

# Effects of grout injection techniques in pressure grouted soil nail system

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**Abstract.** The use of pressure grouting techniques in the soil reinforcement system is frequent as it has many advantages over gravity grouting. Pressure grouting can be injected by pressure and volume (flow) controlled techniques. A preliminary study was conducted for a newly developed pressure grouted soil-nail system, where a latex membrane was used as a liner around the grouting outlet to form a Tube a Manchette (TAM) for direct injection of grout into sand. In addition, a grout bag was formed with the membrane to prevent the grout injection into the sand for simulating a compaction grouting. In the investigation, a newly developed volume controlled injection system was used to inject the cement grout into the sand or grout bag for a specified flow rate and the interaction of injected grouted with the soil mass (i.e., soil stress state) was monitored by the installed total earth pressure cell around the grout outlets. From the investigation, it was found that the injected grout volume was much less for the soil-nail (TAM) than that with a grout bag around for a certain flow rate. In addition, the preliminary results indicated that the pullout capacity of the pressure grouted soil-nail controlled by the injected grout volume (grout bulb).

## 1 Introduction

Soil nailing as a reinforcement technique has been increasingly applied in the field of soil excavation and slope stabilization due to its cost effectiveness and ease of construction [1-3]. It consists of passive inclusions (reinforcements), typically high-yield steel bars called as soil-nails, which are inserted into soil by driving or drilling boreholes in the soils.

Understanding the soil-nail interaction behaviour and its interface shear strength at the soil-grout interface is a foremost concern for a stable and cost-effective design of a soil-nailing system. Bond strength (mobilized shear resistance at the interface) determines the pullout capacity of a grouted soil-nail and impacts the internal stability of the soil-nailed structures. Hence, the pullout capacity is a key parameter that controls the design and deformation of the soil nailing.

Pressure grouting is being progressively used for the soil-nailed structures as an alternate to frequently used conventional gravity (or low pressure) grouting since the pressure grouting technique has the ability to increase the bond strength significantly. Lazarte et al. [4] reported that for a grouting pressure less than 350 kPa in a pre-drilled hole of soil, interface shear resistance could be as high as two times that the resistance from gravity grouting. Previous studies reports that pressure grouting influences the soil-grout interaction behaviour and hence it significantly enhances the pullout capacity of pressure

grouted soil-nail also known as compaction grouted soil-nail [5-11]

It is the authors' understanding that the pressure-control injection technique is mainly used in pressure grouted soil-nail systems. In the pressure-control injection technique, a predefined pressure is set in the injection pump system and the grout is injected at that set pressure for a certain period. Whereas in the volume-controlled injection technique, a constant volumetric flow rate of grout is maintained. To identify the effects of membrane liner in the hollow soil-nail system, a latex membrane is used as a liner around the grouting outlet to form a Tube a Manchette (TAM) for direct injection of the cement grout into sand. In addition to the TAM technique, a thinner membrane is enclosed at the end of the hollow soil-nail to form a grout bag for stopping the direct injection of grout into the soil mass, which actually simulates the compaction grouted soil-nail as reported by Wang et al. [11]. In the investigation, a newly developed volume controlled injection system is used for grouting into the sand or grout bag for a specified flow rate and the interaction of injected grout with the soil mass (i.e., soil stress state) is monitored by the installed total earth pressure cell around the grout outlets. Moreover, a series of laboratory-scale pullout experiments for the soil-nail system was conducted after grouting to monitor the surrounding soil stress-state conditions during pulling the nail out and to evaluate the pullout capacity of the grouted nail under different membrane conditions. The results revealed that the injected grout volume was much less for

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the soil-nail (TAM) than that with a grout bag around for a certain flow rate. In addition, the preliminary study also reported that the pullout capacity of the innovated soil-nail system mainly depends on the injected grout volume, for example, grout bulb-fully hardened grout.

## 2 Experimental program

### 2.1 Materials

In the physical model study, a widely available Stockton beach sand (silica sand) is used and the detailed physical properties of the soil can be found in the report presented by Bhuiyan [12]. The sand is uniformly graded ( $C_u < 4$ ) with a very short range of particle sizes varying from 0.3 ~ 0.6 mm.

Normal, or neat, cement grout is commonly used for grouting in a conventional soil-nailing system. In this grout mixture, locally available ordinary Type-I Portland cement (OPC) is used. A grout composition of water cement ratio (w/c) of 0.5 was primarily selected for this preliminary study. The cement grout develops a compressive strength of 6.6 MPa, 23.73 MPa and 36.73 MPa after 24 hours, 7 and 28 days of curing respectively [13].

### 2.2 Experimental device

For this experimental study, a modified test set up was designed and developed with a volume-controlled grout injection facility. Figure 1 illustrates the schematic layout of the physical model test set up, which consists of four major parts: (1) a physical model box with a modified overburden (surcharge) pressure application system, (2) pressure grouting injection system, (3) soil-nail pullout system and (4) data acquisition system. The model box was originally designed by Wang et al. [13] with a pneumatic overburden pressure application system. In the modified apparatus, further development was made on the surcharge pressure system for converting the pneumatic system to hydraulic. The detailed descriptions of the modified device can be found in the report presented by Bhuiyan [12]. For brevity of the paper, the grout injection system is only outlined in the following paragraph.

The grout injection pump was designed and fabricated to allow control of the grout flow rate. The grout pump is a piston pump and consists of a screw jack with a motor, a grout cylinder and a support frame as shown in Figure 2. The screw jack capacity is 25 kN and the maximum stroke of the lifting screw is 350 mm, where a piston is mounted. A potentiometer (pot) is used to monitor the piston position over the grouting period and hence the injected grout volume can be evaluated. The displacement rate (5mm/s) of the jack can be easily controlled by the 1200 rpm three-phase AC motor, which transfers the rotational displacement to vertical displacement through worm-gear. The grout cylinder has a maximum volume of 5 litres. The flow rate of the grout can be easily controlled from a range 0.5 to 7.5 litre/min. Since the injection pump is screw jack pump, the ultimate injection pressure varies with the speed of the motor, which controls displacement

rate of the screw jack, in other words, flow rate. The pump is able to apply a maximum grout pressure of 2000 kPa. The grouting pressure is measured by a diaphragm pressure transducer mounted at the outlet tube of the pump.

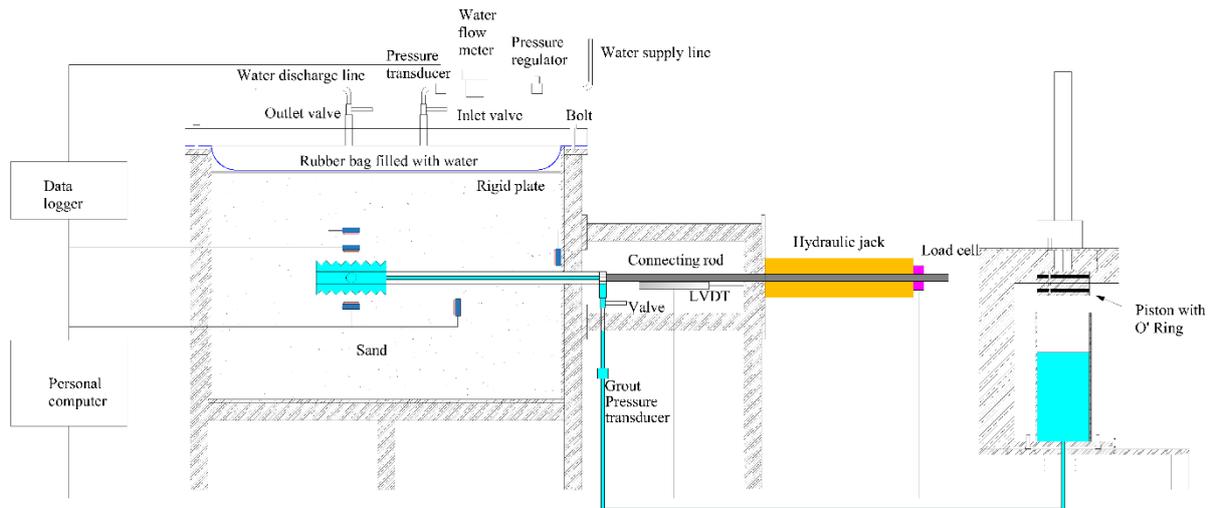
In this study a special type of a soil-nail was designed and developed for the grouting as illustrated in Figure 3. The nail mainly consists of two parts: a hollow nail head and a hollow nail rod. The nail head and nail rod are joined together with a M30 threading. In addition, a bulkhead connector is attached at the end of the nail rod for fixing the grouting tube to the nail head. The grouting tube (10 mm dia.) is mainly used to protect the hollow nail rod from being filled up with the grout and hence, the nail rod can easily be reused. The nail head consists of four holes positioned at the mid-length of the nail head, which actually acts as a grouting outlet. A latex membrane was used as a liner around the grouting outlet to form a Tube a Manchette.

### 2.3 Physical model tests

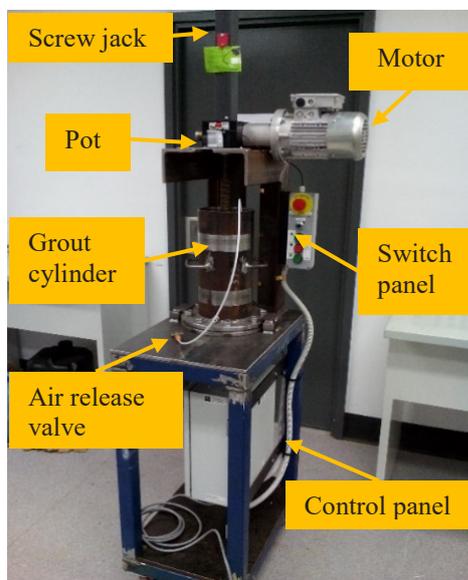
Preparation of the physical models and execution of the pullout tests are briefly outlined here, which have been presented in detail in the report provided by Bhuiyan [12]. Initially, the moist sand (3% water content by weight) was compacted inside the box in layers of 35 to 50 mm, with a controlled dry density of 1.50 g/cm<sup>3</sup>. Once compacted soil reached the height of the sensor position, the earth pressure cells (EPCs) were installed step by step. During this process, the soil-nail was also installed and levelled to minimize the bending effects during the pull-out tests.

Once the soil-nail and the earth pressure sensors were installed and sand compacted up to top level of the box, the hydraulic overburden pressure system was bolted to the top of the box. Before applying overburden pressure, water was injected at very low pressure into the sealed rubber bag (Figure 1) to remove air from the system. Once the rubber bag was filled up with water, the air releasing valve was turned off and the volume of injected water was measured by the digital flow meter. The water injection pressure was regulated to 100 kPa and checked by means of mounted pressure transducer, which was kept constant during the test. When the EPCs reached a stable reading, the soil-nail was pressure grouted by the volume-controlled grout injection pump.

The pull-out test was performed after approximately seven days of curing of the injected grout. To accomplish the pull-out test, the embedded soil-nail was connected to the hydraulic jack by means of a connecting rod. A load cell was mounted to the jack to monitor the pull-out force and a Linear Variable Displacement Transducer (LVDT) tied with the connecting rod was used to measure the displacement of the nail during the pullout process. The pullout displacement rate was maintained at 1 mm/min in accordance with the Federal Highway Administration (FHWA) guidelines [14].



**Fig. 1.** Schematic of physical model test facility.



**Fig. 2.** Photograph of grout injection pump.



**Fig. 3.** Schematic of soil-nail (dimensions in mm).

### 3 Results and discussions

A series of three preliminary pull-out tests of the pressure grouted soil-nails was performed under different membrane conditions at the grouting point. Graphs depicting injection pressure and injected grout volume were plotted to evaluate the effects of membrane as a liner at the soil-grout interface with the soil of degree of saturation ( $S_r$ ) equal to 10%.

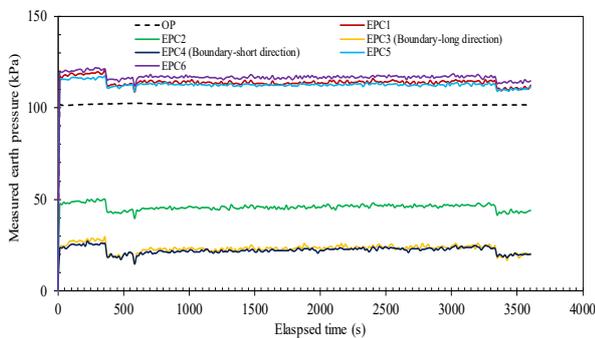
In addition, in this physical model study, six earth pressure sensors were used to monitor the behaviour of soil stress around the soil-nail during the application of overburden pressure (OP) and grouting pressure (GP).

Fig. 4 plots the induced soil stress on the EPCs for the imposed surcharge pressure of 100 kPa for a period of 1 hour, which shows that measured pressures are almost constant and reached a steady state condition over the period. From Fig. 4, it is seen that EPC2, 3 and 4 experience lower pressure than the applied overburden pressure and may be a results of the orientation of installation. EPC2 was installed vertically with the sensor facing parallel to the soil-nail as illustrated in Fig. 2 and explaining why the sensor experiences the 50% of the applied OP in which coefficient of earth pressure at rest ( $K_o$ ) is almost 0.5. However, EPC3 and 4 were installed at the mid height of the box side walls of the box in longitudinal and transverse directions respectively. Thus, both EPCs attached on the boundaries monitor the lateral earth pressure of approximately 25 kPa with a  $K_o$  equal to 0.25. In contrast, EPC1, 5 and 6 experienced approximately 115 kPa on average for the applied surcharge load of 100 kPa, which could be a result from the inclusion effects [15]. EPC1 was installed 50 mm below the soil-nail and EPC5 and EPC6 were installed above the soil-nail – at distances equal to 50 and 100 mm, respectively.

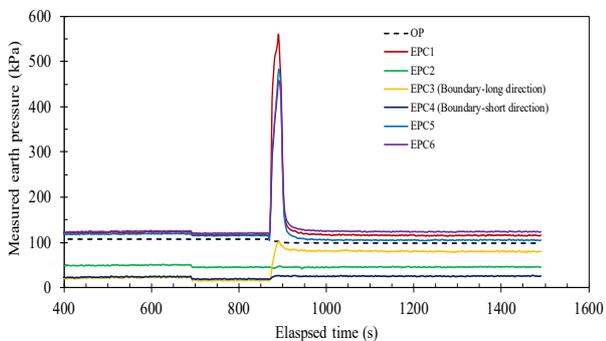
Induced soil pressures on the EPCs during the volume-controlled pressure grouting process are illustrated in Fig. 5. From Figure 5, it is seen that the increment of earth pressure reading around the grout-bulb differs due to the position of the EPCs relative to the soil-nail. In this experiment, grout injection was controlled by flow rate instead of by fixed pressure as investigated by Wang et al. [11] and therefore injection pressure of grout increases gradually with the injecting grout volume and then reaches the ultimate grout injection whenever the injection of grout stops completely (Fig. 6). For the ultimate injection pressure, EPC1, 5 and 6 experienced maximum induced pressure of approximately 560, 480 and 460 kPa respectively and this type of behaviour was also reported by Wang et al. [11]. Other than EPC3, the measured pressures on the remaining EPCs were

unchanged over the grouting process. The induced earth pressure on EPC3 increased from 25 kPa to 100 kPa during the grouting process, which might result from the injected grout compacting the soil in the transverse direction. At the end of the grouting process, the induced soil pressure on the cells (EPC1, 5 and 6) decreased sharply to an approximate value of 100 kPa, which may be a result from consolidation and shrinkage of the injected cement grout.

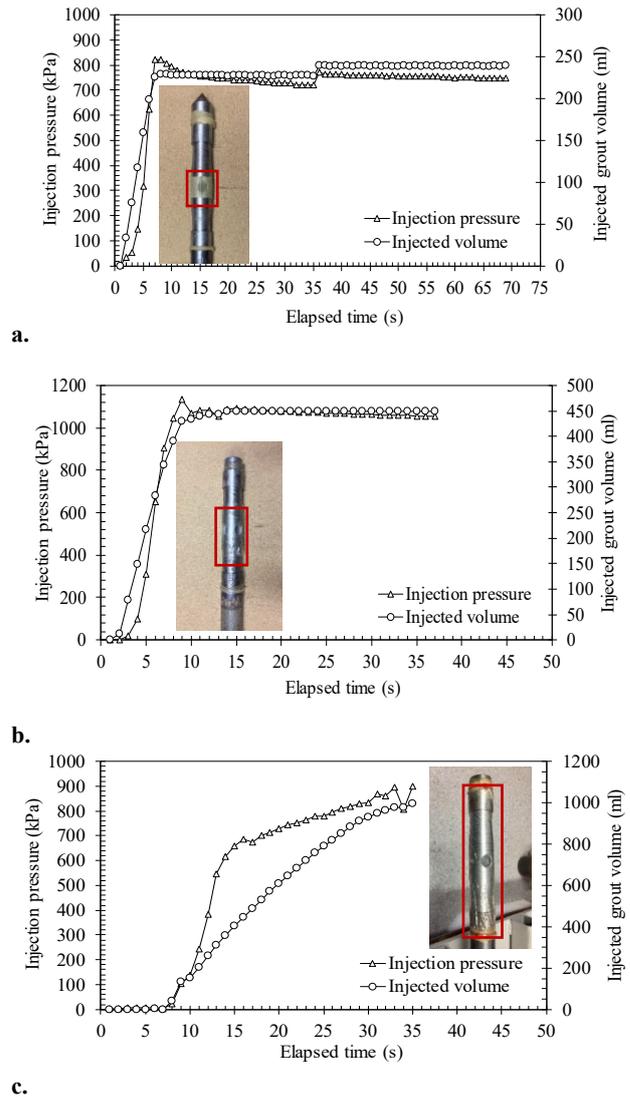
Fig. 6 demonstrates the variation of injection pressure and injected grout volume against time for three tests, e.g. T1, T2 and T3. Fig. 6a demonstrates that ultimate injection pressure reaches to approximately 800 kPa within approximately 7 seconds of the grout injection. This behaviour actually is due to the clogging of the grouting outlet that was embedded into the moist sand. The inserted photograph in Fig. 6a shows the installation of the embedded soil-nail with a covering at the outlet points using a latex membrane (thickness of 0.3 mm) of 50 mm in length as illustrated by a red rectangle. The main purpose for using the small portion of membrane around the outlet points was to protect the outlets from being filled up by the compacted sand around it. Fig. 7a illustrates the excavated soil-nail with small amount of solid grout around the outlet. It is quite interesting to observe that the propagation of the grout in longitudinal direction is almost equivalent to the length of the latex membrane.



**Fig. 4.** Earth pressures around the soil-nail measured by the EPCs for T3.



**Fig. 5.** Measured earth pressure during grouting process for T3.



**Fig. 6.** Variations of injection pressure and injected grout volume for: (a) T1, (b) T2 and (c) T3.

By inspecting the injected grout bulb around the outlet, it could be said that whenever the grout encounters the sand (relatively dry,  $S_r = 10\%$ ), the grout stops without any further propagation and might be a result of the bonding between the grout and relatively dry sand. Gafar et al. [16] reported that the pressurised grout forms a plaster (a thick layer) with the sand by filling the void spaces in the soil matrix at low injection rate and it prevents further penetration of the grout into sand. Hence, the created plaster might take the injection pressure fully or partially and may be the reason of increment of the injection pressure instantaneously as found in Fig. 6a. In addition, in this case, initially the grout was allowed to flow into the soil-nail by gravity through the plastic grout tube connected between the soil-nail and the grout cylinder of the grout injection pump and then the pump was turned on to provide constant flow rate of 2 l/min. Therefore, it is also suspected that friction resistance of the grout on the wall of the injection tube might have influence over the injected grout volume for the volume-controlled injection system since grout is highly viscous suspension and behaves as Bingham fluid.

In the case of second test (T2), a thinner latex membrane (thickness of 0.06 mm) was selected to minimize the membrane liner effects on the surrounding soil. The outlet holes was covered with a membrane of 100 mm in length as demonstrated in Fig. 6b with a red rectangle. Based on the findings from first test (T1), a higher injection rate of 4 l/min was used in this test to inject more grout in a specified time period since a slower injection rate appears to allow enough time to develop the plaster [16]. Fig. 6b shows the ultimate injection pressure is about 1100 kPa for the specified injection rate and the injected grout volume is relatively higher than T1 - approximately 445ml (~ 0.4 Litre). To minimize the frictional resistance of grout along the injection tube, the grout was injected with the specified flow rate from the grout cylinder without allowing any gravity flow of grout into the injection as done for the T1. Fig. 7b illustrates the propagated grout volume and shape into the sand for this specified injection technique. From the Figure, it is determined that the propagation grout in longitudinal direction is almost the same as the length of the latex membrane. The results indicate the same behaviour as found for the T1 and the reason has been described in the previous paragraph.

Fig. 6c outlines injected grout volume and the corresponding pressure distribution for the T3 in which the thinnest membrane was tied to the soil-nail head at 200 mm apart to form a grout bag. The injection rate for this test was 3 l/min and the grout was injected like as the procedure followed for the T2. Fig. 6c illustrates the gradual increase of the injected grout volume, reaching to a peak value of about 1000 ml. The injection pressure also shows the similar behaviour with a sudden drop from ultimate injection pressure of 900 kPa. The drop in the pressure may be a result of breakage of the thin membrane in longitudinal direction at the locations where it was tied with the soil-nail head. The rupture of the membrane at the end of nail head was visually identified after the excavation of the grout bulb as illustrated in Fig. 7c. The injection pressure distribution plot also indicates that whenever the grout encounters the sand that the pressure immediately goes back to the ultimate pressure as found from the previous test results.



**Fig. 7.** Grout bulb under different injection rate with membrane length of (a) 50 mm, (b) 100 mm and (c) 200 mm (left to right).

Prior to the excavation and removal of the grout bulb from the compacted soil mass, a series of pullout tests was performed to identify the pullout capacity of the soil-nail

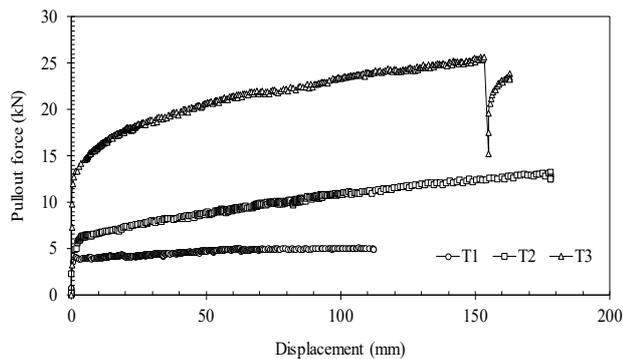
for each of the corresponding test set-up. Fig. 8 illustrates the soil-nail pullout force versus displacement for the three test combinations. It is evident that pullout forces increase with increased volume/size of the grout bulb and therefore, the pullout capacity of T3 is much higher, around 25 kN, followed by T2 and T1 with a maximum pullout force of approximately 10 and 4.5 kN respectively. The behaviour of the pullout force demonstrates that the pressure-grouted soil-nail responds as a completely frictional soil-nail although it is an anchor type soil-nail and this type of response could be the result of the passive resistance of the soil situated in front of the grout bulb. In addition, the pullout force for the T1 could be considered as the resistance of the sole steel-nail, skin friction between steel and surrounding soil, since the volume of the grout bulb is not sufficient to provide any passive resistance. Table 1 summarises the test configurations and the results.

Wang et al. [11] reported a pressure-controlled injection system for the compacted-grouted soil-nail where pressure inside the grout cylinder was increased to a specified target value to avoid blocking of the grout suspension inside the injection tube. Thus, this injection technique might provide impact/instantaneous injection of the grout suspension whereas the volume controlled provides a constant flow injection without any sudden impact of the injection process. In addition, they outlined the variation of pullout force and volume of injected grout for the corresponding injection pressure in which maximum injection pressure was 800 kPa. From their investigation, it was also found that the injected grout volume was 1400 ml for the corresponding injection pressure of 800 kPa, which is almost 40% higher than the volume-controlled injection system although the picked injection pressure is 10% higher than that system (Fig. 6c). This can happen due to the Bingham fluid characteristic of the grout suspension in which a certain pressure is required to flow the suspension. Based on these circumstances, it is can be said that the pressure-controlled injection system provides a constant pressure throughout the injection, which might initiate an instantaneous flow, resulting in more injection of grout.

By comparing the pullout forces reported by Wang et al. [11], it is found that the membrane liner may have significant effect on the pullout capacity for this type of compacted-grout soil-nail. Wang et al. [11] found a pullout force of about 23 kN for a bigger grout bulb of 1.4 litre, whereas the current preliminary study reports a pullout force of 25 kN for a comparatively small grout bulb of 1.0 litre. The effect of membrane liners can be easily visualized from the photograph as illustrated in Fig. 9. It demonstrates that the surface of the grout bulb with a thin latex membrane (thickness of 0.06 mm) is rougher than that grout bulb in which a thick latex membrane (thickness of 0.3 mm) was used. The surface of a grout bulb with a thick latex membrane can be considered as equivalent to a smooth surface where the skin friction may be insignificant. Bosscher and Ortiz [17] reported that a small increment in surface roughness greatly influences the skin friction. Hence, it could be said that the grout bulb with a thin membrane may experience the skin friction, which likely contributes to the pullout capacity.

**Table 1.** Summary of the results.

| Test no. | Membrane length (mm) | Inj. rate (l/min) | Peak pressure (kPa) | Injected volume (ml) | Pullout capacity (kN) |
|----------|----------------------|-------------------|---------------------|----------------------|-----------------------|
| T1       | 50                   | 2                 | 800                 | 228                  | 4.5                   |
| T2       | 100                  | 4                 | 1100                | 445                  | 10                    |
| T3       | 200                  | 3                 | 900                 | 1000                 | 25                    |



**Fig. 8.** Pullout force versus pullout displacement for different test series.



**Fig. 9.** Surface patterns of the grout bulb with thick (yellow colour) and thin (white colour) membrane.

## 4 Conclusions

In this study, a series of compaction grouting tests in a soil-nail system was performed by a newly developed volume-controlled grout injection system. The following major conclusions can be drawn from this preliminary study:

- The injection techniques of grouting greatly influence the volume of the injected grout used in pressure/compaction grouted soil-nail system. Hence, it ultimately influences the pullout capacity of the pressure grouted soil-nail,
- The membrane used to form grout bag acts as a liner that prevents the grout suspension to bond with the surrounding soil (i.e., plastering) and consequently, more grout can easily be injected even at low injection rate,
- The thin latex membrane can be a good alternative to the thick membrane used in the newly developed

compaction grouted soil-nail since it might has ability to provide a rougher surface to the grouted bulb.

Although the study has reported the effects of membrane liner used in a compaction grouted soil-nail, further studies are required to identify the effects of flow rates on the injection of grout directly into a soil matrix. In addition, the influence of w/c ratios of grouts on the injection volume in the pressure grouted soil-nail system will be investigated and hence the pullout strength will be evaluated. To provide better interlocking of the soil-nail with the surrounding soil mass, fracture grouting will be implied in the future experiments.

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