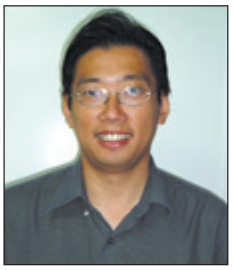


SOIL NAILING & GUNITING

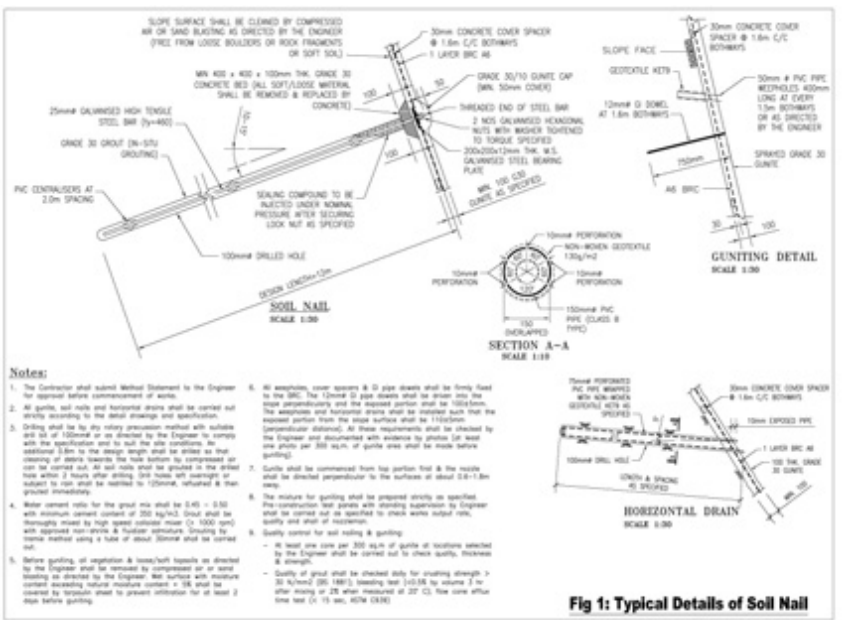
Reported by Ir. Yee Yew Weng, Geotechnical Engineering Technical Division

On 14 May 2004 at IEM Conference Hall, more than 120 engineers were given a special treat by Ir. Neoh Cheng Aik who shared his library of knowledge about soil nailing and guniting for cut slopes. Much of his experience was garnered from the many projects he has been involved in at JKR. Ir. Neoh shared at length various issues, from design concepts to common on site construction pit-falls, and included in his lecture many instructive photos and clear illustrations. Most participants left the talk two hours later with the conviction that the widely applied soil nailing and guniting methods to stabilise slopes require greater attention in both design and site installation technique and control. Most of the current status quo methods appear to fall short of good engineering practice/ standards and may present long term performance concerns.

DESIGN ISSUES

Ir. Neoh explained that soil nail designers have to understand the following basic engineering behaviour and fundamental design concepts of soil nailing in slopes stabilisation:

- Soil nailing is a proven cost-effective technique widely used to stabilise cut slopes or to support deep excavation by reinforcing the insitu ground. It generally consists of drilling, inserting rebar, grouting and nail head construction/facing/ guniting.
- The most important design issue concerns the pull-out resistance of the reinforcing element. In practice, it is usually estimated based on soil data with reference to empirical observations including pull-out test results derived from full scale verification/sacrificial tests on site.
- Some slope movement is required to mobilise load tension in the soil nail (up to 30mm).
- Normally, lateral displacement due to stress-relief of excavated steep soil nailed slope/wall is about 0.1%H to 0.3%H, where H is the total excavated height of the slope/wall. When lateral deformation exceeds 0.5% H, excessive bending and shear in soil nails may happen, resulting in excessive creep and tension cracks in upslope or eventual slope failure, if left unattended. Deformation of steep nailed slope/wall can be monitored by installing some simple markers on the crest of the nailed slope/wall.
- Soil nails need to extend to sufficient length beyond the active zone or any plane of weakness to overcome external stability including (1) overturning, (2) sliding, (3) bearing, and (4) overall slope instability, modes of failure.
- Three internal failure modes must be checked to ensure an adequate factor of safety, i.e. (1) nail pull-out resistance, (2) nail material tensile capacity, and (3) nail head/facing capacity.
- Reference may be made to HA68/94 (1994) and FHWA (1998) for design methods. Prediction of axial forces along soil nails and displacement can be by LEM (limit equilibrium method) and FEM (finite element method).



Typical Details of a Soil Nail

Ir. Neoh remarked that the design of nails is quite fundamental but

designers often do not fully appreciate the engineering behaviour of soil nailed slopes/walls. For instance, the bond strength or pull-out resistance for nails in soil can vary significantly depending mainly on how the drill holes are drilled, cleaned and grouted. The derivation of bond strength in rock is even more complex and requires an understanding of the site geology and knowledge of any inherent localised weakness in the rock mass. According to Ir. Neoh, most designers pay very little attention to specific requirements in drilling techniques and injection of the grout, e.g. grout mixes, grouting pressure, QC, etc. Poorly designed grout mix and unacceptable grouting methods for example can lead to significant reduction in nail pull out capacity.

CONSTRUCTION ISSUES

As for most geotechnical engineering works, equipment type and construction technique plus construction sequence can significantly influence the performance of soil nails. Ir. Neoh highlighted and elaborated the following essential good engineering practice and site control:

- Clearly worded and practical works specification with emphasis on construction method and QC for drilling, inserting the rebar, grouting, nail head construction and slope protection or guniting are very important. The engineer should understand what constitutes good engineering practice and the specific requirements of soil nailing for the site. The engineer should also determine how the specialist soil nailing contractor intends to comply with the specification and specifics. For instance, does the contractor have the required machinery and experience for the job?
- Effective supervision by experienced and competent site personnel is also important. The engineer should check and ensure that the contractor's Method Statement for soil nailing is complete and complies with the specification. A complete method statement should mention specifically and categorically the type and model of equipment/ machine, material and manpower (operator, supervisor, etc) to be deployed. Sequence of works, output of the proposed resources and quality control tests (type and frequency of tests/observations/ measurements) plus the respective acceptance criteria should also be clearly stated.

Ir. Neoh spent a lot of time explaining the various shortcomings of current nail and gunite construction practices and suggested various avenues for improvement. He used real examples from site observations to illustrate some of these issues:

i) Drilling method

- The drilling technique should be such that characteristics like a constant straight diameter, stable drill hole, drilling debris wholly and cleanly removed are achievable. The drill rig shall be attached with a suitable alignment control device to ensure that tolerable limits are achieved, i.e. position ±75mm, deviation 1 in 20 or straightness 20mm in 3m. Drill rods shall be at least N size for long nails (>18m) and in good condition especially at joints (not "leaky" rods.)
- The rotary percussion method using top hammer or down-the-hole hammer capable of completing the drill hole within a short time (< 1 hour) should normally be used.
- The drill log for each soil nail shall not only include the location, time/duration, soil type/strata, but shall also include observed peculiarities such as marked changes in penetration rate/sound and flushing characteristics (wetness, color, nature and sizes of cuttings, etc.) This information is crucial to confirm design assumptions and will also aid in the selection of the representative soil nail for pull-out tests.
- Ir. Neoh also explained how sub-standard drilling methods, using poor equipment may have an adverse effect on insitu soil properties which may lead to slope instability.

ii) Installation of reinforcement bar

- Reinforcement bars in soil nailing act to transfer load mainly through tension. For permanent works, rebars should be protected against corrosion by hot-dip galvanising (BS 729) with a minimum coat thickness of 85 microns or 610 gm/m^2. Rebar may only need to be protected in corrugated HDPE sheath for cases of proven aggressive soil (pH value <4.5; or sulphate >200 ppm; or chlorite content >100 ppm.) Rebar in pregrouted HDPE sheath should be used with care, because the pre-hardened grout is prone to damage during pitching transportation and placement. Couplers when used for nails should be capable of developing the full tensile strength of the rebar and this should be verified by an approved testing facility.
- It is very important to ensure that the centralisers are properly and firmly fixed to the rebar in the drilled hole. Centralisers should be made from galvanised steel or other suitably high quality material dimensioned to fit the rebar at the centre of the hole whilst not obstructing passage of cement grout pipe. Ir. Neoh explained that poorly fitted centralisers (which are commonly made from weak material) are usually damaged during the insertion process into

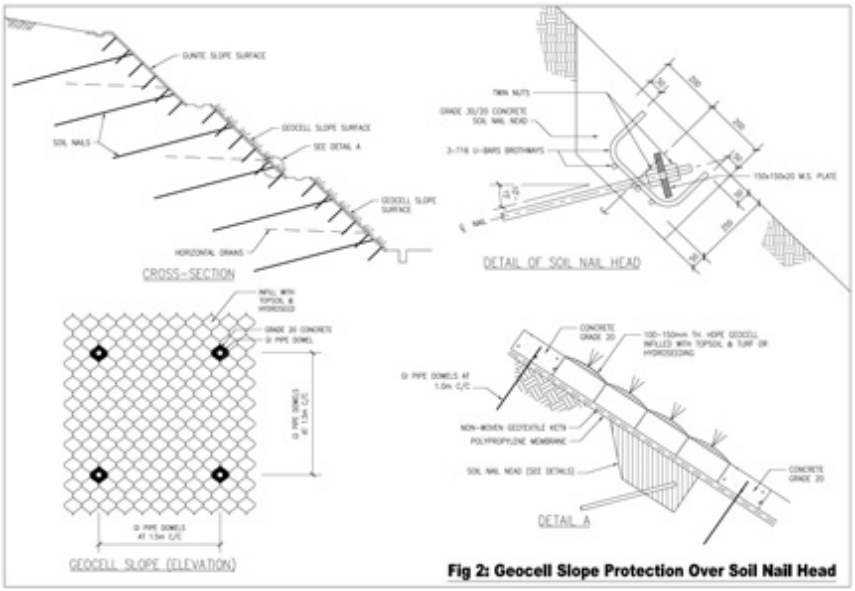


Fig 2: Geocell Slope Protection Over Soil Nail Head

the drilled hole and the resulting distorted and eccentric nail may have reduced capacity.

iii) Preparation of nail head

- The eventual mobilised load on the nail head and facing depends on the steepness of slope, bond strength mobilised, location of slip/rupture circle and the design details for the nail head itself. For steep nailed slope (say >67 degrees), the load on the nail head can be significant. To ensure high nail head capacity, all loose/soft or disturbed soil near the nail head should be removed and replaced by gunite or concrete or grouted sealant. The nail head should be tightened by a suitable torque wrench to reduce displacement.
- Most contractors and engineers pay little attention to nail head construction. Case histories showing how failure of nailed slope due to improper nail head construction were also presented.
- Corrosion protection requirements should be clearly detailed in construction drawings. Ir. Neoh illustrated with case histories where HDPE geocell slope protection systems (Fig. 2) and grid beam systems were adopted to replace normal guniting facing when the client required a green vegetative slope landscape.

iv) Grouting

- The composition of the grout mix usually consists of ordinary Portland Cement, water (water cement ratio of 0.45 to 0.5) and admixture to reduce shrinkage, bleeding and to improve fluidity and workability. Such a grout mix must be designed to give optimum performance in respect to bonding or pull-out resistance, i.e. minimum bleeding and shrinkage but maximum strength.
- Grouting by normal tremie method using a tube of about say 30mm diameter or from bottom up method should be carried out continuously without interruption to avoid any disturbance caused by sedimentation within the grout and to reduce air bubble entrapment.
- Grouting should be carried out as soon as possible or (< 2 hour after drilling) at least within the same day after drilling. Drill holes left for extended periods are prone to excessive swelling or relaxation or hole collapse and may lead to significant loss in bond strength. Ir. Neoh also suggested some measures to check and address the problem of collapse of drilled holes just before grouting.
- Mixing of cement and water should be done using a high speed colloidal mixer (>1000 rpm) to ensure a well mixed grout (free of lumps and undispersed cement). Grout should be pumped into the drilled hole as soon as possible (normally within 30 minutes) after mixing.
- Ir. Neoh noted that most contractors use paddle mixers instead of high speed colloidal mixers to save capital expenditure. Ir. Neoh explained that this practice should be discouraged as the problems caused by a poorly mixed grout can be significant.
- Ir. Neoh advised that QC tests be carried out at least once or twice daily, eg. bleeding test, flow cone efflux time test, crushing strength test and non-destructive insitu grout strength test, etc.

v) Guniting

- Gunite is a mixture of cement, sand and water projected pneumatically at high velocity from a suitable nozzle onto the slope surface to produce a dense homogeneous protective layer. Guniting is commonly used as facing for steep nailed slopes. Dry mix with water cement ratio of about 0.45 to 0.5 is commonly adopted (cement content generally not less than 350 kg/m^3.)
- Weep hole pipes, spacers and dowels should be firmly and securely fixed/anchored and must be adequate and not disturbed/ distorted/deformed/blocked during the guniting process.
- The nozzle man must be

adequately experienced to ensure proper spraying of gunite to produce a high quality finish (distance of spraying should be about 0.6m to 1.5m from treatment surface and angle of spraying should as far as possible be perpendicular to treatment surface in circular motion.) Gunite should be formed evenly in successive layers from top down without gaps or slumps.

- Freshly gunited surfaces should be covered and protected from rain or strong sunlight. Wet or saturated slope surfaces (due to rain) should be allowed to dry by covering with tarpaulin for a few days before guniting. This is to ensure good bonding between the gunite and slope surface. Problems related to 'rebound' can be serious if an improper guniting technique is used.
- Poor site practices are prevalent among most contractors who do not fully understand the need and importance of employing proper guniting techniques.
- Important QC tests for guniting shall include control panel test to ensure proper mix quality and to evaluate the skill of the nozzle man; coring test (at about one core per 150 to 300 square metre) to check thickness, quality of gunite and crushing strength.
- Provision of subsoil drainage and toe treatment was illustrated and explained by Ir Neoh with case histories.

vi) Pull-out test

- The purpose of pull-out tests (up to 2 times the design load) in KN/m is to verify that the nails have achieved the designed pull-out resistance or designed bond strength with adequate FOS. It also allows the quality of work and materials to be assessed. Usually, up to 2%or more of the installed nails should be subjected to pull-out tests.
- Ir. Neoh remarked that the test results should be statistically representative of the untested nails. Hence, the basis of selecting nails for pull-out test should be carefully evaluated based on site observations, nail installation records and the design report. Ir. Neoh also elaborated on pull-out test procedures, and interpretation and acceptance criteria of test results, with the aid of case histories.

CONCLUDING REMARKS

Ir. Neoh concluded the evening lecture by reminding all participants that the behaviour and performance of soil nails not only depend on desktop study (i.e., realistic design input parameters such as shear or bond strength, slope and nail geometry,) but more importantly on the adopted site practices (i.e., the actual pull-out resistance that can be mobilised at the soil/grout and grout/rebar interfaces using the particular construction method.) The designed pull-out resistance of soil nails can only be ensured by employing proper tools (such as suitable equipment) and drilling techniques, whilst not compromising on the quality of the grout mix and delivery system. Care should also be exercised in the construction of the nail head and gunite facing. Of equal significance is the role played by an experienced and diligent supervisor on site. Adequate QC tests to verify material and workmanship should also be specified to prove compliance to good engineering practice and to assure reliable performance of the finished product i.e., a stable and durable soil nailed slope/wall. ■

REFERENCE

Neoh CA (2004). Notes/slides for Soil Nailing & Guniting — Practical Construction Aspects.