Slope stabilisation by soil nails and replacement by anchored bored pile wall for area development

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Singapore’s undulating tree-covered hills mean construction projects often require wide areas of single level or multiple level platforms.

At the Institution Building site, expansion of the existing level area for a new development was achieved by steepening an adjacent hillside to form a uniform 45° face. The freshly cut slope was stabilised with soil nails, ground beams and drainage holes plus a surface water run-off system.

In 2000, the site was to be further extended into the soil nailed slope to allow construction of a three storey building (Figure 1). An anchored pile wall was designed to retain the remaining vertical cut face and the scheme was completed in September 2001.

The incorporated soil nails
Soil nail holes of 150mm diameter were drilled to depths up to 12m using rotary air flush drilling, generally in medium dense clayey sand becoming highly weathered sandstone. 50mm diameter steel rebars were installed incorporating 200mm cut threaded ends and couplers at 6m depth. Lantern spacers were fitted to the bars in an effort to achieve grout cover and reduce bar corrosion (Figure 2). Grout was mixed in a paddle mixer with a water-cement ratio of 0.45. The nail bore was grouted using normal tremie methods and grout from normal Ordinary Portland Cement.

The nail head and ground beams
Ground beam trenches were hand excavated into the 45° cut slope which were filled to form lightly reinforced concrete beams on a 2.5m grid. The beam sections were around 350mm square and the soil nails were predrilled at the intersection of each horizontal and downslope beam section. The head of the nail was cast into the beam and a 150mm square, 12mm thick steel bearing plate fitted in contact with the beam surface and retained by a lock nut. The exposed steel components were painted with bitumen and further corrosion protection was provided by a mound of mortar (Figure 3).

Slope drainage and erosion control
Drainage holes were drilled at a sub-horizontal angle into the slope to a depth of 6m. Perforated ducts were installed to hold the bore open and allow porewater pressure dissipation from the soil. Main surface slope drainage was provided by use of downslope trenches containing interlocking precast units, as is common practice in the area. At the top of the slope, a sub-horizontal drainage trench diverted storm water from above the cut slope and around the sides. The exposed soil surface within the beam grid was protected against soil erosion by turfing with an appropriate weather resistant ground cover (Figure 4).
Slope performance
There were no indications during its 15 year working life that the drained, nailed slope exhibited any problems with slope stability performance. Inspection during regrading indicated some erosion of the soil from the downslope precast drainage segments, but intense local rainfall means such minor occurrences due to overwash are frequent. Shallow downslope runnels formed by water erosion were also visible on the vegetated slope surface.

However there were no indications that the 45° cut slope had undergone “sloughing” – where several square metres of slope unrestrained by geogrid peel off the surface (as is occasionally visible alongside UK motorways). Neither was there any evidence of deep seated soil movement.

Exhumed nails
Inspection of the nail heads at the beam intersection points and of the nails and grout bodies exposed to a depth of 2m was possible.

Where visible, it appeared that the lantern spacers had provided some 5mm to 10mm of grout cover to the steel nails which inevitably lay close to the base of the bore. This grout cover protection along with the mortar cover of the nail head appeared to have severely limited corrosion attack on the steel components of the nails (Figures 2 and 5).

Rust appeared in most cases to be superficial and on the bars there was little evidence of any deep pit formation. In some cases grout remained bonded to the bars (Figure 2). In some instances head plates contained relatively shallow pitting where both the bitumen paint and the grout mortar had been eroded (Figure 5).

However the state of corrosion of the steel nail at greater depths where, in a working load condition, the grout would inevitably be cracked, could not be inspected. Neither was it possible to inspect the corrosion in the coupler zone, another area where grout cracking is most likely and the nail member is most vulnerable.

Another particular interesting aspect of exhumation and observation was the existence of an annulus of dark coloured grout around the outer extent of the grout body (Figure 6).

It has been acknowledged (Barley 1997), that during pressure grouting such an annulus is frequently formed, as applying pressure forces excess water in the mixed grout from the grout body around the borehole perimeter into the water permeable soil. The cement grout particles are too large to penetrate the soil mass.

It appears that in Singapore, the ultra dry soil around the nail bore had withdrawn surplus water from the grout body at the perimeter, thereby leaving the clear presence of this annulus of particularly dense grout. The cause of such a well-defined inner extremity of the dark dense grout is not immediately apparent.

Inspection of 2 out of the 12 nails visible was indicative of the presence of small voids or a loose soil zone along the...
upper surface of the grout at the top of the bore. This is not an unusual occurrence and one that nailing contractors frequently overlook.

The provision of a head of grout at the nail head to fill this wedge shaped void in the bore is recommended to prevent steel exposure. In Singapore the vegetation roots took the opportunity to fill the void and progressed further along the upper surface of the grout body.

Comparison of the in situ nail protection with other recommended practices
The current draft the Eurocode “Execution of special geotechnical work- Soil nails”; which is overdue for publication includes the following statements:

“The reinforcing element shall have a minimum thickness which guarantees the mechanical behaviour during the entire design life.”

and

“The required design life for a particular situation may be achieved by a variety of methods or a combination of methods. Normally corrosivity assessment of the ground will be required to determine what level of corrosion protection is required”.

The code goes on to provide further guidelines:

“The main approaches for achieving the desired service life are:
• sacrificial thickness allowances
• surface coating
• encapsulation (with grout)
• impermeable duct
• a combination of the above."

The production of this particular part of the code was both controversial and time consuming.

Those with an anchor related background wished for some compatibility with the corrosion protection requirement of the current anchor document: Execution of Special Work – Ground Anchors EN 1537:2000, in the form presented in modes 3, 4 and 5.

Others sought to use methods that achieve high nail productivity and look particularly to modes 1 supplemented by 3, which represents the protection system originally provided on the Singapore site. Based on limited observation of the nail head and upper nail member, with due consideration of the relatively short life span to date, there are indications that this was an appropriate design approach in the mildly aggressive soil condition.

However, one should not overlook an experience in similar climatic conditions in Hong Kong; (Can corrosion rule slides? – letter, GE April 1998). Here, totally exposed nail heads exhibited extreme conditions of corrosion and loss of section.

Alternative solutions providing isolation of the steel tendon (modes 3 and 4) have been used extensively in the UK for 15 years; having been developed from single corrosion protection anchor technology (Photo 7).

Fig 7: UK steel soil nails are frequently threaded into pre-placed corrugated plastic ducts to provide isolation from the environment. Ducts are clearly visible during work on the M11 at Stansted.

The anchor and bored pile wall works
The contiguous bored pile wall was to be retained by three rows of 800kN working load anchors, but to reduce the number of anchors and to save time, contractor L&M Geotechnic proposed installing half the number of anchors using the high capacity Single Bore Multiple Anchor (SBMA) System, which has been used to install 15,000 anchors worldwide.

Before the method was accepted for the Singapore contract, however, it had to comply with the designated BS8081 anchor specification. This required a demonstration of a test anchor capacity of 4500kN in the very weak sandstone bedrock and the establishment of ultimate bond stresses at the grout/ground interface (using short test SBMAs).

Furthermore, since L&M Geotechnic elected to fabricate all its own double protected anchor tendons, the integrity of the bond, the quality of the encapsulations and the state of the corrosion protection under load, demanded the completion of “gun-barrel tests” prior to the site trials (a mandatory requirement in the anchor Eurocode).

Site anchor trials, along with L&M’s in-house gun-barrel tests, were carried out and completed successfully in March/April
2001. This allowed installation of the double plastic protected 1500kN working load anchors to progress rapidly in conjunction with the piling work (Figure 8).

Fig 8: Installation of prefabricated double corrosion protected tendon with multi-unit encapsulation.

The entire anchor works, including test loading of each and every anchor to 2250kN (Figure 9), was completed in August 2001. This allowed construction to proceed into the bored pile wall area to achieve early completion (Figure 10).

Fig 10: Completed wall at Institution Building site

Summary
The inspection of insitu geotechnical components after a decade or more of use is infrequent. Soil nails are still considered to be novel, and development is only just arriving above "infancy".

The opportunity to inspect partially exhumed soil nails and report on evidence of only mild forms of corrosion in the upper nails is therefore of value to the industry. The satisfactory performance of the nailed slope enhances confidence in the soil nail solution, although attention should always be paid to the potential corrosion of the tensile member.

The slope replacement by a bored pile wall incorporating very high capacity multiple anchors confirms that safe working capacity of anchors in soil and weak rock has been safely doubled within the last decade.

References
Execution of Special Works – Ground Anchors EN1537:2000
Execution of Special Works – Soil Nails Draft form.