Effect of Variation of In Situ Moisture Content on Pullout Capacity of Grouted Soil Nail

Avishek Ghosh, Sayantan Chakraborty, and Ashish Juneja

Abstract Soil nailing has traditionally been used as a method to retain soil excavation and to stabilise soil slopes. The effectiveness of this method depends on the pullout resistance of the nail, amongst other factors. There have been instances when the shear resistance between the soil and the nail has deteriorated when the soil volume reduces or when the soil shrinks with the decrease in moisture content. This can happen during the curing period of the cement used in the grouted nails. In the present study, a number of laboratory model tests were conducted in cemented grouted nails installed within silty soils. The variation of pullout resistance with curing period of the cement grout was determined. Spatial variation of the moisture content with depth and distance away from the nail was determined after each pullout test. To support the findings, direct shear tests were performed between the cement grout and the soil at the same moisture content at which pullout tests were conducted. The results indicate a reverse behaviour of the interface friction angle due to the change in moisture content.

Keywords Cement grouting · Pullout capacity · Soil nailing

1 Introduction

Soil nailing technique has been widely used for soil excavation during the construction period of the highway, underground metro lines, widening the purpose road under existing bridge ends, stabilising the slope and reconstruction of the existing soil nailing structure, e.g. (Hong et al. 2003). The interlocking between the nail and the soil is enhanced with the use of grout (Cheng and et al. 2013). Determination of pull out force is an important parameter for designing purpose of soil nailing during earthwork. When sliding of huge soil mass occurs due to the natural or manmade cause, a critical slip surface develops which pulls out the grouted soil nails. The skin

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friction between the grouted soil nails and the surrounding soil resists that outward pull movement and correspondingly stabilises the soil mass (Schlosser 1982).

The pullout capacity of grouted nail depends upon many parameters such as the type of soil, soil–nail interface strength, installation procedure, nail geometry and method of grouting (Gurpersaud et al. 2011). The soil–nail interface strength is influenced by the moisture content of the soil surrounded by the nail. Though the infiltration of the cement grouting increases the bond between soil and nail and the hydration effect of the cement hardening can reduce the moisture content of the surrounding soil. Aytekin and Nas (1998) stated that hydrated cement fetched up to 20% of its own weight of water from the surrounding soil. Cheng-Yu et al. (2013) stated that the moisture content of soil samples decreases closer to grouted body soil when compared to the distant soil sample. So change in the moisture content in the soil is an important factor to be considered during design which will ultimately affect the final strength of the soil.

In the present study, the effect of moisture content of soil on the pullout capacity of grouted soil nail was experimented. Extensive laboratory tests were performed for this experimental study. Due to the limitation of providing proper vertical confining stress and difficulties of drilling to the horizontal face of the soil for grouted soil nail in the 1-g model test, the pullout tests were carried out on the vertically inserted soil nails. Franzen (2001) proposed that vertical pullout test is an alternative method to determine the effect of different parameters on the pullout capacity of the soil nails. A series of direct shear tests were also performed between grout cement and soil to examine the change in interface strength with curing period. It helps to predict the cement grouted soil nail behaviour with time and correspondingly determine the soil model parameters for the numerical studies.

2 Experimental Setup for Pullout Test

2.1 Soil Property

Fine grained soil was used in the tests. The soil property is given below (Table 1) (IS 2720(IV) 1985).

2.2 Pullout Procedure

The tank dimension was 690 mm × 340 mm × 555 mm. Soil bed was prepared at optimum moisture content. The soil was compacted in layers up to a height of 450 mm. A hammer of 0.025 kN was used for compaction and each layer was compacted 30 times.

Table 1 Characteristics of tested soils

Parameters	Powai soil
Moisture content (OMC)	18%
Degree of saturation (OMC)	90.47%
Liquid limit	50.2%
Plastic limit	33.4%
Shrinkage limit	15.5%
Cohesion (kN/m^2)	22
Angle of internal friction(Φ)	27°
Sand	44%
Silt	38%
Clay	18%

After preparing the soil bed, a borehole of 60 mm in diameter and 300 mm in height was prepared. The grout with a w/c ratio of 0.45 was then poured into the hole at a constant rate and allowed to settle for about 5–10 min. Nail of 280 mm length and 16 mm diameter was then pushed into the grouting cement. With this arrangement, nails were installed in the vertical direction. This is not the usual orientation at which the nails are installed in the field, wherein the inclination is only 10–20° to the horizontal. Since the overburden was small, the nail orientation was unlikely to significantly affect its pullout capacity. This was the case as the pullout capacity was investigated only due to the effect of moisture changes. This arrangement also enabled the use of the existing setup without any significant changes.

Dial gauges were then installed to measure the displacement of the nail. To minimise the influence of the front wall, the front wall was lubricated by glycerin (Palmeira and Milligan 1989). Three nails at a distance of 225 mm and 175 mm from each were inserted and pullout tests were carried out after 7, 14 and 21 days (see Fig. 1). According to Nicholson (1986), the nail spacing should be around 6–10 times its diameter. In this experiment, the spacing was kept above 10 times its diameter, as the diameter of the nail was 16 mm. The nail head was firmly connected to a load cell of 50 kN capacity during the time of tests. Figure 2 shows the complete setup of the experimental setup.

3 Results

Total 2 sets of pullout tests were done at 7, 14 and 21 days. The first pullout was done on the middle nail after 7 days and then following the other two nails were done at 14 and 21 days. Stress-controlled pullout test was performed using a hydraulic jack.

To measure the change in moisture content due to cement grouting, the soil from the surrounding grouting and at a radial distance of 45, 60 and 90 mm from the centre

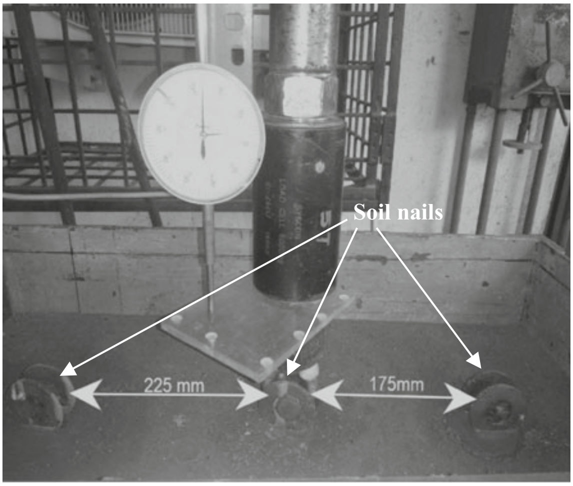


Fig. 1 Nail setup

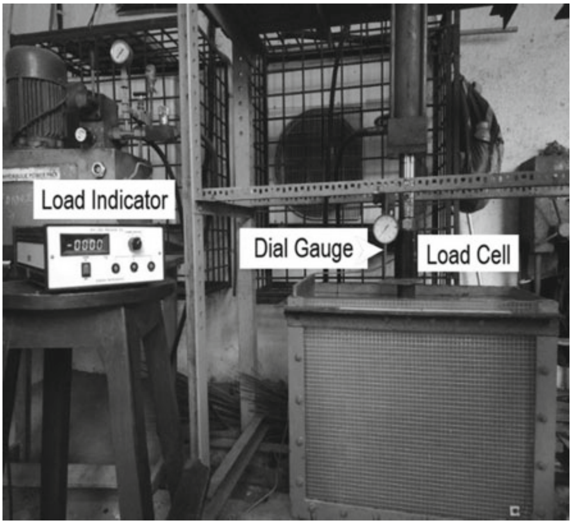


Fig. 2 Complete setup

of the grouted nail were taken. The moisture content measurement zone is presented in Fig. 3.

Figure 4 shows the vertical pullout test results after 7, 14 and 21 days. The peak pullout force after 7 days was approximately 5.8 kN whereas it was decreased to 2.5–2.7 kN after 14 days and 2.05–2.3 kN after 21 days.

It can be seen that the pullout strength decreased significantly between 7 and 14 days but became almost constant after 14 days. The test results showed almost repeatable behaviour in both trials. In those tests, moisture content was the only parameter which varies with time due to evaporation. This evaporation can be

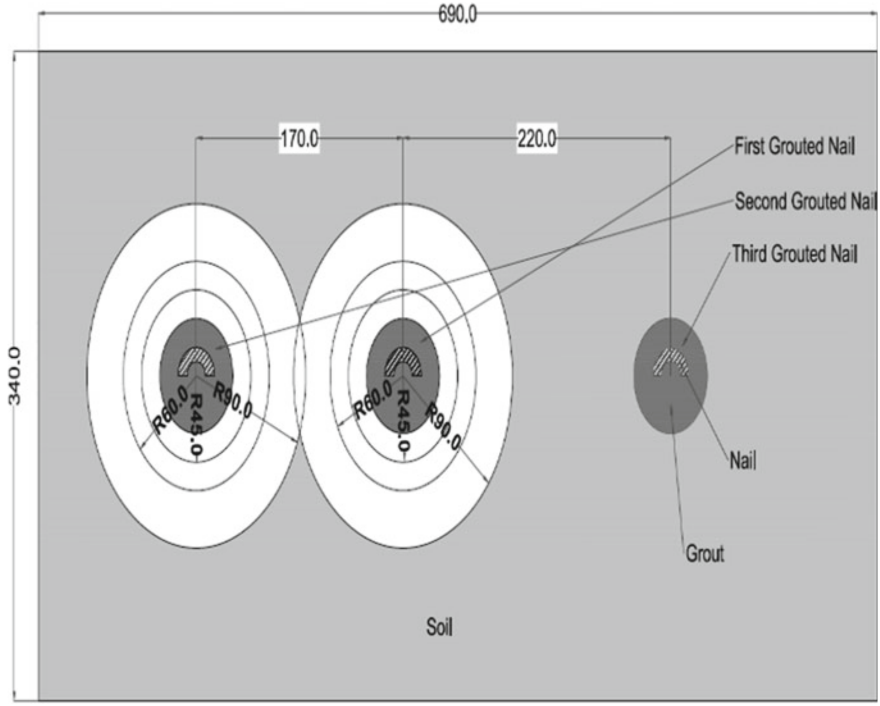
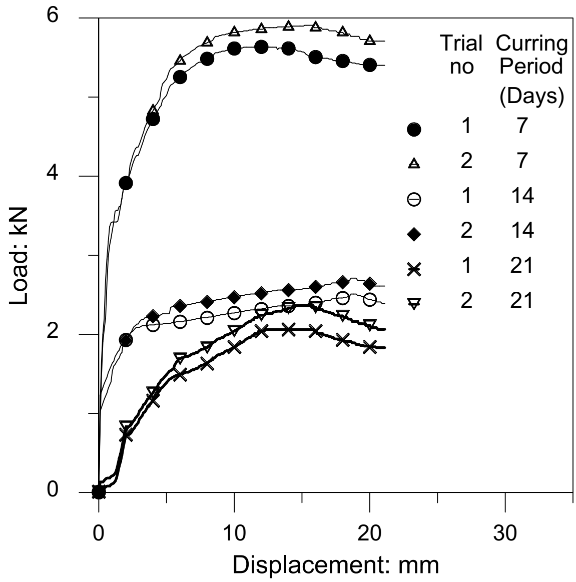


Fig. 3 Moisture content measurement zone (top view) (all dims. are in mm)

Fig. 4 Pullout test results of soil nails after different curing periods



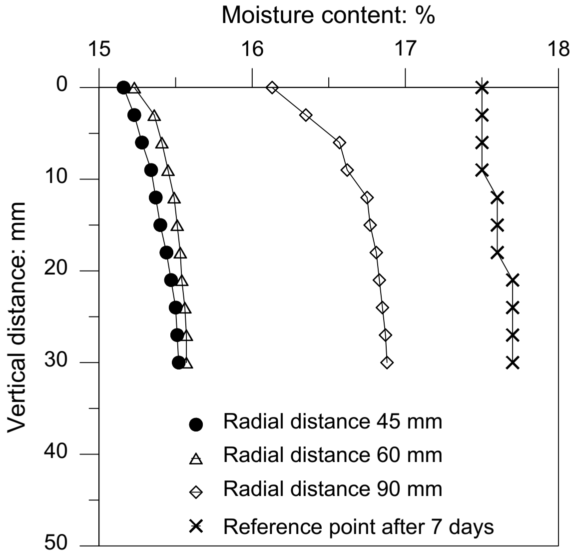


Fig. 5 Moisture content in between 1st and 2nd nail after 7 days

happened due to temperature variation in the atmosphere and temperature variation due to curing of the grouted cement. So an experimental study was carried on to check the variation in the moisture content of the soil with time. Then those results were compared with the pull out strengths to derive the reason behind the decrease in strength. In the experiments, the soil nails, which were pulled out after 7 and 14 days, were pushed back again into the soil to observe the moisture content variation along those nails up to 21 days.

Figures 5, 6, 7, 8, 9 and 10 show the change in moisture content between 1st and 2nd nail and 2nd and 3rd nail after 7, 14 and 21 days. The moisture content was measured up to a depth of 30 mm using a spiral screw of 40 mm length. Moisture content was measured only in the top 30 mm of the soil so as to not to disturb the structure and cause the soil to flow around the remaining nails.

As there is evaporation happening due to atmospheric temperature, a polyethene sheet was used to cover the soil from the above. Still, there was evaporation. So a reference point on the soil was chosen which is far away from the soil nails. The moisture content variation on that point was considered only due to evaporation by atmospheric temperature. When the moisture content variations near the soil nails were compared with the reference point results, it will give a clear idea about the effect of curing of cement grout on the moisture content of the soil.

Figures 5, 6, 7, 8, 9 and 10 show that moisture content reduction is more near to the soil nails up to a radial distance of 60 mm and beyond that this reduction decreases with the radial distance from the nails. If the moisture content near the soil nails is compared with the moisture content at a reference point, a significant variation can be observed. It implies the effect of curing period on the moisture content of the surrounding soils of the soil nails. This reduction in the moisture content of the soil

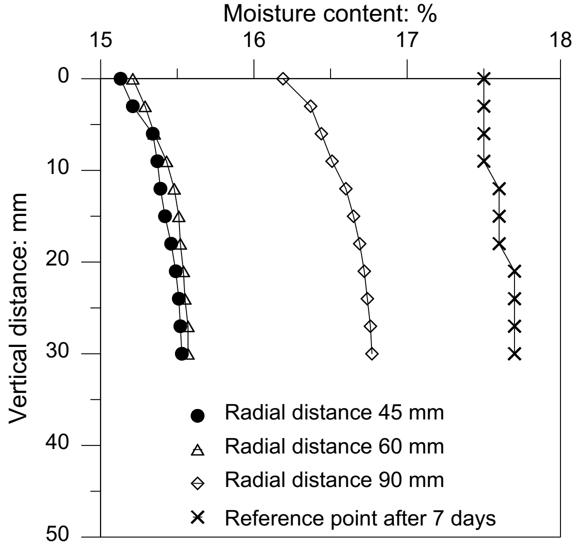


Fig. 6 Moisture content in between 2nd and 3rd nail after 7 days

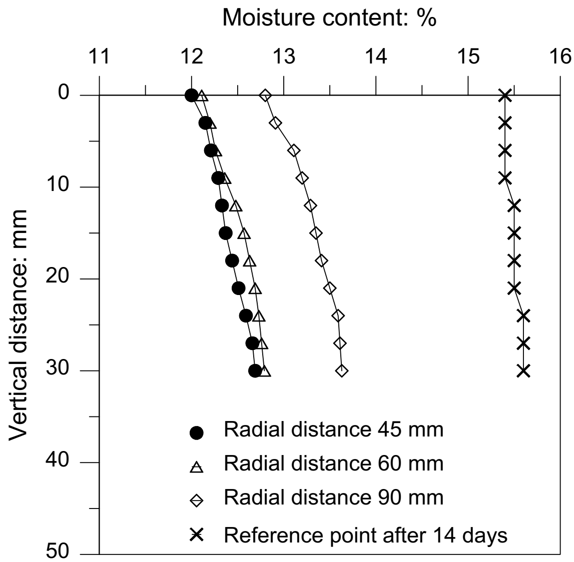


Fig. 7 Moisture content in between 2nd and 3rd nail after 14 days

sample may be responsible for shrinkage of the soils near the soil–nail interface. So a gap created between soil and nail was the reason for the reduction in pullout strength with time.

It can also be seen from the figures that the moisture content near the soil nails reduced below the shrinkage limit after 14 days. Therefore, the variation in the pullout strength after 14 days becomes almost constant as shown in Fig. 4. Figure 11 shows

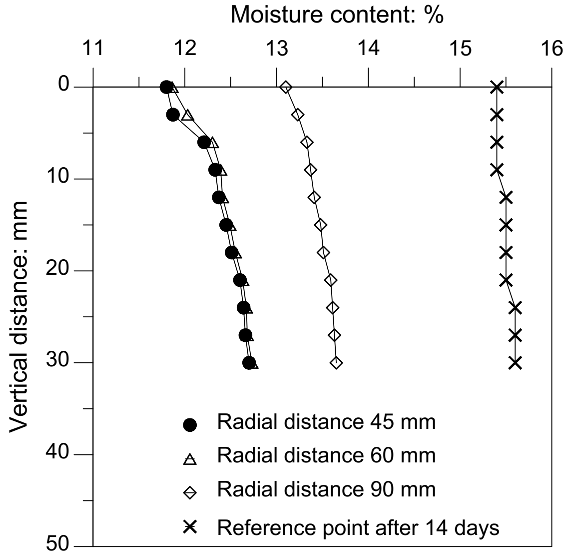


Fig. 8 Moisture content in between 2nd and 1st nail after 14 days

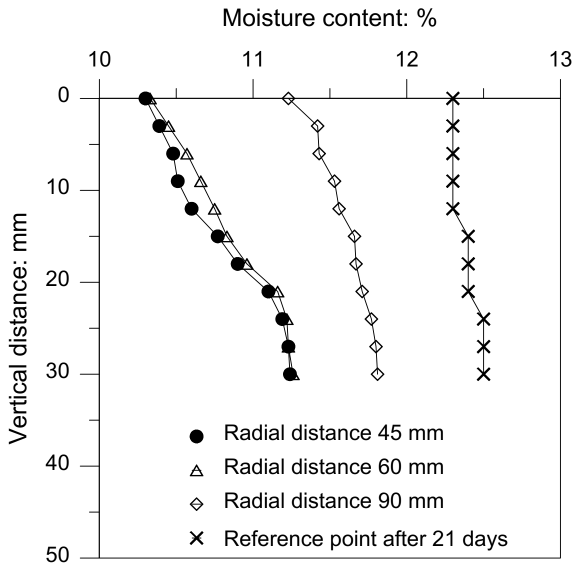


Fig. 9 Moisture content in between 2nd and 1st nail after 21 days

the average moisture content variation with time. It can be seen that the average value of the moisture content of the soil reduces almost linearly up to 21 days.

Fig. 10 Moisture content in between 3rd and 2nd nail after 21 days

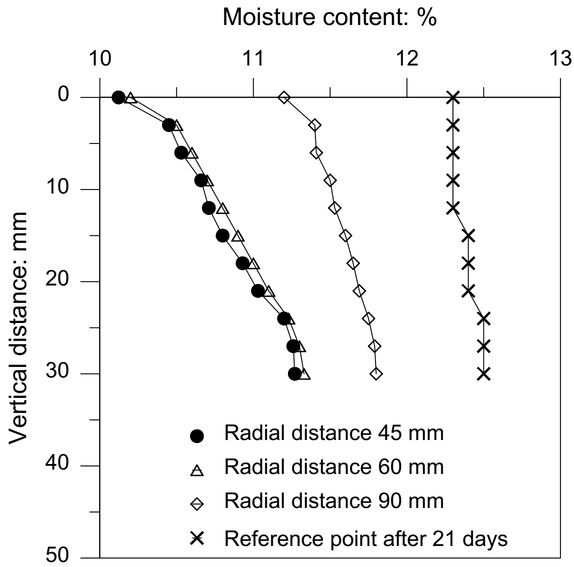
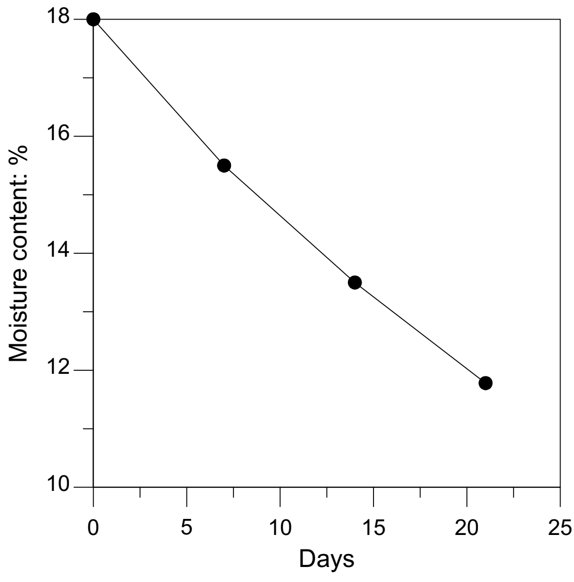


Fig. 11 Average variation of moisture content after 7, 14 and 21 days



4 Skin Friction Between Soil and Grouting Materials

In the present experiment of vertical pullout tests, the results showed that the pullout capacity of grouted nails reduced with time. The reduction of pullout capacity may be attributed due to the reduction of skin resistance between soil and grouting material.

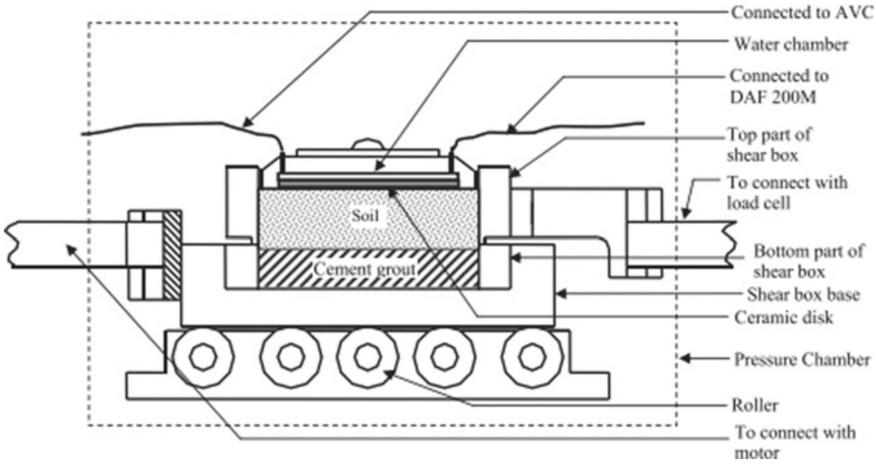


Fig. 12 Direct shear test setup (from Hossain and Yin 2014)

To determine the effect of moisture content reduction on the skin resistance between grout and soil, a series of direct shear tests on the same soil and grout were performed. The method of preparing the soil sample had to be representative and the same water–cement ratio was employed during the nailing tests.

Following ASTM D5321, (ASTM D5321/D5321M 2014) the soil–cement interface skin friction angle and adhesion between the soil–cement were determined under various normal stresses. After the grouting mixture was prepared at the bottom layer of the direct shear box, the top layer of the box had been filled up with soil. A total number of nine samples were prepared and sets of three samples were taken. The first set was kept for 7 days curing and other two were kept for 14 and 21 days, respectively. The strain rate was kept at 1.2 mm/min throughout the test. After the tests were done, the moisture content of the soils was measured. Though the interface thickness between soil–cement can't be completely identified for moisture content measurement (Hossain and Yin 2014), the moisture content of the soil was taken 2 mm distance from the soil grout interface.

The soil–cement was sheared in the direct shear box of 72,000 mm^3. The arrangement of the setup is shown in Fig. 12. The soil was also shared at the optimum moisture content of 18%. The top surface of cement paste had kept rough to simulate the result similar to the pullout test.

5 Skin Friction Results

The moisture contents were found around 16, 13 and 11% after 7, 14 and 21 days at the interface, which was almost same when the moisture content was measured at the interface after the vertical pullout tests were done. Figure 12 shows the direct shear test results of soil–cement interface for different curing periods and those were compared with test result performed only on the soil. To perform the direct shear test on the soil only, soil was compacted at OMC value of 18% and tested immediately after preparation. It can be seen that soil–cement interface strength is less than soil shear strength after 7 days of curing but it is more after 14 days of curing. It can also be seen from the figure that the soil–cement interface strength increases with curing period which is an opposite phenomenon compared to the pullout tests of the soil nails. Two possible reasons could be there. First of all, it was not known the thickness of the soil cement interface in the cement grouted soil nails. In the direct shear tests, the interface strength was measured exactly at the soil–cement joint which may be few grains thick in the actual case. The soil grains exactly in contact with cement can change their fabric orientation and can go for higher strength. Also reduction in the moisture content with curing period may also be the reason behind that. The second reason is that the normal stress upon the soil restricts the soil particles to lose its contact with cement after shrinkage due to a reduction in water content. Another observation can be drawn from Fig. 13 that the variation in the shear strength is minimal after 14 and 21 days of curing though there is a reduction in 2% of moisture content. It may be due to the reduction in moisture content reaches a value less than shrinkage limit of the soil after 14 days of curing. So fabric orientation due to change in moisture content after 14 days would be minimum and corresponding change in strength is also insignificant. The adhesion and skin friction values determined from direct shear test results are listed in Table 2.

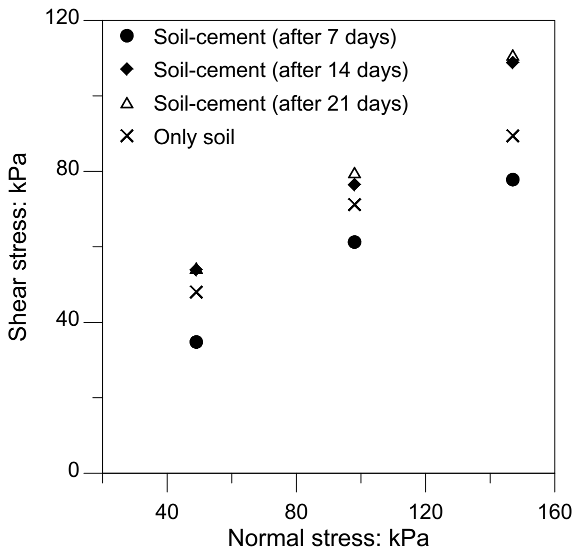


Fig. 13 Shear strength variation of the soil–cement interface with curing period compared with only soil

Table 2 Skin friction test results

Curing period (day)	M/C (%)	Adhesion c_a (kN/m^2)	Skin friction angle, δ
7	16	14.9	24°
14	13	24.8	29°
21	11	25.2	30°
Only soil	18	28.1	23°

6 Conclusions

This paper discussed the effect of the heat generated during curing of the cement grouted soil nails on the moisture content of the surrounding soils and the corresponding effect on the pullout strength. A significant reduction in moisture content was observed within a radial distance of the 4 times the diameter of the soil nails with curing period. This reduction became minimal beyond that distance. In vertical pullout tests, the strength was reduced with time. This was due to loosening of the contact between the soil and nail as the soil shrank with a reduction in moisture content. This reduction in strength became minimal after 14 days of curing as the moisture content reduced below the shrinkage limit of the soil. So there would be no further gap created between soil and nails. Therefore, it can be concluded that the pullout strength after 14 days could be considered for the design purpose. On the contrary, the direct shear test results showed an increase in the soil–cement interface strength with the curing period. This may be due to the unknown of the thickness of the soil–cement interface on the soil nails above which interface friction has to be considered. Another reason is the normal stress upon the soil in the direct shear test which restricts the creation of the gap between the soil and cement due to reduction in the moisture content. A thorough study can be possible to carry out in the future on those aspects. It was also observed that the increment of the interface strength with time was minimum after 14 days of curing period as the moisture content reduced below the shrinkage limit of the soil.

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