A Study on Pullout Behavior of Reinforcement Due to Variation of Water Content of Soil

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ABSTRACT

Pullout behavior is one of the major phenomena towards the effective design of many agricultural and civil engineering structures such as reinforced-soil, slopes and embankments. It is known that the success of reinforced soil structures depends not only on the types of reinforcements and backfill materials but also on the water content of the soil. In view of this objective, the effect of water content on pullout behavior is carried out by performing a series of pullout tests under varying water content of soil. A comparative study of four water contents of soil, two of which are on the dry-side of optimum and another two are on wet-side of optimum with four normal stress conditions is demonstrated. Based on the analyses of the experimental data, the pullout strength of reinforcement due to the variation of water content of soil is examined. It is concluded that the pullout strength of reinforcement decreased with the increase in the amount of the water content of soil under any normal stress conditions. The paper reports the pullout behavior in the form of stress-displacement relationships those are given in various charts and diagrams as a ready reference to aid in the practical design and constructions of reinforced earth structures.

Keywords: Pullout behavior, water content, geogrid mesh, clayey backfill

1. INTRODUCTION

One of the major factors that control the performance of reinforced soil structures is the water content of soil. With the change of season, the substantial amount of water in soil varies throughout the year all over the world. It is, therefore, necessary to investigate the effect of water content on pullout strength of reinforcement in order to safe design of reinforced soil structures during construction and on service. Literature review evidently indicated that among various types of soil reinforcing materials, the geogrid mesh is most commonly used material not only in Japan but also in the globe because of its ease of availability in the local market, cost-effectiveness, durability and handling facilities.

Concerning the design of reinforced earth structures, researchers have extensively used pullout tests to evaluate interface interactions (Jewell, 1996). Madhav, Gurung and Iwao (1998), Gurung and Iwao (1999) illustrated the general applicability of bilinear shear stress-displacement model for soil reinforcement interaction during pullout tests with extensible and inextensible geo-reinforcements. Lawers (1991) and Murata (1992) have studied the geotextiles/cohesionless soil interfaces and have adopted a suitable test method to simulate field conditions. A soil-geosynthetic reinforcement interface model based on rigid plastic shear stress mobilization has been reported by Sobhi and Wu (1996) for extensible reinforcement (geotextiles). Mahmood, Zakaria and Ahmad (2002) have studied geotextiles/soil interface shear behavior with two types of soils namely sandy soil and organic clay.

The success of reinforced soil structures depends not only on the type of reinforcement and backfill materials but also on the water content of soil. The water content that plays a vital role towards the safe design and considerable versatility in the development of reinforced soil structures has not been given considerable attention yet in the evaluation of soil reinforcement interaction. Also, no attempt has so far been made in the technical literature to study the effect of water content of soil on pullout strength of reinforcement. This investigation is, therefore, aimed at generating information on the overall response of water content on the pullout strength of reinforcement embedded in soil. A series of pullout tests with four stages of water content such as 6.57, 16.45, 25.31 and 32.54% where optimum water content (W_{opt}) of soil is 20.50% (Figure 1) under variable normal stresses are performed in order to find out the effect of water content on pullout strength of reinforcement embedded in soil. Test results in the form of pullout stress-displacement relationships which is the measure of pullout behavior are demonstrated and the performance of the pullout strength of reinforcement with variation of water content of soil is depicted.

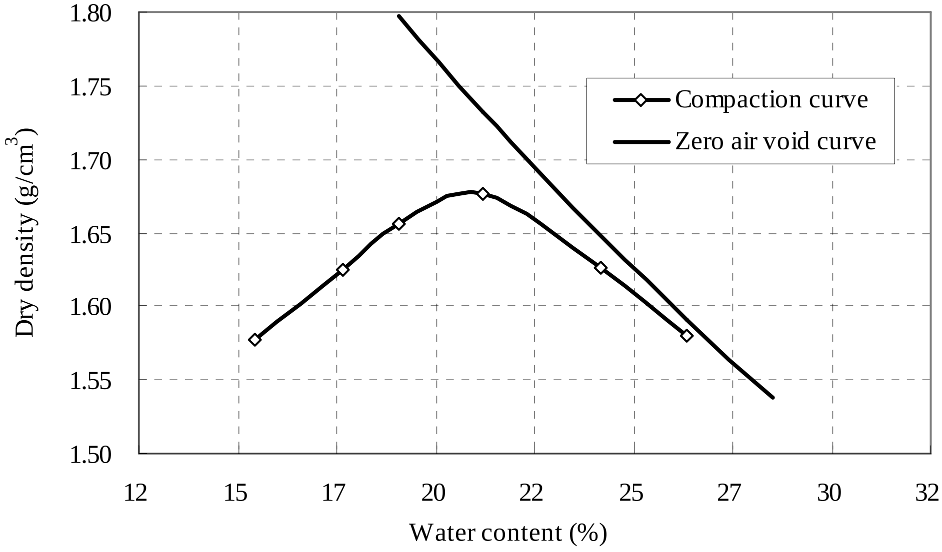

Figure 1. Compaction curves of soil

2. MATERIALS AND METHODS

2.1 Soil Properties

The particle size distribution curve given in Figure 2 revealed that 34% is sand, 33% is silt and 33% is clay. Liquid limit, plastic limit and the plasticity index of the soil are 56.2, 29.3 and 26.9% respectively. The average specific gravity of the soil is calculated as 2.701. The other properties of the soil used in these tests are given in Table 1.

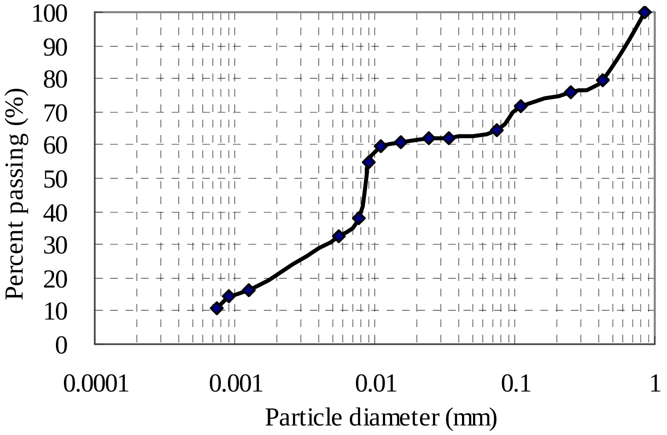

Figure 2. Particle size distribution curve of soil

Table 1. Properties of soil

Parameters	Properties
Max dry density (ρ_d), g.cm^{-3}	1.68
Optimum water content (W_{opt}), %	20.50
Specific gravity (ρ_s)	2.701
Cohesion (c), kPa	157.40
Angle of internal friction (ϕ),^{o}	32.80
Sand, >75μm, %	34.00
Silt, 5-75μm, %	33.00
Clay, <5μm, %	33.00
Liquid limit, %	61.00
Plastic limit, %	27.80
Plasticity index	33.20

2.2 Properties of Reinforcement (geogrid)

The physical appearance of reinforcement (geogrid) obtained commercially is manufactured from polyester yarns (Figure 3). It is locally nomenclature as fortrac mesh. The junctions of this geogrid are directly connected and greatly improved by interweaving the yarns and then it is coated with a protective sheathing. The strength of the junctions is adequate to transmit the envisaged loadings. The cross-section of geogrid strand is 2×6 mm in longitudinal direction and 1.0 mm filament diameter in transverse direction with center to center (c/c) openings of 24.0 mm in longitudinal direction and 20.0 mm in transverse direction. This geogrid is commercially nomenclature as Type 150/30-20 which has a tensile strength of 150 kN/m in the longitudinal direction and 30 kN/m in the transverse direction.

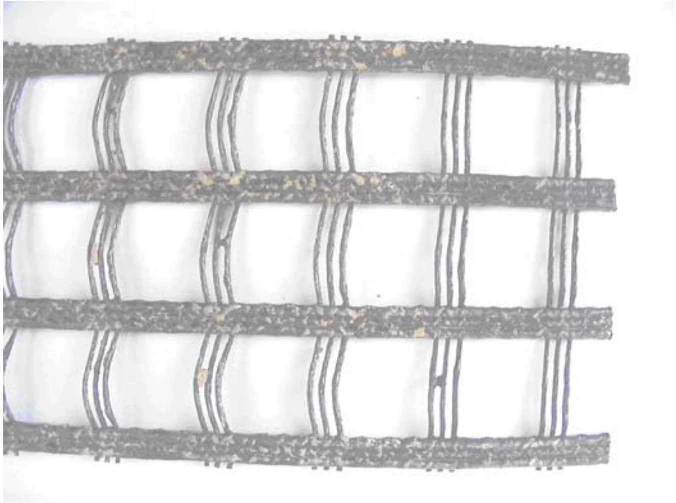

Figure 3. Physical appearance of the geogrid mesh

2.3 Pullout Apparatus

The pullout box is a rectangular shape of size 150 mm in length, 100 mm in width and 100 mm in height. The box is divided into two parts namely lower box and upper box both are 50 mm in depth. For convenience of the readers, the important components of the testing equipment (Figure 4**)** are numbered numerically starting from top-left to right-down in the increasing way such as, the number from [1] to [12], where the number [1] is the pullout stress monitoring display, [2] is the supporting plate of reaction of the applied normal stress, [3] is the upper part of the pullout box, [4] is the electrically operated pullout jack, [5] is the pullout stress measuring device, [6] is the reinforcement clamping jack, [7] is the test reinforcement, [8] is the clearance adjusting screw and fixing system of the upper box, [9] is the lower part of the pullout box, [10] is the horizontal displacement measuring dial gauge, [11] is the vertical displacement measuring dial gauge and [12] is the applied normal stress measuring dial gauge.

2.4 Setup and Procedure

At first, the required amount of soil with desired water content were poured into the lower part of the pullout box (No.9, Figure 4) and compacted uniformly by means of a compactor made of same width as of the pullout box. The lower box was filled completely and the surface of the soil was leveled precisely. The mesh of same width was laid on the soil of lower box and fastened with clamping jack as shown in No. 6 of Figure 4. The upper part of the pullout box (No.3) was placed on the mesh (No.7), and required clearance between the mesh and upper box was set by means of adjusting screw by No.8. In the second stage, the soil was gradually spread over the mesh inside the upper box and compacted uniformly to pour the soil into the mesh. The tests were carried out in the way of pulling out the mesh from the soil with constant speed of 1.0 mm/min by means of screw jack (No.4) under electrically operated constant pressure. The pullout force was measured using a tension load cell (No.5) with a least count of 5.0 N. The load cell was set between the mesh and the jack to facilitate direct load measurement on the cell avoiding any frictional discrepancy of the machine components. The displacements were measured at the front of the mesh by means of a dial gage (No.10) with least count of 0.001 mm. The vertical displacement and applied normal loads were measured by the dial gages as shown in Figure by Nos. 11 and 12, respectively.

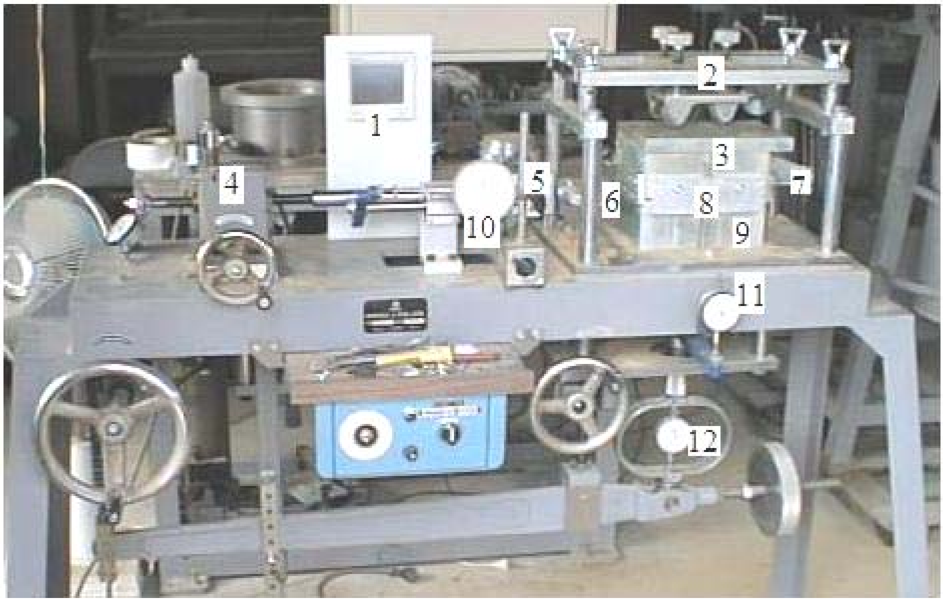

Figure 4. Pullout testing equipment and its components

3. RESULTS AND DISCUSSION

3.1 Pullout Stress-displacement Relationships for 6.57% Water Content

The relationships between the pulling stress and the displacement of mesh under normal stress of 48, 96, 144 and 192 kPa with water content of 6.57% are given in Figure 5. It is noted that the pullout stress increased with the increase in displacement of about 7.0 to 10.0 mm for all normal stress condition. After that, the pullout stress decreased with the increase in displacement of about 30.0 mm. It is also observed that the difference of the pullout stresses under different normal loading conditions were comparatively smaller at the initial loading till attaining the peak value as compared to the difference of the pullout stresses obtained at the final loading condition after peak value. It is evident that the pullout stresses decreased after attaining the peak value for all the cases. As expected, for all the test results, the pullout resistance is more for higher normal stress. The ultimate pullout strengths for 6.57% water content of soil are calculated as 253.35, 272.01, 300.96, 372.29 kPa for normal stress of 48.0, 96.0, 144.0 and 192.0 kPa, respectively. It is observed that occurrence of vertical displacements is almost zero after approximately 10 to 20 minutes of the application of normal stresses as shown in Figure 6. Therefore, the pullout tests are started after 20 minutes of the application of normal stress, i.e. when consolidation became smaller. Given in Table 2, the amounts of consolidation i.e. vertical displacements for the soil containing 6.57% water content is found as 3.33, 4.45, 5.03 and 6.08 mm for normal stress of 48.0, 96.0, 144.0 and 192.0 kPa, respectively. The dilatancy behaviors shown in Figure 7 indicated that there are positive and negative vertical displacements at lower normal stresses whereas only positive displacement occurred under higher normal stresses. Negative vertical displacement indicates the increase in volume and positive vertical displacement indicates the decrease in volume.

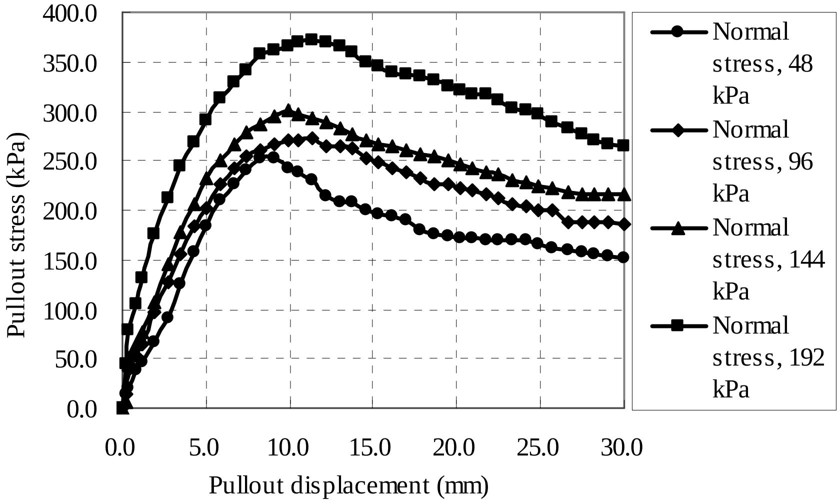

Figure 5. Pullout stress-displacement curve with 6.57% water content

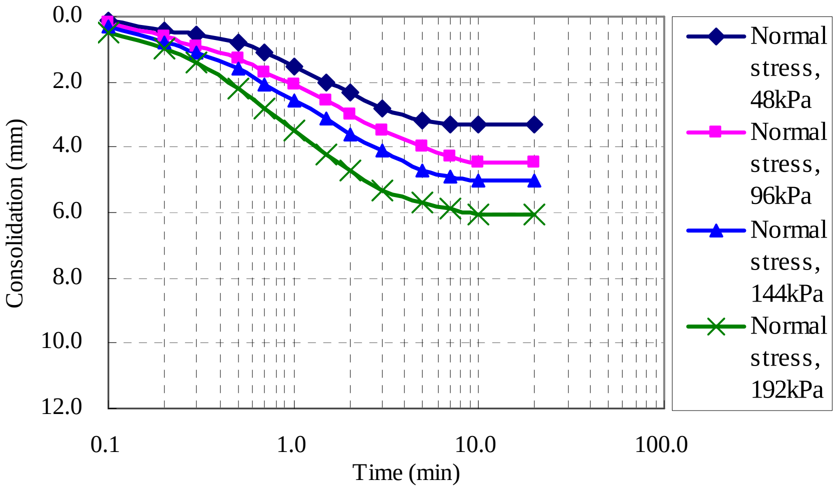

Figure 6. Consolidation vs. time relationships for 6.57% water content

Table 2. Amount of consolidation for 6.57% water content

Parameters	Values			
Normal stress (kPa)	48.00	96.00	144.00	192.00
Total initial height of soil (mm)	100.00	100.00	100.00	100.00
Amount of consolidation (mm)	3.33	4.45	5.03	6.08
Height of soil after consolidation (mm)	96.68	95.55	94.98	93.93

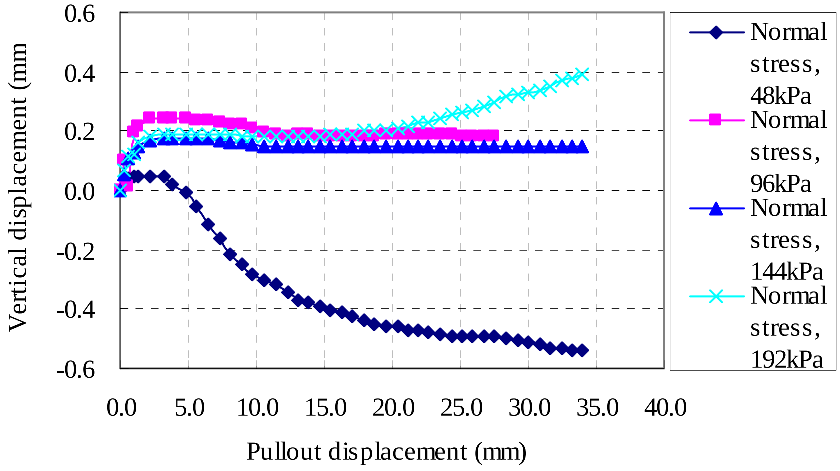

Figure 7. Dilatancy behavior for 6.57% water content

3.2 Pullout Stress-displacement Relationships for 16.45% Water Content

A typical stress-displacement relationship of the pullout tests for 16.45% water content of the test soil is depicted in Figure 8. An inspection of the plotted results of the stress-displacement relationships indicated that they were, in general, apparently curvilinear characteristics. Different from the curves of 6.57% water content as given in Figure 5; the curves do not show any clear peak values for all the cases. The decreasing trend started after the pullout displacement of nearly 20.0 mm showing the effect of water content of soil on the pullout behavior. Similar to the previous case, ultimate pullout strengths for 16.45% water content were recorded as 200.00, 228.00, 251.48 and 293.96 kPa corresponding to normal stresses of 48.0, 96.0, 144.0 and 192.0 kPa, respectively.

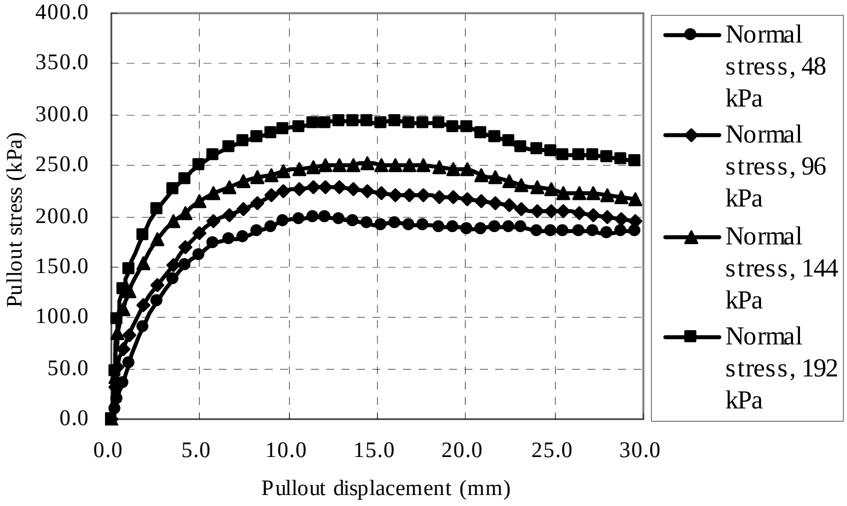

Figure 8. Pullout stress-displacement curve with 16.45% water content

The consolidation behavior after the application of normal stresses given in Figure 9 showed that the soil with 16.45% water content possesses higher consolidation than that of the soil with water content of 6.57%. After 20 minutes, the amounts of consolidation in this case are recorded as 4.40, 5.60, 6.30 and 7.40 mm, respectively, for normal stress of 48.0, 96.0, 144.0 and 192.0 kPa (Table 3). Similar to the previous cases, 16.45% water content has negative vertical displacement (increase in volume) under lower normal stress and positive vertical displacement (decrease in volume) under higher normal stresses as can be seen from the dilatancy behavior given in Figure 10.

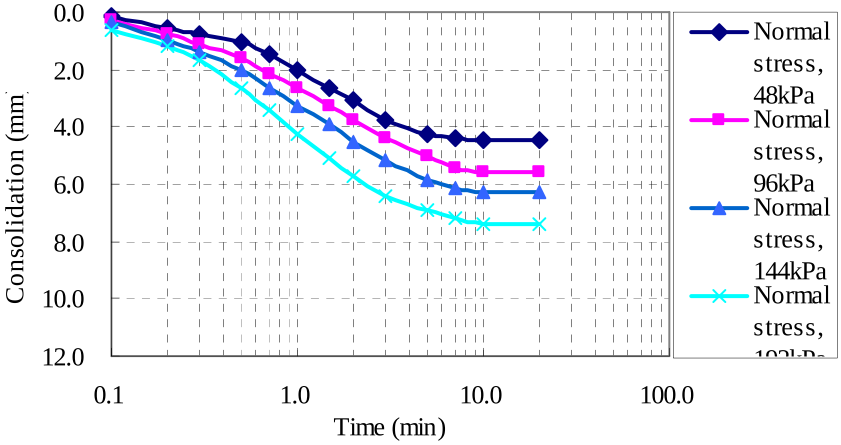

Figure 9. Consolidation vs. time relationships for 16.45% water content

Table 3. Amount of consolidation for 16.45% water content

Parameters	Values			
Normal stress (kPa)	48.00	96.00	144.00	192.00
Total initial height of soil (mm)	100.00	100.00	100.00	100.00
Amount of consolidation (mm)	4.40	5.60	6.30	7.40
Height of soil after consolidation (mm)	95.60	94.40	93.70	92.60

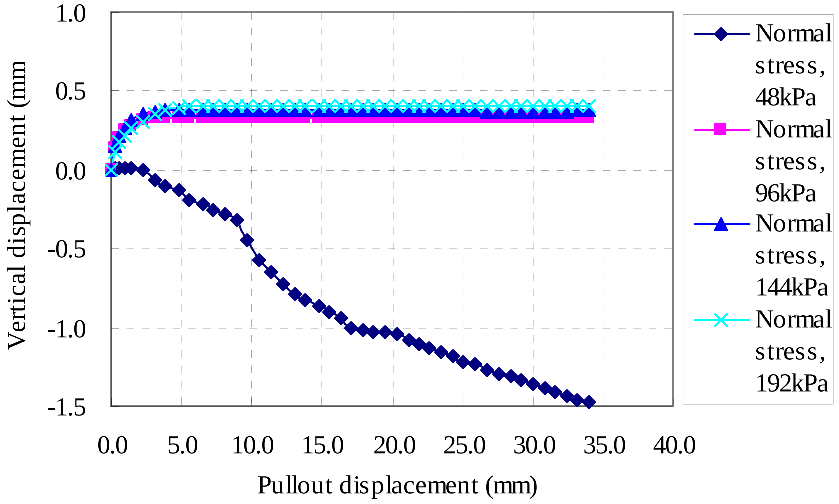

Figure 10. Dilatancy behavior for 16.45% water content

3.3 Pullout Stress-displacement Relationships for 25.31% Water Content

Figure 11 depicts the stress-displacement relationships of pullout tests with water content of 25.31%. All the four graphs belong to the same characteristic curves having the peak values at about 10.0 mm displacement and after that, all the curves showed their decreasing trend with the increase in displacement of up to 30.0 mm. For 25.31% water content, upon attaining the peak load, the decreasing trend of the pullout stresses with the increase in pullout displacement was more as compared to 16.54% as shown in Figure 8. It was also observed that the range of the pullout displacement at which the ultimate pullout stress occurred was more (nearly 10.0 to 20.0 mm) for the case of 16.54% water content than that for the case of 25.31% water content (nearly 8.0 to 12.0 mm). On the other hand, compared to 6.57% water content as shown in Figure 5, the curves in Figure 11 did not show significant fluctuation especially beyond the peak pullout stress. It is also found that the difference of the pullout stresses under different normal stress conditions particularly after the peak value were occurred to a lower degree for 25.31% water content than that for 6.57% water content. Similar to the previous two cases, the ultimate strengths varied apparently; they have values of 139.47, 186.68, 209.61 and 218.68 kPa for the four applied normal stresses, respectively. Compared to the previous two cases of water content, the consolidation phenomena of soil containing 25.31% water content are more as shown in Figure 12. For clarification, the numerical values are depicted in Table 4. The vertical displacement, on the other hand, revealed a completely different behavior in the case of 25.31% water content as shown in Figure 13. The negative vertical displacements under lower normal stresses those were observed in the cases of 6.57% and 16.45% water contents, are conspicuously absent in the case of 25.31% water content indicating a decrease in volume of soil.

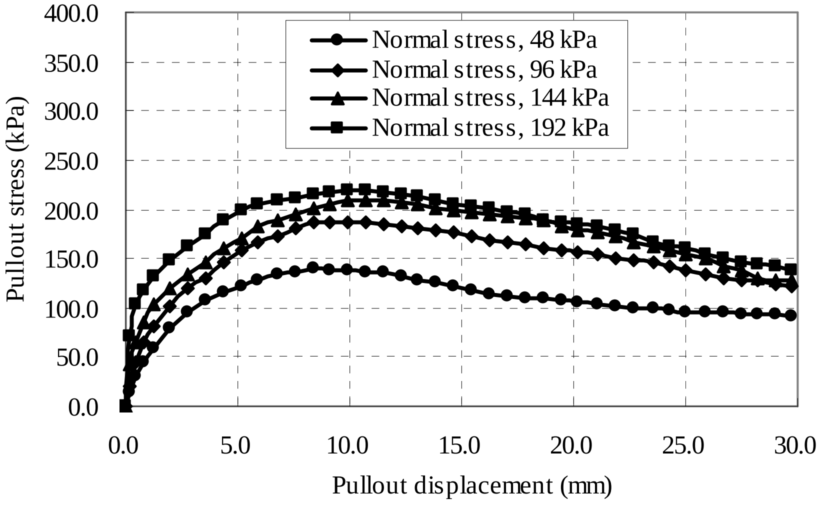

Figure 11. Pullout stress-displacement curve with 25.31% water content

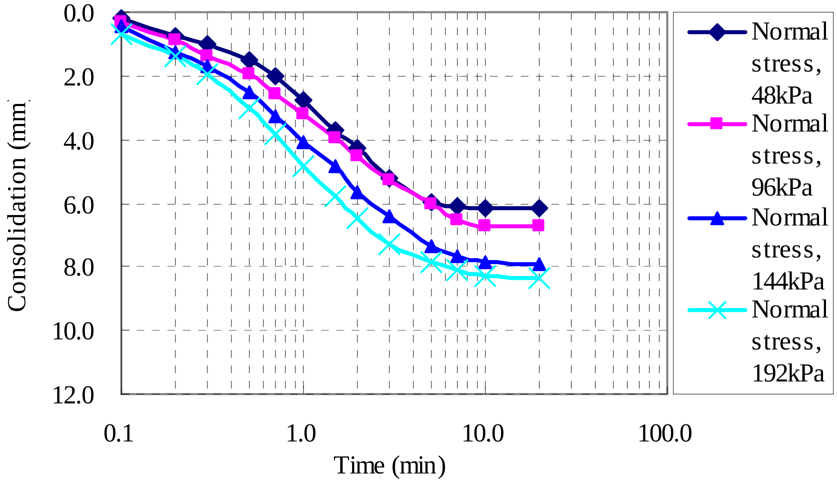

Figure 12. Consolidation vs. time relationships for 25.31% water content

Table 4. Amount of consolidation for 25.31% water content

Parameters	Values			
Normal stress (kPa)	48.00	96.00	144.00	192.00
Total initial height of soil (mm)	100.00	100.00	100.00	100.00
Amount of consolidation (mm)	6.18	6.73	7.90	8.35
Height of soil after consolidation (mm)	93.83	93.28	92.10	91.65

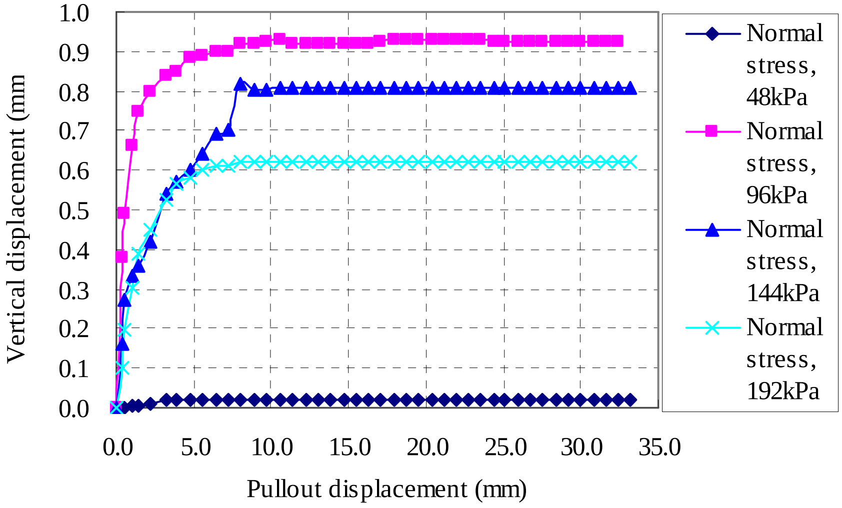

Figure 13: Dilatancy Behavior for 25.31% Water Content

3.4 Pullout Stress-displacement Relationships for 32.54% Water Content

The stress-displacement relationship of pullout tests having 32.54% water content is given in Figure 14. The pullout stress displacement behavior that were observed in the previous three cases are obviously scarce for the case of 32.54% water content, i.e. the stress-displacement relationship are not showing any softening behavior even up to the pullout displacement of 30.0 mm. Under all the normal stress conditions, the pullout stresses are not higher as compared to the previous cases. Obviously, this discrepancy depends on the higher water content of soil on the wet side of W_{opt} and far beyond the W_{opt}. Unlike all the previous cases, the water content of the soil is much higher and therefore, it takes time to release from the soil that prevent the increase in pullout stresses even with the increase in pullout displacement under any normal stress conditions. This is natural because much higher the water content of soil far beyond the W_{opt}, much more possibility of the occurrence of slippage of the soil particles taken place due to liquidity increment (Soni and Salokhe, 2006). The ultimate pullout stresses for 48.0, 96.0, 144.0 and 192.0 kPa normal stresses were found as 77.87, 103.99, 128.01 and 148.01 kPa, respectively. Further increase in the water content of soil also increases the consolidation as can be seen in Figure 15 while the pattern of the consolidation versus time curves remains same as of the previous three cases. The rate of the consolidation after 20 minutes also shows a clear relaxation in this case. The amount of consolidation is provided in Table 5 for additional clarification. A maximum of 10.8 mm consolidation can be observed in the case of 32.54% water content with applied normal stress of 192 kPa. The vertical displacement versus pullout displacement depicted in Figure 16 indicates that the decrease in volume is more apparent in the case of 32.54% water content. It is also obvious that there is positive vertical displacement only under any normal stress conditions for this case only.

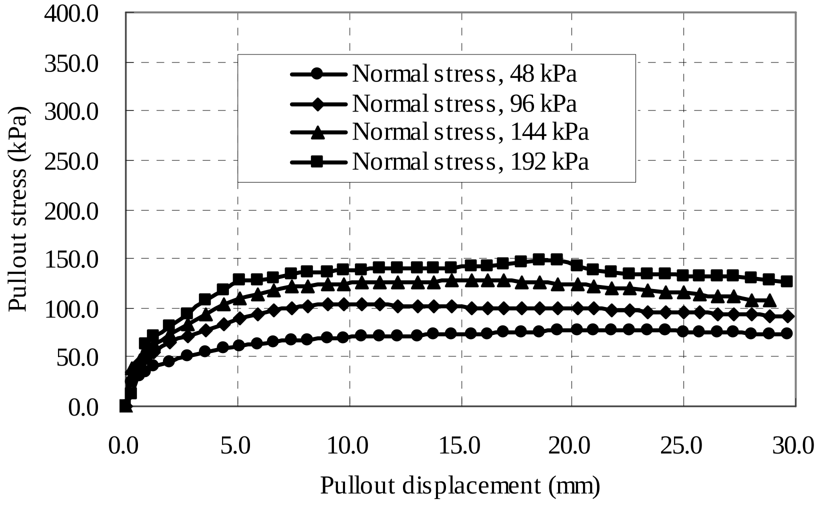

Figure 14. Pullout stress-displacement curve with 32.54% water content

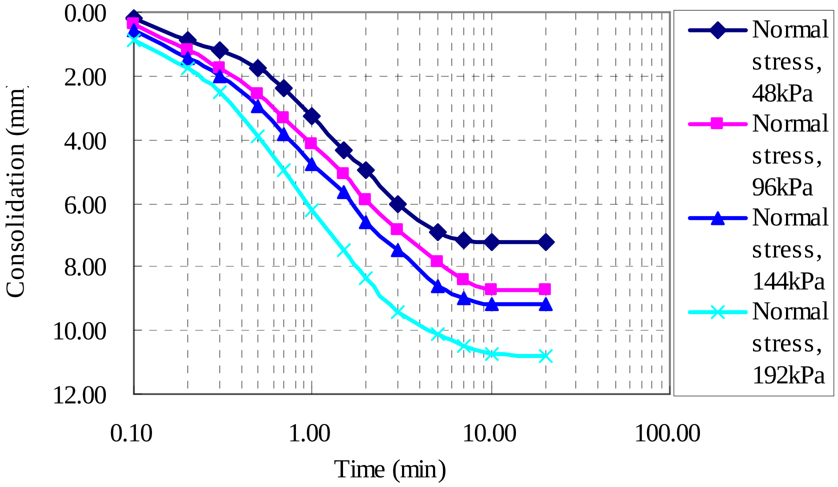

Figure 15. Consolidation vs. time relationships for 32.54% water content

Table 5. Amount of consolidation for 32.54% water content

Parameters	Values			
Normal stress (kPa)	48.00	96.00	144.00	192.00
Total initial height of soil (mm)	100.00	100.00	100.00	100.00
Amount of consolidation (mm)	7.20	8.73	9.20	10.80
Height of soil after consolidation (mm)	92.80	91.28	90.80	89.20

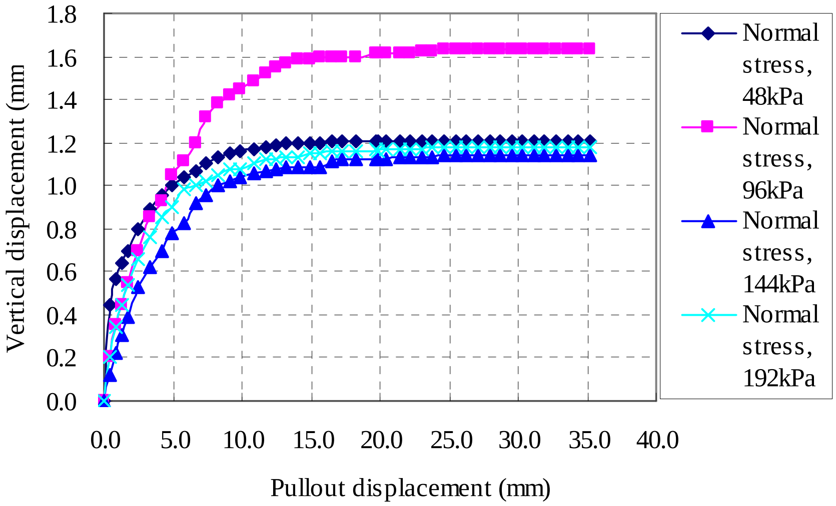

Figure 16. Dilatancy behavior for 32.54% water content

3.5 Comparison of Ultimate Pullout Strength

The ultimate pullout strengths corresponding to the different normal stresses of the reinforced soil with different water content are depicted in Figure 17. It is evident that the ultimate pullout strengths are increasing with the increase in normal stress on soil containing any amount of water content such as 6.57, 16.45, 25.31 and 32.54%. The pullout strength for soil with water contents at dry side of W_{opt} are more than for soil with water contents at wet side of W_{opt}. This phenomenon is mainly dependent on the consolidation behavior of soil occurred at different water contents of soil. As discussed in the previous section, the soils containing lower water contents has less amount of consolidation, i.e. are less compressible than that of the higher water content of soil and thereby, indicating more resistances at water content on the dry side of optimum water content (W_{opt}).

For further elucidation of ultimate pullout strengths among the four water contents of soil reported in this paper, least square linear regression lines of the ultimate pullout strengths corresponding to applied normal stress are depicted in Figure 17. This figure indicates the applied normal stress as the controlled variable as given in abscissa and ultimate pullout strengths as the random variable as given in the ordinate. It can be observed from this figure; the rate of increase of the ultimate pullout strength is slightly more for soil with lower water content than for soil with higher water content with the increase in applied normal stress. This feature is mainly attributed owing to the emancipation of the soil particles with higher water content. Because of the increase in the amount of water content, the soil particles possess higher water on its surface and thus, it gives more mobility characteristics of the soil particles. For the sake of clear perception of the pullout strength with the increase in water content of soil, relationships of ultimate pullout strength to water contents of soil are given in Figure 18. In general, it is observed that ultimate pullout stresses are getting decrease with the increase in water content of soil.

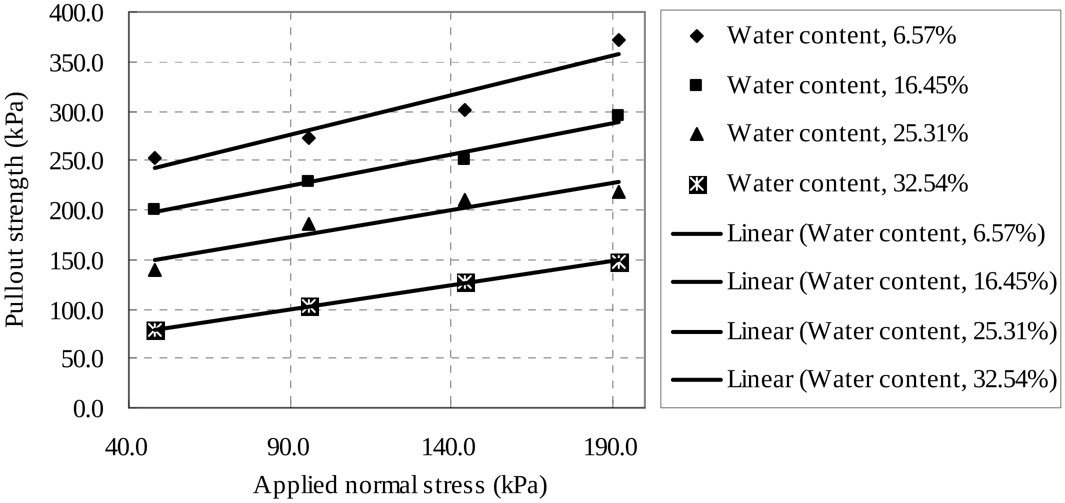

Figure 17. Applied normal stresses vs. ultimate pullout strengths

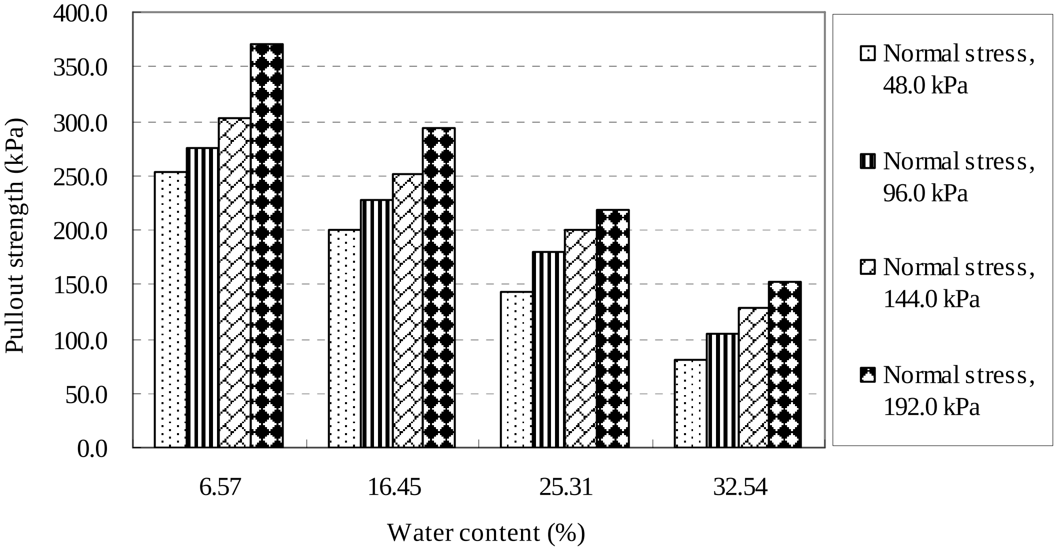

Figure.18. Water content of soil vs. ultimate pullout strength

4. CONCLUSIONS

The pullout stress showed its increasing trend with the increase in applied normal stress irrespective of water content of soil. If the water content of soil increased, the decrease in the pullout strength is profound. On dry side of W_{opt}, the pullout stress-displacement relationships revealed a clearly peak value and a wider range at 6.57 and 16.45% water contents, respectively. Vis-à-vis on the wet side of W_{opt}, such as, at 25.31% water content, the pullout stress-displacement relationships show a downswing trend after the peak pullout stresses. Further addition of water conspicuously altered the pullout stress-displacement behavior, such as, at 32.54% water content, neither the certain point of the peak pullout stresses nor the softening behaviors are clearly observed. Further investigations are suggested to study the pullout behavior for a wider range of water content of soil with various reinforcements as well as theoretical modeling. Nonetheless, the results depicted in this paper are fairly encouraging to aid in the design of reinforced soil structures.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Jewell, R.A. 1996. Soil strength and bearing capacity. Soil reinforcement with geotextiles, CIRIA, Thomas Telford. 55-83.

Madhab, M.R., N. Gurung. and Y. Iwao. 1998. *A theoretical model for the pullout response of geosynthetic reinforcement*. Geosynthetic International. 5 (4): 399-424.

Gurung, N and Y. IWAO. 1999. *Pullout test analysis for georeinforcement*. Geotextiles and Geomembranes. 17: 157-170.

Lauwers, D.C. 1991. *PVC geocomposite for improved friction and performance properties, Geosynthetics*. IFAI, Atlanta, GA. 101-112.

Murata, O. 1992. *Loading test of geosynthetic-reinforced soil retaining walls and their stability analysis*. Proceedings of the International Symposium on Earth Reinforcement Practice. 1: 373-378.

Sobhi, S. and J.T.H. WU. 1996. *An interface pullout formula for extensible sheet reinforcement*. Geosynthetic International. 3 (5): 565-582.

Mahmood, A.A., N. Zakaria. and F. Ahmad. 2002. *Studies on geotextiles/soil interface shear behavior*. Electronic Journal of Geotechnical Engineering. 13: 1-14.

Soni, P. and Salokhe, V. 2006. *Theoretical analysis of microscopic forces at soil-tool interfaces: a review*, Agricultural Engineering International, the CIGR Ejournal, 8:1-13.