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# Installation method and overburden pressure on soil nail pullout test

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ABSTRACT: Laboratory soil nail pullout tests have been recently carried out in Hong Kong to investigate into the effect of installation influence and surcharge pressure on the pull-out resistance of soil nails. Based on the findings of a preliminary numerical analysis, published laboratory results, together with data obtained from field tests, this paper discusses the possible factors which may influence the pull-out resistance of soil nail, in particularly, the installation procedure and overburden pressure.

## 1 INTRODUCTION

There are very few publications available on the pull-out resistance of soil nail pull-out tests carried out on site. Most of the design methods assumed a threshold value of soil nail skin friction (i.e. 120 kPa) or taking a calculated soil nail skin friction based on the overburden pressure, as discussed by Yeo & Leung (2001).

Heymann & Rohde (1992) cited results of 40 field pull-out tests of soil nails, 100 mm in diameter with a bond length of 1.0 m to 1.5 m, in residual Andesite and Granite in South Africa to demonstrate the importance of soil dilatancy in the prediction of soil nail pull-out resistance. It was observed from the results that the ultimate shear stresses of the test nails are independent of depths of the nails where the nails were embedded, which varied from 2 m to 6 m below ground.

Franzen & Jendeby (2000 and 2001) conducted full-scale field tests on pull-out capacity of different types of soil nails including a grouted-nail type. The results indicated that at a low overburden pressure (about 25 kPa) the pull-out capacity is dependent of a local stress field rather than the overburden pressure. The results further indicated that the local stress field around the nail would mainly depend on the installation method and the volume of sand that the nail would displace during the installation and loading.

Li & Lo (2007) also pointed out that the behaviour of soil nail is highly dependent on the method of construction. In Hong Kong, soil nails are commonly installed in existing slopes or newly formed slopes. The construction method involves forming a drillhole, inserting a deformed bar and grouting under gravity. When a stable drillhole is formed, the radial stress in the vicinity of the soil face will be close to zero, therefore completely different from the test conditions as carried out in the laboratory pull-out tests. The variation of local stress field of soil around the soil nail may be resulted from arching effect of soil around the drillhole during installation and from soil dilatancy during loading of the soil nail. Soil arching and constrained dilatancy should therefore be addressed in studying the behaviour of soil nail in laboratory in order to evaluate the ultimate capacity of pull-out resistance of the soil nail in field.

## 2 LABORATORY WORKS ON PULL-OUT TESTS

Many laboratory studies of soil nail behaviour have been attempted in recent years. Davies and Le Masurier (1997) made use of a steel shear box and an air bag on top to apply confining pressure for soil nails (2.8 m long and 25 mm diameter steel or aluminium bars without grout) in medium dense sand under confining pressures of 100 kPa and 200 kPa. Strain gauges and soil pressure cells were installed on each test nail and soil around it respectively for measurements of the soil and nail responses. It was observed in the study that the maximum shear stress increased with an increase in confining pressure, but not proportionally. The authors pointed out that it was because at lower confining pressures, the sand displayed relatively higher dilatancy and higher apparent cohesion.

Lee et al (2001) & Pradhan et al (2003) investigated the pull-out resistance of nails in loose fill as a function of vertical pressure and relative compaction using a pull-out box. They obtained similar findings on the effect of overburden pressure on the pull-out resistance of soil nails when carrying out pull-out test of soil nails for three different vertical pressures, i.e., 25, 75 and 125 kPa. Similar findings about the effect of overburden pressure on the pull-out resistance of soil nails were also obtained by Chu & Yin (2005) when carrying out soil nail pull-out tests in shear box and pull-out box under the influence of vertical pressure.

In addition, Chu & Yin (2003) carried out a series of laboratory pull-out tests on grouted soil nails in soil of two different degrees of saturation of 74% and 78% for testing under a normal pressure of 300 kPa. The results indicated that the shear strength decreased by 11.43% for an increase in degree of saturation of only 4%. However, test results were very limited to indicate a clear trend of the effect of degree of saturation of soil on the pull-out resistance of soil nail. The installation procedure was not simulated in this study.

There seems to be inconsistent results between the findings of laboratory pull-out tests under different overburden pressures and the results of field pull-out tests on grouted nails. This may be attributed to the fact that in the laboratory studies, the overburden pressure has been applied after the nail was installed. Therefore the effect of installation method on behaviour of soil nail has warranted further investigation.

## 3 INFLUENCE OF INSTALLATION METHOD AND OVERBURDEN STRESS

The investigation of the influence of installation method can be looked into from three different perspectives, namely analytical, experimental, field performance.

### 3.1 *Preliminary numerical study*

A segment of the soil nail was idealized as a unit cell as illustrated in Figure 1. This simplifies the problem from 3D to axi-symmetric but allows an investigation into the local stress near the nail-soil interface and the effect of constrained dilatancy in the vicinity of the interface (Lo 2003).

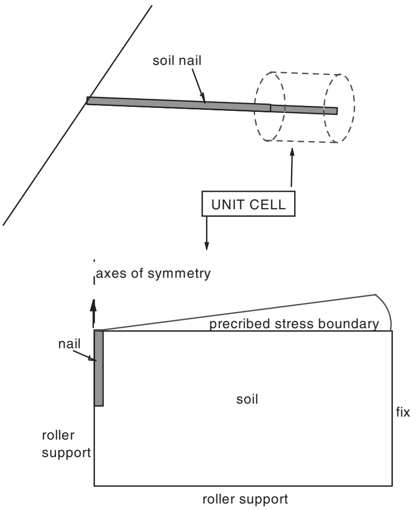

Figure 1. Unit cell for modeling a soil nail.

#### 3.1.1 *Numerical model*

The radial distance to the far boundary is set at an artificially large distance of 5 m so that fixity at this boundary will only have a small effect on the local stress generated by constrained dilatancy around the nail. The other dimensions are: height of unit cell = 2 m, length of nail segment = 1 m, nail radius = 0.067 m. As the soil nail is of a grout-in installation, it included both steel bar and grout, the latter gave a perfectly rough interface with the surrounding soil. The soil was modeled as a Mohr Coulomb elastic plastic material. The soil parameters are:

G = elastic shear modulus = 10 MPa,
$\phi$ = friction angle = 36°,
$\nu$ = dilatancy angle = 0 to $\phi/2$, c = cohesion = 20 kPa during nail installation and reduced to 0 prior to application of nail pullout.

The drop in cohesion implies that the cohesion is an apparent value due to matric suction. Therefore, the critical design condition is one after prolong wetting matric suction being reduced to a negligible value. Although the above are assumed parameters they are considered as reasonable and probably conservative values.

The stress state was first initialized by applying the following boundary stresses:

- $\sigma_r$, radial stress, of 100 kPa representing the vertical and lateral stresses in the soil.
- $\sigma_z$, stress along axes of symmetry, of 50 kPa representing the stress in the soil along the direction of nail.

The drilling of the nail hole was modeled by the removal of soil elements at the nail location. This led to a change in local stress around the nail hole. The insertion of the nail and grouting was then modeled by re-activating the elements at nail location back on as elastic elements. At this stage the radial stress at the nail-soil interface was reduced to zero. The

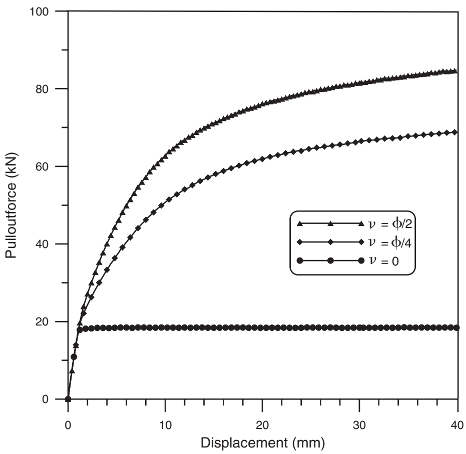

Figure 2. Pullout force versus displacement.

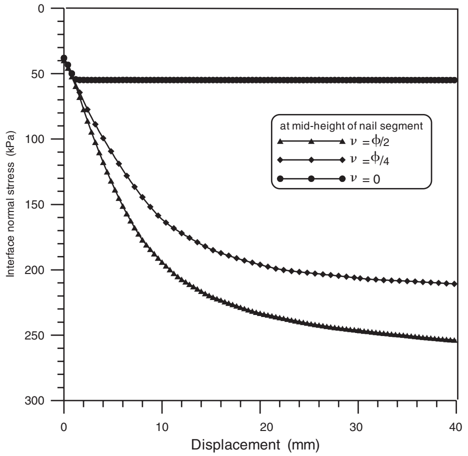

Figure 3. Interface normal stresses versus displacement.

cohesion was also dropped to zero. Radial stress was re-introduced at the nail-soil interface. Pullout of the nail is then imposed. Details of the analysis and numerical procedure were contained in Lo (2002), whereas this paper focuses the interpretation of the behaviour pattern of a soil nail. It needs to be emphasized that the intention was not to make a quantitative prediction. Rather, this is a qualitative investigation.

### 3.1.2 *Results of analysis*

The computed pullout displacement relationships for 3 different values of dilatancy angle, $\nu$, are presented in Figure 2. It can be seem that the computed pullout response of the nail segment is highly dependent on the dilatancy angle of the soil.

Figure 3 examines the radial stress along the nail-soil interface. This is the local normal stress that determines the failure shear stress along the interface. This local radial stress was initially at a small value due to the nail installation procedure. However, it increases with pullout displacement and thus enhancing the pullout force that can be mobilized. This local stress generated by the pullout displacement is due to the constrained dilatancy mechanism (Lo 2003) and thus strongly dependent on $\nu$, as evident in Fig. 3. For the cases of $\nu \geq \phi/4$, the local interface normal stress generated during pullout is several times that at the commencement of pullout. This indirectly infers that the in-situ overburden stress is of a minor effect.

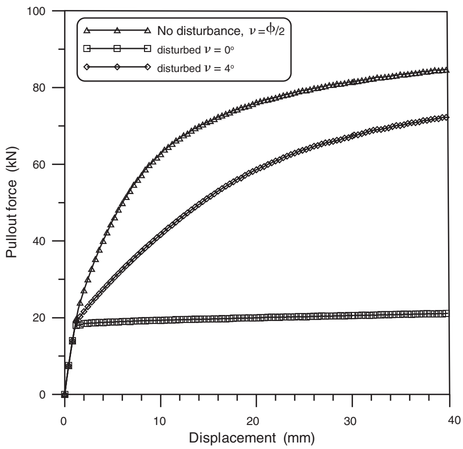

Figure 4. Influence of disturbed zone.

The influence of hole disturbance was investigated by setting the dilatancy angle in a 40 mm zone around the nail a reduced value of either 0 or 4°. The "undisturbed" dilatancy angle was taken to be $\phi/2$. As evident from Fig. 4, this can have a considerable adverse effect on the pullout response of the soil nail. For $\nu = 4°$ in the disturbed zone, the pullout response is similar to that of an undisturbed dilatancy angle of $\phi/4$. If the dilatancy of this small zone around the nail is completely lost, then the pullout resistance dropped to $\sim$25% of the undisturbed value.

## 3.2 *Laboratory studies*

Yin & Su (2006) and Su et al (2006) carried out laboratory investigation using a fully instrumented pull-out box to study the influence of overburden pressure, degree of saturation of compacted completely decomposed granite and influence of installation procedure on pull-out resistance of grouted nail. The general layout of the box is as shown in Figure 5. The internal dimensions of the pull-out box are 1000 mm in length, 600 mm in width and 830 mm in height. The soil chamber has equipped with set of instrumentation to monitor the soil nail performance and soil

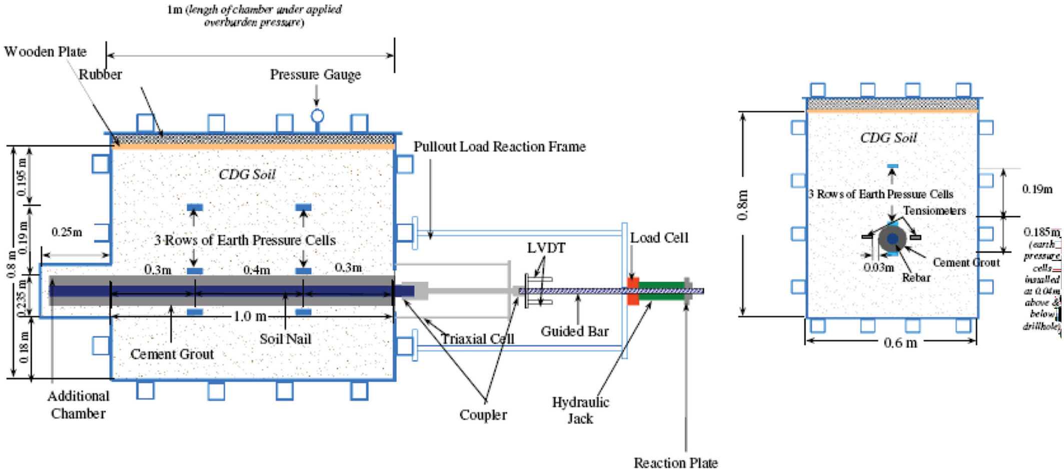

Figure 5. Layout of instrumented pull-out box.

mass response during the course of the laboratory testing. In addition, the soil chamber has provision of an access hole for installation of the test soil nail. The soil is compacted and overburden stress applied prior to installation of soil nail as described below.

An electric drilling machine was used to drill a 100 mm diameter drillhole in the soil through the access hole. Soil nail was then installed in place. Grout was subsequently pumped into the drillhole by using soil sample extruder driven by a motor. After curing for about 5 days when the cement grout had reached a strength of at least 21 MPa, soil nail was pulled out by a hydraulic jack. The soil nail was initially pulled out by a number of load increments (held for about 1 hour). As the peak load reached, the pull-out test continued with a constant rate of 1 mm/min. The procedure adopted is similar to the field test procedure as recommended in Design Technical Guideline No. 11 (GEO, 2004).

Earth pressure cells are installed at different locations within the soil chamber to record the soil responses before and after the formation of the drillhole during installation of test nail. It was reported that uncased drillhole remained stable under a high overburden pressure of 200 kPa.

Su et al (2006) reported a number of pull-out tests carried out under different overburden pressures of range from 40–300 kPa and with different degrees of saturation of 38% and 75%. A typical response of changes of average total earth pressure at different stages of testing for tests with soil at 38% degree of saturation is presented in Figure 6. The authors concluded from the test results that the pull-out resistance of soil nail is dependent on the local stress state of soil around the drillhole at the time of pull-out. The stress in the soil around the drillhole was largely released after drilling and the recovered stress was very small in comparison with the applied overburden pressure. The authors also reported that during the constant rate pull-out test, the average earth pressure measured increased with the development of pull-out resistance and then decreased with subsequent displacements after the peak value had attained. It is apparent that this increase in normal stress was due to the effect of constrained dilatancy caused by shearing of the dense granular soils around grouted nail. Therefore in design of soil nailing system, the normal pressure on the soil nail surface should not be taken as the weight of the soil above the soil nail as a matter of course. This is consistent with the observations of field pull-out tests by Cartier and Gigan (1983) and Clouterre (1991).

### 3.3 *Field testing*

Cheung et al (2005) reported the behaviour of two soil nails instrumented with strain gauges under pull-out tests. Drillholes were sunk in close proximity to the testing locations to obtain SPT ‘N’ values and pressuremeter tests were performed at the bond section levels of the test nails.

A grouted length of approximately 2 m was formed for the bond section. Packers were used to ensure the integrity of the grouted bond length of the soil nail. Pull-out tests were carried out using standard set up and test procedures as recommended by Design Technical Guideline No. 11 (GEO, 2004). The general set up of the soil nail pull-out test are as shown in Figure 7.

The authors reported that the overburden pressure of the test nails was about 8 m, with average SPT ‘N’ values of 75 and 40 at the level near the bond section of the test nails. The average bond strength of the two

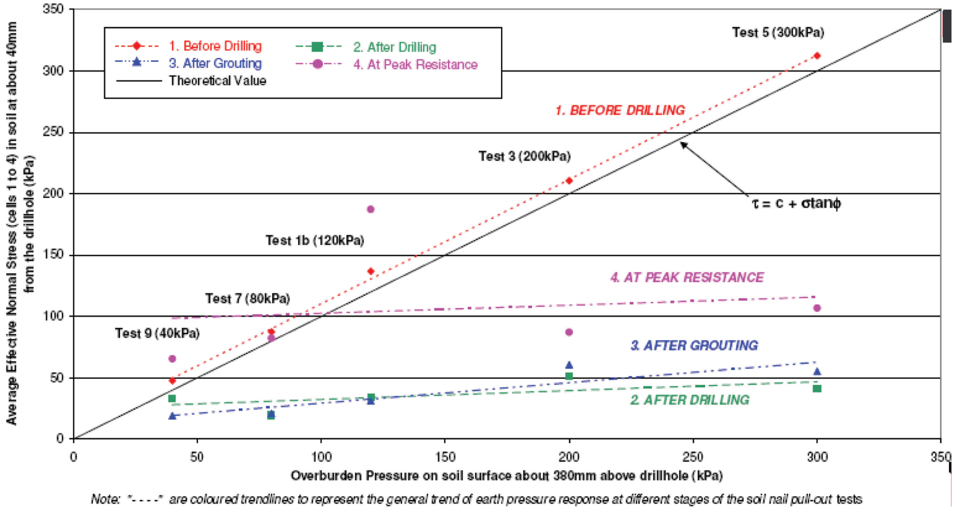

Figure 6. (Typical) average effective normal stress at various stages of soil nail installation vs overburden pressure (for Sr = 38%).

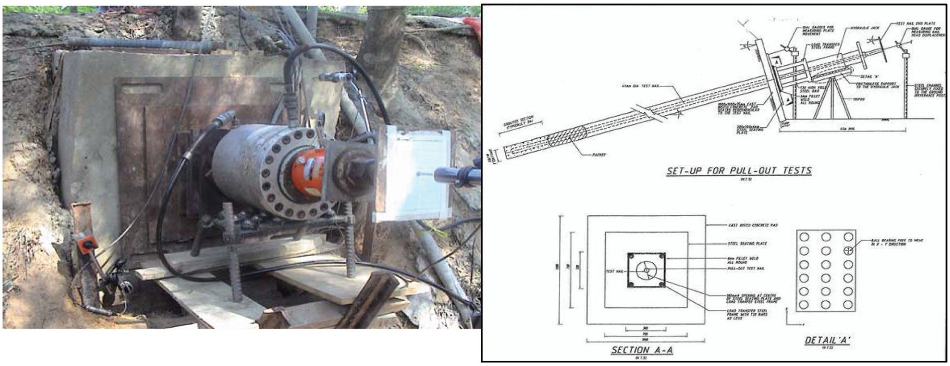

Figure 7. Testing seup of the field pull-out test.

test nails, namely A1 & A2, at the maximum test load was 193 kN/m$^2$and 183 kN/m$^2$.

Leung & Fu (2005) reported the failure mechanisms of three soil nails using packers under pull-out test, adopting the set up and test procedures as recommended in Design Technical Guideline No. 11 (GEO, 2004). The test nails were installed at about 3 m below ground into colluvium of hard stratum. It was reported that the test nails, namely B1, B2 & B3 were terminated at maximum test loads corresponding to bond strength of 426 kPa, 348 kPa & 451 kPa respectively. The pull-out resistance of soil nail from the field data can be summarized as in Table 1.

It can be seen that the pull-out resistance observed from the field tests do not increase with the increase in overburden height, but may likely directly affected by the SPT 'N' value and by the local ground conditions.

Table 1. Summary of Max. Pull-out Resistance vs SPT 'N' Value, Overburden Height and Local Ground Conditions.

| | Resistance | SPT | Overburden | local ground |
|---|---|---|---|---|
| Site/Nail | (kPa) | 'N' | height (m) | Conditions |
| A1 | 193 | 75 | 8 | CDV IV/V |
| A2 | 183 | 40 | 8 | CDV V |
| B1 | 426 | NA | 2.5 | Hard Stratum |
| B2 | 348 | NA | 2.5 | Hard Stratum |
| B3 | 451 | NA | 2.5 | Hard Stratum |

## 4 DISCUSSION & CONCLUSION

Finding of the preliminary numerical analysis is in line with field test results reported by other researchers. In

Table 2. Recommended values of bond strength at soil/grout interface.

| Countries | Soil types | Recommended soil/grout bond strength in kPa | References |
|---|---|---|---|
| China | Dense Sandy Soil | 160 to 200 | (CECS 1997) |
| Japan | Sandy soil of N-Value from 30 to 50 | 180 to 240 | (JH 1998) |
| United States | Very dense silty sand and gravel | 120 to 240 | (FHWA 1994 and 1998) |
| France | Sand of limit pressure at pressuremeter test ranging from 0.5 to 3 MPa | 50 to 125 | Clouterre (1991) |

essence, the installation of soil nail changes the local stress around the soil and subsequent pullout response is strongly influenced by the dilatancy characteristic of the soil.

Laboratory tests on pull-out resistance of grouted soil nails under a constant displacement rate were carried out in compacted completely decomposed granite under different overburden pressures and different degrees of saturation.

The test results indicated that the soil nail pull-out resistance was dependent on the local stress state of soil around the drillhole at the time of pull-out. The stress in the soil around the drillhole was largely released after drilling and the recovered stress was very small in comparison with the applied overburden pressure. Therefore the pullout resistance is largely dependent on the local interface normal stress generated by constrained-dilatancy. The pull-out resistance may decrease as the degree of saturation increases.

It has also observed from the field tests carried out that the effect of overburden pressure on the pull-out resistance was not obvious. In addition, the results indicated that the pull-out resistance observed on site is affected by the local ground (stress) condition (may be also the ground water condition) during installation. The local soil condition probably affects the constrained dilatancy. The ground water condition is probably related to the extent of disturbance during nail installation. It should be noted it is important to ensure that field testing are adopting a similar set up and testing procedure which enables inconsistency in testing method to be minimized and allows pull-out test results for different site conditions to be compared meaningfully. The adoption of using consistent grouting technique (i.e. packers) enables inconsistency in grouting bond length to be ascertained. The pullout resistance from the field tests indicated a bonding stress of 200 kPa to 400 kPa may develop depending on the local ground conditions which may be reflected using SPT ‘N’ value. The ultimate bond strength of under 200 kPa at the soil/grout interfaces may be comparable with those recommended in the codes of practice for soil nails in various countries as shown in Table 2.

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