tensile forces in the soil nails reinforce the ground by directly supporting some of the applied shear loadings and by increasing the normal stresses in the soil on the potential failure surface, thereby allowing higher shearing resistance to be mobilised. Soil-nail heads and the facing also provide a confinement effect by limiting the ground deformation close to normal to the slope surface. As a result, the mean effective stress and the shearing resistance of the soil behind the soil-nail heads will increase. They also help to prevent local failures near the surface of a slope, and to promote an integral action of the reinforced soil mass through the redistribution of forces among soil nails. The resistance against pullout failure of the soil nails is provided by the part of soil nail that is embedded into the ground behind the potential failure surface. The nail-ground interaction is complex, and the forces developed in the soil nails are influenced by many factors. These factors include the mechanical properties of the soil nails (i.e., tensile strength, shear strength and bending capacity), the inclination and orientation of the soil nails, the shear strength of the ground, the relative stiffness of the soil nails and the ground, the friction between the soil nails and the ground, the size of soil-nail heads and the nature of the slope facing.

Reference


- Guide To Soil Nail Design And Construction. Geotechnical Engineering Office Civil Engineering And Development Department The Government Of The Hong Kong Special Administrative Region.