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Study on the interface shear strength of soil nails in a completely decomposed granite soil by laboratory pullout tests and large-size direct shear box tests

Etude sur la force de cisaillement d'interface de clous de sol dans un sol de granite complètement décomposé par les tests de retraite en laboratoire et des tests de cisaillement direct sur boxe de grande taille

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ABSTRACT
Two laboratory pull-out boxes were developed to investigate the interface shear strength behaviour of a soil nail and a surrounding soil. The soil was a typical Completely Decomposed Granite (CDG) soil taken from a soil nail stabilized slope site in Hong Kong. In addition to the pull-out box tests, a large-size direct shear box was also used to measure the interface shear strength between the CDG soil and a cement grout plate. A number of laboratory pull-out tests and large-size shear box tests were performed with a cement grouted nail (or cement grout plate) in the CDG soil. Major results are presented and discussed in the paper. The results are used to examine the influence of (a) overburden pressure, (b) soil degree of saturation, (c) surface roughness of soil nail, (d) stress release in drill hole, and (e) the interface dilation on the interface shear strength.

RÉSUMÉ
Deux boîtes détachables en laboratoire ont été développées pour examiner le comportement de force de cisaillement d'interface d'un clou de sol et un sol environnant. Le sol était un granite typique complètement décomposé (CDG) pris d'un clou de sol en site de pente stabilisé a Hong Kong. En plus de la boîte détachable, une boite des cisaillement de grande taille aussi a été utilisée pour mesurer la force de cisaillement d'interface entre le sol de CDG et une plaque de mastic de ciment. Un nombre de tests en laboratoire détachables et cisailles de grande taille emballent des tests ont été exécutés avec un ciment a mastiqué le clou (ou la plaque de mastic de ciment) dans le sol de CDG. Les principaux résultats sont présentés et sont discutés dans le papier. Les résultats sont utilisés pour examiner l'influence de (un) surcharge de la pression, (le b) le degré de sol de saturation, (le c) la rugosité de surface de clou de sol, (d) le relâchement de tension dans le trou d'exercice, et (l'e) la dilatation d'interface sur la force de cisaillement d'interface.

1 INTRODUCTION

Soil nailing has been widely used for stabilizing existing slopes in Hong Kong. For the design of a soil nail system, pull-out capacity of a soil nail is an important design parameter. Field pull-out tests are normally carried out to verify the pull-out resistance assumed at the design stage. However, the pull-out capacity of a soil nail in the field is influenced by a number of factors, such as variation in the soil properties, variation in the installation procedures, types of soil nail, and stress levels. Thus, field testing has a number of limitations. To overcome the limitations, two laboratory pull-out boxes was developed to investigate the interface shear strength behaviour of the soil nails and a surrounding soil. In this study, the soil is a typical Completely Decomposed Granite (CDG) soil taken from a soil nail stabilized slope site in Hong Kong. In addition to the pull-out box tests, large-size direct shear box tests were performed to measure the interface shear strength between the CDG soil and a cement grout plate. A series of laboratory pull-out tests and large-size shear box tests have been carried out with a cement grouted nail (or cement grout plate) in the CDG soil (on the CDG soil for the shear box tests). This paper introduces the two new soil nail pullout boxes, a large direct shear box, and major test results.

2 TWO SOIL NAIL PULLOUT BOXES

An old version and a new version of a soil nail pullout box – soil nail are shown in Fig.1 and Fig.2, where a longitudinal section is in top and a cross-section in bottom. Others are as shown in the figure. The old version is simple and convenient to use. However, it has three major problems – (a) the stresses on the soil nail surface are not very uniform since a cavity at the nail end is formed after the nail is pulled, (b) the water

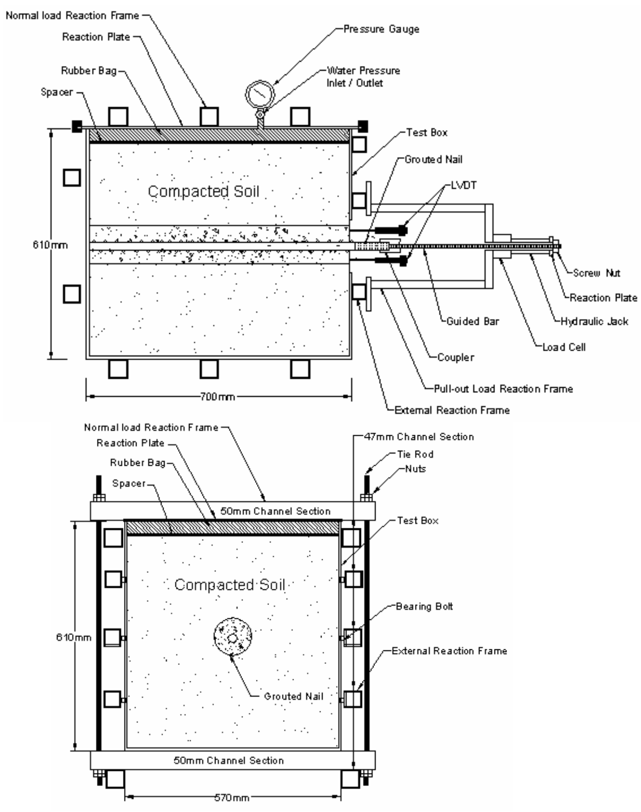

Fig.1. A soil nail pullout box (old version) (not to scale) (after Chu and Yin 2005)

saturation of the soil is difficult and (c) there is no instrumentation in the soil and nail.

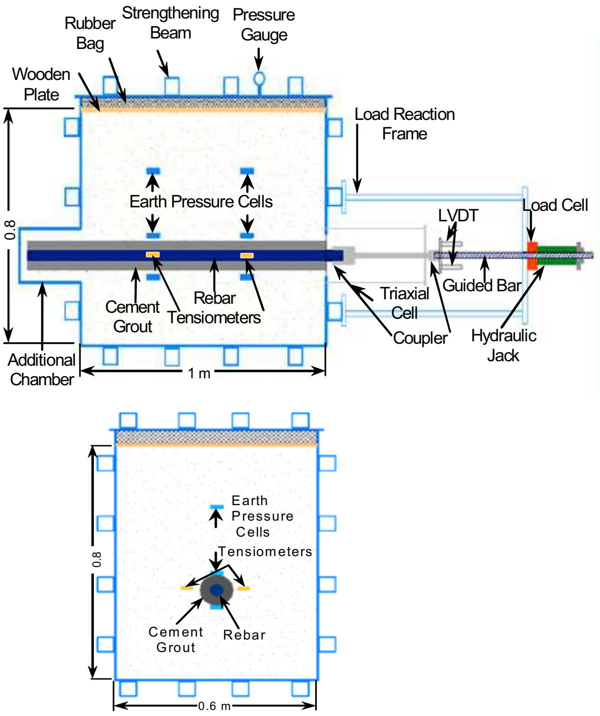

Fig.2. A soil nail pullout box (new version) (not to scale) (after Sun et al 2005)

The new soil nail pullout box in Fig.2 overcomes the above three limitations of the old version. An additional chamber is built to the end of the box (see Fig.2 – top). The soil is compacted in the chamber. The soil nail is installed all the ay from the right to the left into the chamber (see Fig.2 – top). When the nail is pullout, the stresses on the soil nail inside the box is more uniform. As shown in the right in Fig.2 (top), a special triaxial cell with coupler inside was attached. The triaxial cell can be used to seal the nail head during pulling out. A number of plastic pipes are connected to the bottom, top and sides of the box. De-aired water is supplied via the pipes into the soil. Back pressure is also applied through the pipes and used to speed up water saturation of the soil inside the box. This will increase the degree of saturation of the soil. In addition, full instrumentation is implemented in the new box. This includes (a) earth pressure cells, (b) miniature tensinometers, (c) porewater pressure transducers all in the soil, (d) strain gauges on the re-bar, (e) volumemeter for in/out-flow of de-aired water in the top rubber bag as indication of the vertical compression of the soil in the box, (f) load cell and (g) two LVDTs at the soil nail head.

Both the old soil nail pullout box and the new box have been used in the test program.

3 A LARGE DIRECT SHEAR BOX

A large direct shear box is shown in Fig.3 and used to measure the interface shear strength between a compacted CDG soil and cement grouted on the soil surface. The lower box has internal space dimensions of 305mm wide, 406mm long and 102mm high. The upper box has dimensions of 305mm wide, 305mm long and 102mm high. A special procedure was used to grout cement slurry on the CDG soil. The CDG soil was first compacted in a wooden box. After compaction, the cement slurry was placed on the CDG soil in the box. After curing of a few days, the cement (top)/CDG soil (bottom) was turned upside down leading to in the cement (bottom)/CDG soil (top) and was placed in the direct shear box (see Fig.3).

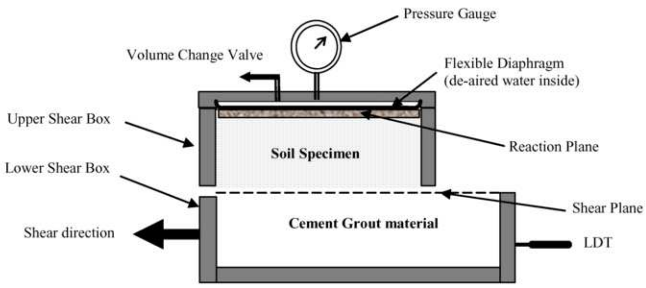

Fig.3. A large direct shear box for measuring soil-cement interface shear strength

Direct shear box interface shear tests can overcome the some limitations of pull-out tests: (a) a constant normal stress is maintained during the test, (b) the shear failure surface is controlled to occur along the soil-cement grout interface, and (c) the effect of each influencing factor on the soil-cement grout interface can be investigated under a controlled testing condition.

4 TYPICAL PULLOUT TEST RESULTS

The typical results of pullout tests on a CDG soil (natural wet) using the old box is shown in Fig.4. The CDG soil had 28.22% of gravel, 37.19% of sand, 19.59% of silt, and 15.00% of clay. The specific gravity of the soil was 2.64 and the permeability of the soil was 4.54x10-5 m/s. The maximum dry density of the soil from a standard compaction test was 1.70 Mg/m3 and the corresponding optimum moisture content was 19.00%. The shear strength parameters of the fully saturated CDG soil from conventional consolidated undrained (CU) triaxial tests are c'=0 and ϕ'=31.2^o.

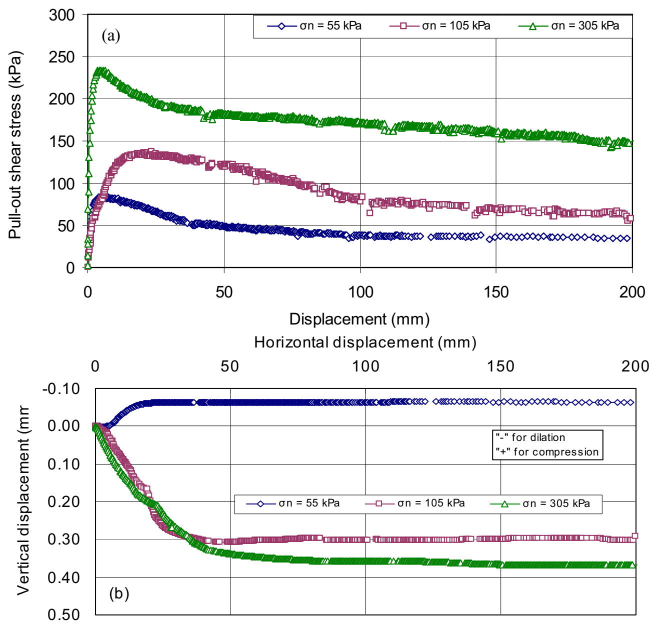

Fig.4. Pull-out test results of regular nails in natural wet condition – (a) pull-out shear strength vs. displacement and (b) vertical displacement vs. horizontal displacement (after Chu and Yin 2005).

The "natural wet" means the soil with nature moisture content. The natural wet soil had a moisture content of 19% and a degree of saturation of 70% only. The soil was first compacted into the box at 95% of the maximum dry density. The soil nail was installed in the drill hole first. After this, a vertical pressure was applied. Therefore, no stress was released during the hole drilling and nail installation. This was different from the field case.

From Fig.4, it is seen that (a) the curves of average pullout stress on the soil nail vs pullout displacement show clearly peaks, (b) the higher the vertical pressure, the higher the pullout resistance, (c) there is more dilation after smaller vertical stress.

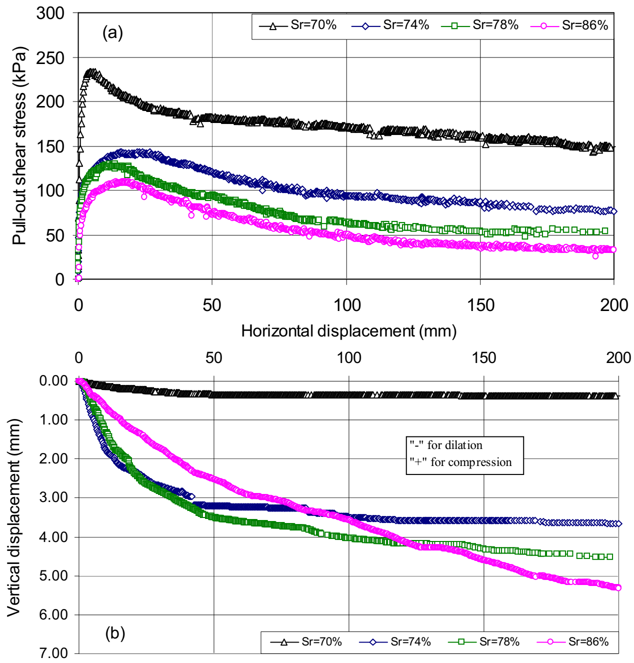

Fig.5. Pull-out test results of regular nails in the degree of saturation, S_r=70%, 74%, 78% and 86% under the normal stress of 300kPa – (a) pull-out shear strength vs. displacement and (b) vertical displacement vs. horizontal displacement (after Chu and Yin 2005)

The influence of the degree of saturation S_r on the pullout shear behaviour can be seen in Fig.5. The vertical pressure is the same of 300 kPa. The only variation is the S_r from 70%, 74%, 78% to 86%. It is seen from Fig.5 that the peak and the "residual" shear strengths and the dilation all decrease as S_r increases.

Fig.6 shows the variation of the vertical total (earth) pressure from six earth pressure transducers buried in the soil with time during (a) hole drilling and (b) soil nail pulling out. It is noted that the CDG soil in Fig.6 is different. The CDG soil was first compacted in the box at 95% of the maximum dry density with an initial degree of saturation of 38%. A vertical pressure of 120kPa was applied on the soil surface. A hole was drilled horizontally while the vertical pressure was kept. The hole drilling totally released the stress in the hole, causing a degrease of the vertical stress as shown in Fig.6 (top). The sudden increase of the earth pressure at time 50 to 90 mins was caused by the drilling bit heating and pressurization at the drill bit location.

During soil nail pullout, the earth pressure increased to a peak and then decreased to a small value as shown in Fig.6 (bottom). The increase of the earth pressure is believed cased by the shear dilation at the interface between the soil nail cement surface and the surrounding CDG soil. As mentioned before, the new pullout box had a number of advantages over the old pullout box.

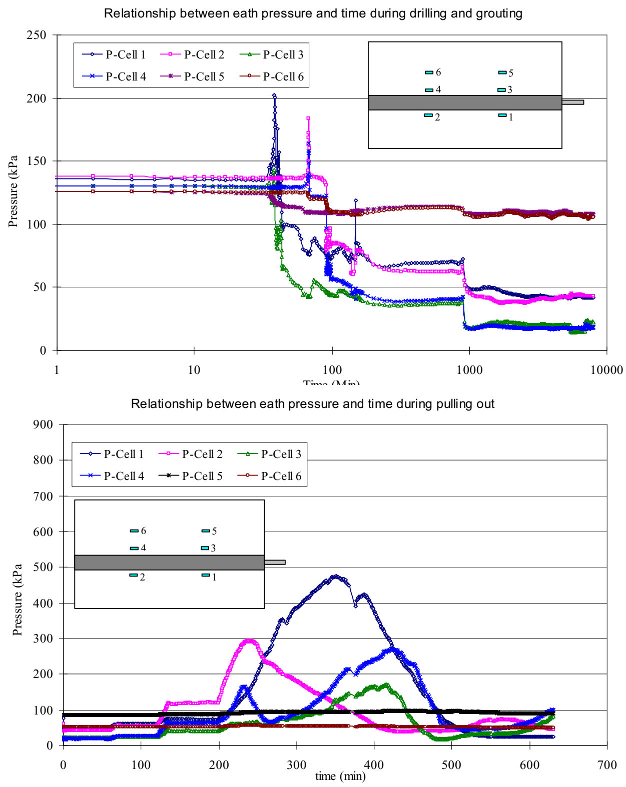

Fig.6. The vertical earth pressure changes with time – (a) during hole drilling (top) and (b) during soil nail pullout (bottom) using the new pullout box

5 TYPICAL SHEAR BOX TEST RESULTS

Shear box tests have advantages over pullout tests. A number of shear box tests have been carried out to investigate the interface shear strength behaviour of soil-cement grouted samples in different controlled conditions by carrying out large-size direct shear tests. The soil used in the tests was the same Completely Decomposed Granite (CDG) soil used in the pullout tests. The interface shear samples and their preparation were a simulation of procedures of a grouted nail installation in a soil slope. Four different degrees of interface surface "waviness" were created to simulate the surface profile of the drill hole. The following influences on the interface shear strength are investigated using the interface shear tests: (a) influence of different applied stress levels of 50, 100, and 300kPa, (b) influence of soil moisture contents (natural wet and water submerged) on interface shear strength, and (c) influence of surface profile of a cement grout material with different surface waviness angles of 0, 10^o, 20^o and 30^o. Typical test results and failure of the interface are shown in Fig.7, Fig.8 and Fig.9.

Fig.7 shows (a) interface shear stress vs. horizontal displacement and (b) vertical displacement vs. horizontal displacement for soil-cement grout interface shear tests with interface waviness angle 10^o in the natural wet condition under vertical pressure of 50 kPa, 100 kPa and 300 kPa. It is seen from the figure that the shear resistance increases and dilation decreases as pressure increases. However the peak is much smaller than that observed in soil nail pullout tests.

Fig.8 shows a typical shear surface of the soil-cement grout interface shear tests under a lower applied normal stress 50kPa in the natural wet condition after test. It is seen the failure occurs mostly along the waviness shape at the cement/soil interface. However, under higher normal pressure of 300 kPa, the failure plane was almost inside of the soil as shown in Fig.9.

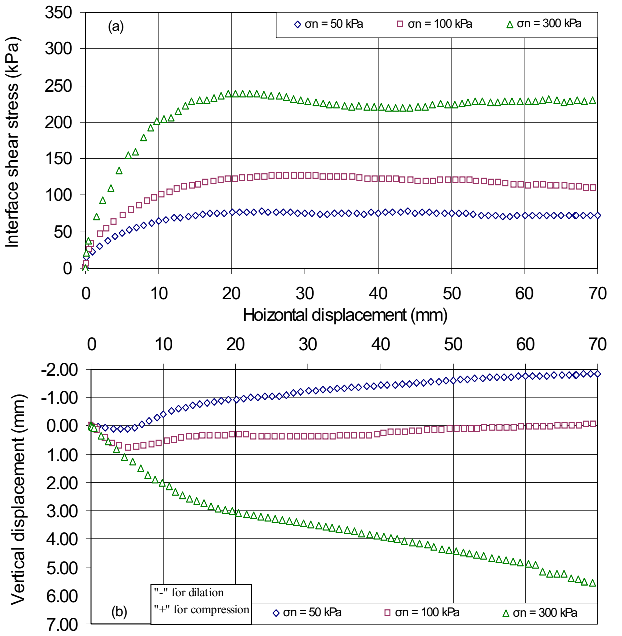

Fig.7. Soil-cement grout interface shear test results of an interface waviness angle 10° in the natural wet condition – (a) interface shear stress vs. horizontal displacement and (b) vertical displacement vs. horizontal displacement (after Chu and Yin 2005)

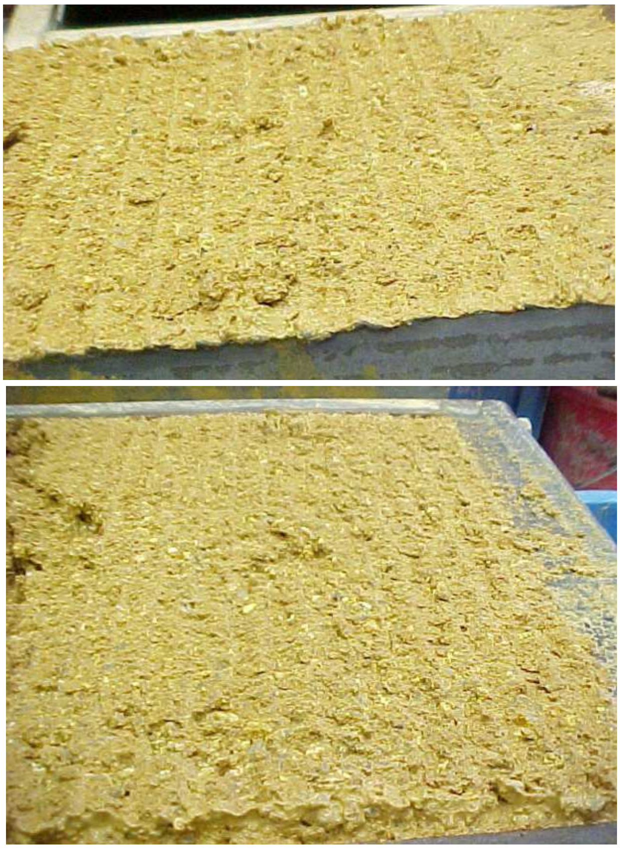

Fig.8. Typical shear surface of the soil-cement grout interface shear tests under a lower applied normal stress 50kPa in the natural wet condition – (a) cement grout failure surface (top), and (b) soil failure surface (bottom) (after Chu and Yin 2005)

Fig.9. Typical shear surface of the soil-cement grout interface shear tests under a higher applied normal stress 300kPa in the natural wet condition – (a) cement grout failure surface (top), and (b) soil failure surface (bottom) (after Chu and Yin 2005)

6 SUMMARY

Two soil nail pullout boxes and one large-size direct shear box are briefly descried. The advantages and limitations of these boxes and corresponding tests are pointed. Typical test result are presented and briefly discussed. The study using these apparatuses is still in progress. More results will be reported and published.

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