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The effects of variable geology on soil nail pull-out test results in Hong Kong

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ABSTRACT : It is now common practice in Hong Kong for designers to upgrade marginally stable slopes by reinforcing them using soil nails. The variable geological conditions of Hong Kong, however, which range from highly fractured plutonic and volcanic bedrock to insitu saprolitic and residual soils and colluvium, affect the design and construction of the soil nail bars. In addition, the geological profile may have an effect on the results of the testing of the soil nail bars. The paper provides a preliminary analysis of the effects that the nature of the soil or rock type being nailed may have on the deformation results obtained during the pull-out testing of the soil nail. The geological conditions of a number of sites are outlined and comparisons are made between the pull-out test results and local geology.

INTRODUCTION

The geology of Hong Kong can broadly be divided into in-situ variably decomposed igneous rock, (Figure 1), with minor occurrences of metamorphic and sedimentary deposits in the north, with overlying transported 'superficial' soil comprising colluvium and man-made fill. The strata in the urban areas, where many soil nail sites exist, comprise completely and highly decomposed members of the granite family, or similarly decomposed varieties of volcanic tuffs and occasional lavas (McFeat-Smith et. al. 1989).

Soil nailing is a practical and proven technique used for stabilization of slopes by reinforcing the ground in-situ with relatively small, fully bonded inclusions, usually steel bars (Bruce and Jewell, 1986). Using this method the marginally stable existing slope will not be significantly disturbed by temporary or permanent excavation, and thus the confidence gained from the long term performance will be retained (Powell and Watkins, 1990). In addition, the combination of the soil nails and soil mass produces a homogeneous and resistant material which can withstand tensile and shearing forces (Guilloux and Schlosser, 1982). Although the analytical methods are still being 'fine-tuned', there is no doubt that the installation of soil nails increases the existing factors of safety of the slope (Watkins and Powell, 1992). The Geotechnical Engineering Office (GEO, formerly the Geotechnical Control Office) of the Hong Kong Government has an ongoing Landslip Preventive Measures Programme (LPM) for all existing cut slopes in Hong Kong. In this programme the slopes are investigated to determine their existing stability and if below standard, landslip prevention work is undertaken. Soil nailing techniques have been used in Hong Kong as a permanent slope stabilising method since the late 1980's. In cases where soil nails are used, the design assumptions are verified by means of the soil nail pull-out test.

PULL-OUT TESTS

In Hong Kong the soil nail bars used for pull-out tests are normally sacrificial to the overall design. Testing frequency is dependent upon the number of nails being employed, with a minimum of 3 tests for < 50 nails, 6 tests for between 50-100 nails and 6% for over 100 nails. The contractor is provided with a full specification as part of the contract documentation. Quality Assurance is provided for by material and procedural specifications and the on site field testing.

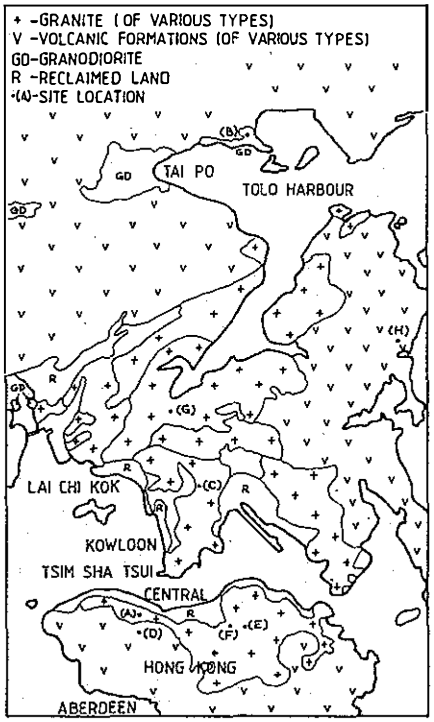

Figure 1 Broad overview of the rock type distribution in Hong Kong

PULL-OUT TEST PROCEDURE

The GEO design engineer provides the contractor with the following information :-

i) test load, (T_P); (ii) length;

iii) angle of installation;

iv) nail and drillhole diameters;

v) nail locations and vertical and horizontal spacings.

vi) grouted length for pull-out test.

When the design soil nails have been marked out on site, additional locations for the pull-out test nails are agreed and inserted, and the pull-out tests are then performed. The apparatus and set up for the pull-out tests are shown on Figure 2. Records of drillhole penetration rates are compared with the known geological profile to confirm that the nails are loading the expected 'soil' type.

The pull-out test procedure is detailed below :

(a) The soil nail is grouted over the length to be tested (2.0 m) and the grout left to set and reach a cube strength of 21 MPa.

(b) The test load (T_P) is taken to be 1.5 times the working load.

(c) An initial load (Ta) equal to 20% of T_P is applied, the range between Ta and T_P being divided into three equal steps of magnitude.

(d) A programme of three loading and

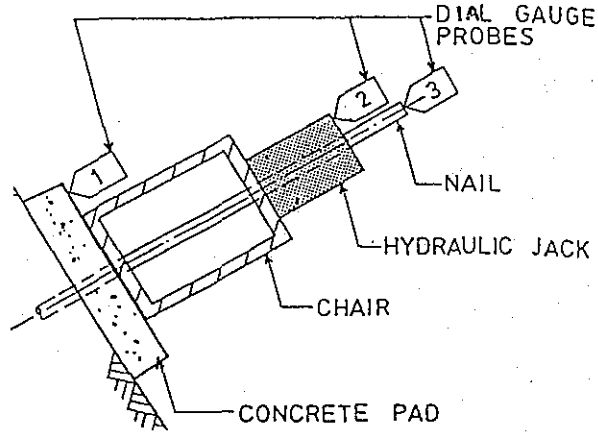

Figure 2 Diagrammatic representation of equipment and typical set-up for soil nail pull-out test

unloading cycles is then carried out with the load being increased from Ta in successive cycles by T, 2T up to T_P. After the peak loading in each cycle is reached, measurements of the deformation increase with the load held constant for 60 minutes are taken.

(e) When the above measurements have been taken for each cycle, the load is reduced to Ta and the deformation is recorded.

The test soil nail bar is then either removed from the slope and the hole infilled with grout, or is cut off flush with the slope surface. The maximum allowable test load should not exceed 80% of the ultimate tensile strength of the steel bar forming the nail. The soil nail movement and applied load are recorded and plotted.

METHOD OF ANALYSIS USED IN THIS STUDY

The deformations recorded during the test for each nail will comprise elastic elongation of the free length of the steel bar, movement between grout and soil, and deformation within the soil mass around the anchored section. In order to determine the effect of the specific geology on the test, the theoretical elastic deformation has been removed. This resulting value has been termed the 'corrected deformation'. In addition, the shear stress acting on the tested section has been determined (allowing for 50 mm gap between the end of the bar and the end of the hole). Figure 3 shows these two parameters plotted against each other for variable geological conditions, while Figure 4 shows ranges of corrected deformation over shear stress for each material type.

SITE SPECIFIC CONDITIONS

The following section discusses very briefly a number of randomly chosen sites, outlining the different geological models, resulting soil nail designs and testing carried out. The approximate location of each site is shown on Figure 1.

(A) This site is located in the Mid levels area, Hong Kong Island. Site investigation revealed colluvium comprising a firm, gravelly sandy silt matrix with angular and subangular moderately and highly decomposed tuff boulders, with a boulder content in areas of over 60%, overlying partially weathered granite. One hundred and eighty nine 25 mm diameter soil nails were installed in nine rows in the colluvium in 100 mm diameter holes, the nails being 7 to 14 m in length, inclined at 10^{o} to the horizontal. Twelve pull-out tests, with test loads of 110 kN, were performed.

(B) This site is located in Tai Po, New Territories. The site investigation revealed a significant thickness of structureless silty sandy residual soil (grade VI material), overlying completely and highly weathered insitu granodiorite comprising silty fine to coarse sand with rock fragments. Fifty seven 32 mm diameter soil nails were installed in the granodiorite in holes of 100 mm diameter, 10.0 and 11.0 metres long at 10^{o} inclination to the horizontal. Six pull-out tests, with test loads of 75 kN, were carried out.

These two sites are plotted on Figure 3. It is interesting to note that the insitu materials of (B) deformed to generally the same extent as those nails in the transported soils of (A) for roughly the same test load. The range obtained for the transported soil, however, is much greater than that for the in-situ soil.

(C) This slope is located in Kowloon, on the mainland. Site investigation revealed a thin veneer of loose sandy and gravelly fill materials with building debris, overlying completely decomposed granite in the form of yellow, pink and white mottled silty fine to medium sand, with corestones of moderately decomposed granite. In total, 114, 20 mm diameter soil nails were inserted into the granite in 75 mm diameter holes, the nails being 5.0 and 6.0 m in length, at 10° to the horizontal. Eight pull-out tests were performed with test loads of 40 kN.

(D) This heavily vegetated site is located at the Peak, on Hong Kong Island. The investigation revealed sandy fill and bouldery colluvium, overlying variably decomposed volcanic tuff. The tuff was found to be completely decomposed to a gravelly silty fine sand with cobbles at the top, becoming moderately decomposed moderately strong, highly fractured tuff with closely spaced rough, stained joints, at around 4.0 to 5.0 metres depth. Here, the soil nails extended into the moderately decomposed tuff, ie 'bedrock', and the design was based on the rock/grout bond strength. In total, 35 nails were installed, each nail 25 mm diameter in 75 mm diameter holes, at 10° to the horizontal. Five pull-out tests, with test loads of 97.5 kN and 67.5 kN were performed.

(E) This slope is located along Wong Nai Chung Gap Road on Hong Kong Island. Essentially, this is a rock slope, with decomposed, silty sandy granitic soil at the top. The materials being nailed were examined by surface excavation and found to comprise a veneer of completely and highly decomposed granite in the form of loose becoming dense, cream silty sand with moderately decomposed corestones. This saprolite was found to overlie bedrock comprising moderately becoming slightly decomposed, well jointed fine to medium grained granite. Joints were found to be widely to closely spaced, tight, dry and rough. Due to geomorphology, site investigation boreholes were not undertaken, and the nails passed through saprolite into bedrock material. Three rows of 25 mm diameter nails were used in 75 mm diameter holes, in total 36 nails, each 10.0 m long inclined at 15^{o} to the horizontal. Three pull-out tests were performed with test loads of 90 kN.

Figures 3 and 4 indicate that bars embedded into the highly fractured tuff (D) and moderated decomposed granite (E) deformed generally to the same extent at similar shear stresses. It could be interpreted from figures 3 and 4 that the highly fractured tuff deforms to a slightly greater extent than the generally less fractured more intact granite. This may be due to the condition at rockhead with greater deformation due to the shattered nature of the tuff. Obviously, a greater data base is required to analyse the actual effect of rock mass characteristics on the soil nail performance.

(F) This slope is located at Mt Nicholson, Hong Kong Island. The slope comprises loose fill material of silty sand and boulders, overlying residual soil comprising loose fine to medium silty sand and decomposed granite. The completely decomposed granite comprised yellowish brown, mottled white fine to medium sand,

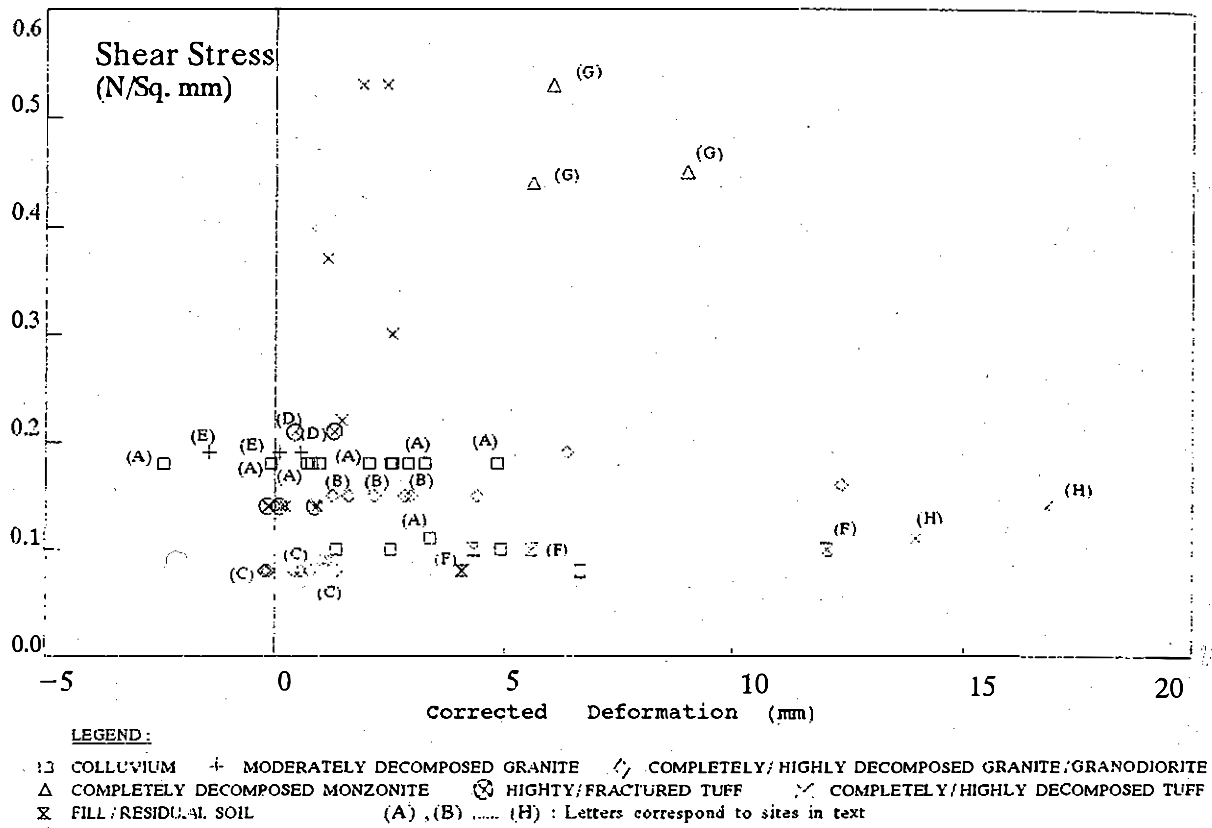

Figure 3 Shear Stress versus corrected deformation for variable Geological Conditions

with only a partial relict texture, indicating a transition material between residual soil and saprolite. In total 71, 32 mm diameter nails were inserted beyond the fill into the residual soil/transition material in 100 mm diameter holes, the nails being 7.0 m long, inserted at an angle of 10° to the horizontal. Six pull-out tests were performed with test loads of 53 and 60 kN.

Figure 3 shows that these nails which pass through fill deposits into grade VI material, ie rock decomposed insitu to a soil with no or very little relict texture, deform to the same degree as those embedded in completely and highly decomposed in situ deposits with relict bonding, etc, at much lower stresses.

(G) This previously failed slope is located adjacent to Lion Rock Tunnel, Kowloon, on the mainland. Slope forming materials generally comprise highly and completely decomposed granite and quartz-monzonite, the monzonite being decomposed to a medium dense becoming very dense, red and yellow brown silty fine to coarse sand with gravel. Sixty two soil nails were used in four rows in the completely decomposed monzonite, each 32 mm diameter in 100 mm diameter hole, with nails 9.0 m long inserted at 10° to the horizontal. Three pull-out tests were performed with test loads of 165 kN, 210 kN and 274 kN.

It is interesting to note that the grouted lengths of the test sections were 1.0 m, 1.5 m and 2.0 m respectively for the above three test loads, and that the lower two lengths both experienced sudden jumps in extension at high loads whereas the third test with the highest test load but with the standard grout test length of 2.0 m experienced no sudden extension. It may be argued from this that the length of the tested section has affected the deformation of the nail under test conditions.

(H) This slope is located in Sai Kung, New Territories, on the mainland. The ground investigation revealed medium dense to dense silty sandy colluvium with cobbles and boulders overlying completely decomposed tuff comprising firm brown sandy silt. The design included three rows of soil nails each 7.0 m long, 20 mm diameter inserted into 75 mm diameter holes, in the completely decomponsed tuff. In total 45 nails were used, with two pull-out tests being performed at test loads of 50 and 70 kN. The pull-out test results shown on Figure 3 indicate high deformations in both tests. One nail extension jumped 7.47 mm on an increase of loading of 60 to 70 kN. The second nail did not 'jump' but has a corrected deformation of 13.94 mm. These results only represent two individual nails and so actual reasons for the high deformations are not clear. They may be partly due, however, to the fine grained nature of the materials (completely decomposed tuff comprising silty soil), or may be due to unforseen circumstances, such as hole collapse, etc.

PULL-OUT TEST RESULTS

Figures 3 and 4 outline the variation of pull-out test results for each material type for general comparison purposes. It can be seen that a fair scatter of points is obtained on Figure 3. A number of preliminary observations can be made, however, from this relatively low data base:-

(a) Soil nails embedded into highly fractured moderately decomposed bedrock of differing types appear to deform to the same approximate extent. This may indicate that while the individual rock mass condition is important, once nails are embedded into bedrock, deformation will be minimal and of the same order for variations in bedrock type. A further study with a greater data base is required to determine the effects of variations in the detailed rock mass characteristics on soil nail pull-out tests and soil nail peformance.

(b) Soil nails embedded into the highly fractured bedrock deformed to much the same extent as the nails embedded in the insitu highly and completely decomposed rock. A greater spread is, however, obtained for nails embedded into saprolite than bedrock (Figure 4).

(c) In general, the nails embedded into the colluvium deformed to similar degrees as those inserted into in-situ deposits. However, Figures 3 and 4 show a large range of results for the colluvium. This may be due to the variable nature of the colluvial deposits, and for those result indicating large deformations at relatively low loads, this may reflect the destruction by transportation of the original intrinsic bonding between grains of the parent material. The only nail to actually fail totally in the sites chosen was embedded in colluvium at site (A). This nail failed at a test load of 80 kN, equal to a shear stress of 0.11 (N/mm^2) with a corrected deformation prior to failure at around 3.36 mm.

(d) Nails embedded into fine grained soils, e.g. completely decomposed tuff (silt deposit) deform to much the same extent as those in the coarse grained silty sand deposits, e.g. completely decomposed granite. They do, however, appear to produce a larger range of results for corrected deformation. This may reflect the greater variation in composition, grain size distribution, etc, of the volcanic parent rock. This may also be due to a greater bonding ability between grout and the coarser sandy soils.

(e) As expected, soil nails embedded through fill and into totally decomposed residual soils tend to deform to greater degrees than less decomposed materials at similar test loads.

(f) It would appear that the test length is important to the deformations obtained. Test lengths of 1.0 and 1.50 m for site (G) experienced sudden 'jumps' in extension, while the deformation of a third nail at a higher load, with the standard test length of 2.0 m, did not experience rapid extension.

A number of results indicate 'negative' corrected deformation using this method of analysis. These anomalous results may be due to innaccurate measurements and the difficulty of obtaining very accurate information concerning the actual grouted length of the nail, due to the possibility of dislodged packers, collapsed holes, leaking grout, etc.

CONCLUSIONS

The geological setting of the site will affect the design of the soil nails and possibly their construction. This preliminary study has shown that the local geological conditions may also affect the performance of the soil nail during pull-out testing. The study has shown that :-

(a) More detailed analyses are required to determine with more certainty the effects of the geology on soil nail performance, including more accurate recording of grouted lengths for determination of actual sheared surface areas (together with more control on the grouting process) and more information on hole behaviour prior to testing.

(b) A series of controlled trials could be undertaken in variable geological conditions using soil nails without the normal variables required for individual designs.

The study has also indicated that :-

(1) Deformation of soil nails embedded into highly fractured bedrock appears to be

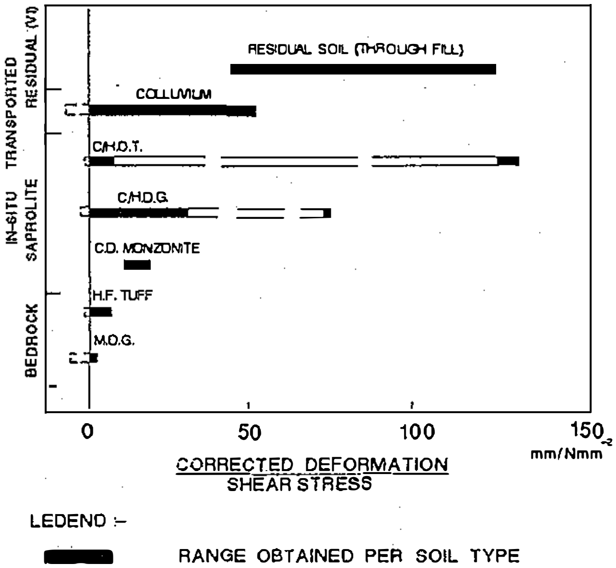

Figure 4 Corrected deformation/shear stress shown as a range for each 'soil' type

of the same order as those embedded into saprolites, although saprolites appear to have a greater deformation range.

(2) Deformation of nails embedded into transported soils is generally very variable and depends upon the condition, nature and origin of the transported materials.

(3) Deformation of soil nails in different rock types of similar mass characteristics is of the same order. Very little deformation is recorded for soil nails embedded into bedrock.

(4) Nails embedded into coarser grained soils deform much the same as finer grained soils, although finer soils tend to give a greater range of results, possibly reflecting the variation in parent rock petrology.

It is evident that there are many variables which affect the performance of soil nails and each variable is an integral part of the soil nail design, not least the geological conditions of the site. A greater understanding of the effect on the nail performance relative to the site geology would be an advantage for designer and contractor alike, and with continued development a reduction in the detailed site investigation with associated cost savings may be realised. The Hong Kong Government is, for example, now letting contracts out for relatively small slopes, around 10.0 m maximum height, for which a detailed site investigation is not being obtained. Rather, the site conditions are being determined during the construction of the remedial works and the soil nail design 'updated' as information is obtained (Powell, 1992).

With soil nailing techniques still being developed, we need to consider all variables and their effects on performance. More trials and analyses of this type will result in more realistic designs and in the future save resources of time, energy and money.

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