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EFFECT OF RESTRAINED DILATANCY ON PULLOUT RESISTANCE OF STRIP REINFORCEMENT

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ABSTRACT

A series of pullout tests on strip polymer geogrid embedded in dense sandy gravel was carried out and the normal stresses at the soil-reinforcement interface were measured by small earth pressure cells. On basis of these tests, it is found that the restrained positive dilatancy, observed at lower applied normal stresses, results in the increase in actual normal stresses at the soil-reinforcement interface, thereby increasing the pullout resistance of the reinforcement. It is observed that for the strip polymer grid, increase in the normal stresses is the resultant of pullout resistance of transverse members under plane strain conditions plus the edge effect of strip reinforcement under the true three dimensional conditions.

INTRODUCTION

In last thirty years or so, reinforced earth technique has well established itself as a separate discipline of geotechnical engineering. Both metallic and geosynthetic reinforcements are used in the construction of reinforced earth structures. Depending upon the shape, reinforcements could either be bars (with or without anchors), sheets (with or without corrugations) or grids [1]. In the construction of reinforced earth structures especially when the reinforcements are expected to carry heavier loads (for e.g., in case of stabilization of natural slopes, railraod structures, etc.), understanding of soil-reinforcement interaction mechanism is of prime importance.

Alfaro et al. [2] presented the conceptualized model for pullout interaction mechanism of geogrid strip reinforcement. Although, this model was originally conceptualized for geosynthetic grids, it has wide applicability and can be extended to other forms of reinforcements as well as for the metallic reinforcements. This conceptualized model is a combination of two dimensional (2-D) and three dimensional (3-D) interaction mechanism; 2-D interaction mechanism (generated over the middle section) being the classical soil reinforcement interface friction while 3-D interaction mechanism (generated at both the edges of strip) being the consequence of restrained soil dilatancy at the interface due to non-dilating neighbouring soil zone.

Figure 1 shows the conceptualized stress conditions at the soil-geogrid interface for the cases of free dilatancy and restrained dilatancy. If displacement $2\delta d$ is restrained, then increase in stresses $\Delta\sigma_n$ is expected at the soil-geogrid interface. In this paper, actual normal stresses measured at the soil-reinforcement interface for both full width (representing sheet reinforcement) and half width (representative of strip reinforcement) geogrid during pullout test is presented. Moreover, normal stress distribution at soil-reinforcement interface for full and half width geogrid is compared.

TEST EQUIPMENT AND MATERIALS

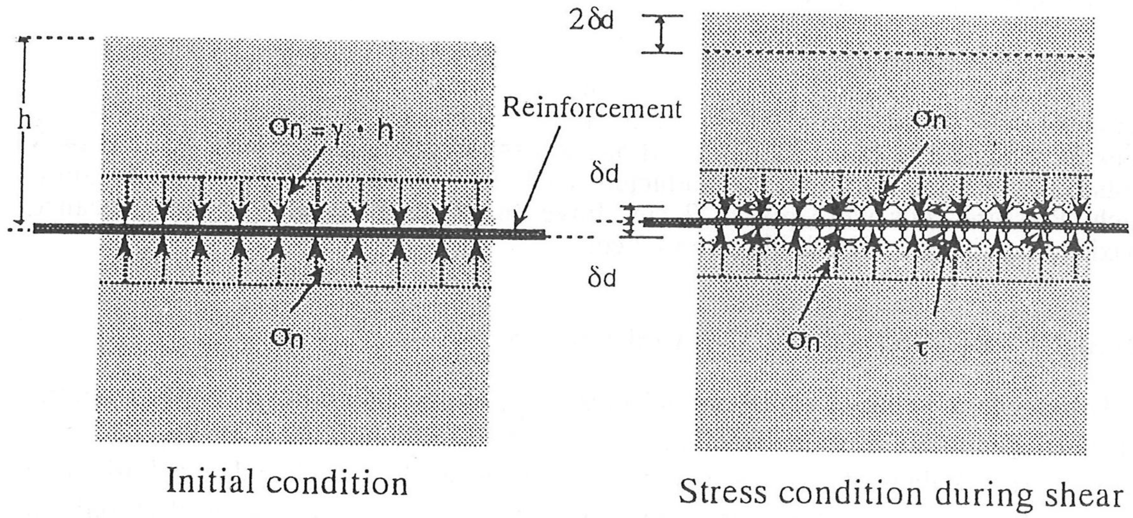
The pullout test apparatus used in this investigation is made of rolled steel plates, angles, channels, and H-sections, welded or bolted together. The soil thickness above and below the reinforcement were 15 cm and 25 cm, respectively. A rubber air bag was used to produce a uniformly distributed vertical pressure on top of the backfill soil. Linear displacement transducers were used to measure the displacements along the reinforcement length and also the dilatancy during pullout tests while the applied pullout load was measured by a load cell. Nodal displacements along the reinforcement length were measured through the wires connected to the Linear displacement transducers mounted on the rear wall of the box. These wires, which run inside the stiff tubings to protect them from direct contact with the soil, were always kept tensioned by the built-in springs of the Linear displacement transducers. The nodal displacements were used to calculate the average tensile strains between two adjacent nodes. All instrumentations were linked to a personal computer through an electronic datalogger which was programmed to scan the measurements at desired time intervals. Details of the test equipment and instrumentations can be found in Alfaro et al. [3].

A well-graded sandy gravel was used as backfill soil with grain size distribution as follows: average grain size, d_{50} = 4.74 mm; uniformity coefficient, C_u = 15; and coefficient of curvature, C_c = 1.67. The maximum and minimum dry unit weights were 19.10 kN/m^3 and 14.32 kN/m^3, respectively. The internal friction angle of the compacted soil as obtained from the laboratory triaxial compression test was 45 degrees for 95 % relative density. Tensar SR geogrid, a uniaxial polymer grid normally used for reinforced soil walls and steep slopes, was employed as reinforcement specimen.

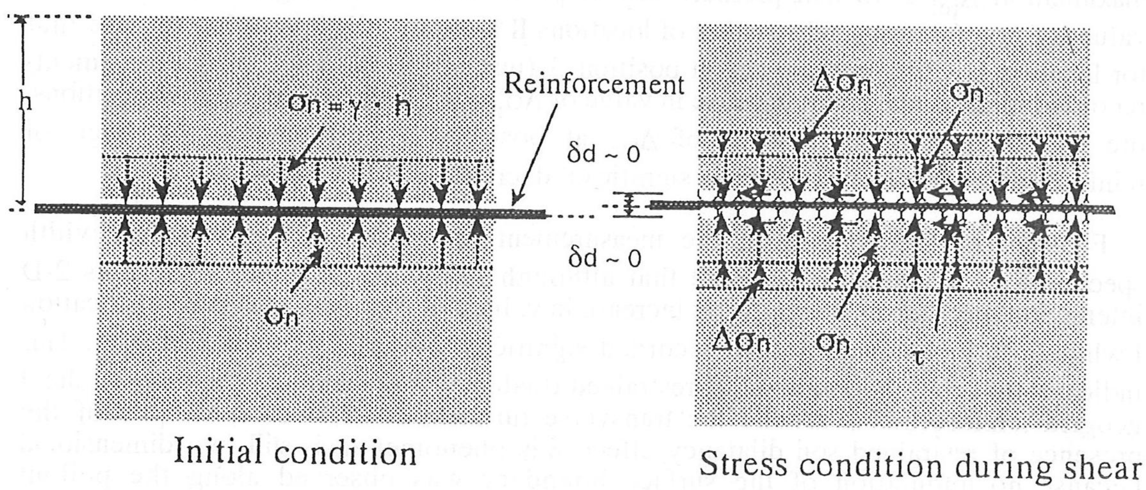
TEST PROCEDURE AND INSTRUMENTATION

The backfill soil was compacted in the pullout testing box by manual tamping, each layer not exceeding 10 cm in thickness so as to provide uniform compaction. Friction between the soil and the side walls of the box was minimized by the use of rubber membrane lubricated with silicone grease. This was verified by installing pressure cells near the reinforcement level at the half width of the box and near the side walls of the box. The pressure cells did not indicate any relative difference in the measured normal stresses at these locations, indicating minimal wall friction.

A total of six pullout tests were conducted to measure the changes in normal stresses at the soil-reinforcement interface due to the restrained dilatancy effect. These tests were conducted on two different specimen widths (B_G = 0.30 and 0.58 m) at constant applied normal stress, σ_n = 20 kPa. For tests on full width specimens (B_G = 0.58 m), 2-D interaction mechanism was envisaged to be appropriate because the lubricated side walls would not induce restraining effect which might have been caused by the presence of the dilating and the non-dilating zones within the backfill soil. On the other



(a) Free dilatancy



(b) Restrained dilatancy

Fig. 1 Stress Conditions for (a) free dilatancy (b) restrained dilatancy hand, tests on half width specimens (B_G= 0.30 m) correspond to the condition wherein the pullout resistance would be either the combination of 2-D and 3-D interaction mechanisms or pure 3-D interaction mechanism as discussed earlier.

To measure the normal stresses, pressure cells were laid at 3 different locations (Inset, Fig. 2) along the geogrid specimen - I being 4.25 cm in front of node 2, II being in center of node 1 and 2, and III being 4.25 cm back of node 2. At each location, pressure cells were placed at four different positions across the geogrid specimen. A total of 3 tests per specimen width were conducted, each test corresponding to one location each. Pressure cells were placed 2 cm above the reinforcement specimen because maximum grain size of backfill soil was 2 cm.

RESULT PRESENTATION AND DISCUSSION

Difference in value of actual normal stress, σ_{act} above the value of applied normal stress, σ_n due to the restrained dilatancy effect has been denoted here as $\Delta\sigma_n$ (i.e., $\Delta\sigma_n = \sigma_{act} - \sigma_n$). Values of $\Delta\sigma_n$ as associated with both changes in relative horizontal distance between node 2 and pressure cells (denoted here as Δ_{rel}) as well as pullout displacement of node 2, Δ_{h2} are shown in Fig. 2.

In general, pressure cells at locations II and III recorded negative values of $\Delta\sigma_n$ at all positions for tests on half width specimens [Fig. 2(a)]. For location I, while pressure cells at positions 2, 4 and 3 recorded significant increase in values of $\Delta\sigma_n$, attaining maximum at $\Delta_{rel} \cong 15$ mm, pressure cell at position 1 recorded gradual decrease in values of $\Delta\sigma_n$ (almost similar to that of locations II and III). It is interesting to note that for location I, while pressure cell at position 3 (just inside the edge of reinforcement) recorded highest maximum increase in value of $\Delta\sigma_n$ ($\cong$ 280 kPa) amongst all positions, the maximum increase in value of $\Delta\sigma_n$ at position 2 (just outside the edge of reinforcement) was only 140 kPa, a significant decrease of 140 kPa.

Figure 2(b) corresponds to the measurement of values of $\Delta\sigma_n$ on full width specimens. It is interesting to note that although full width specimen represents 2-D interaction mechanism, a significant increase in values of $\Delta\sigma_n$ was observed at location I while both locations II and III recorded significant decrease in values of $\Delta\sigma_n$. This indicates that the phenomenon of restrained dilatancy is present even in case of sheet geogrid reinforcements around the transverse rib members. However, in spite of the presence of restrained soil dilatancy effect, this phenomenon is still two dimensional because no undulation of the surface boundary was observed along the pullout direction. The surface profile remained plane during the pullout test. Thus, the rise in actual normal stresses around the transverse rib members in case of full width geogrid samples is essentially the plane strain phenomenon.

From Fig. 2(b), it may be seen that for full width specimens, the average value of maximum $\Delta\sigma_n$ is of the order of 75 kPa for location I. However, in case of half width specimens, the pressure cell at position 4 for location I, recorded the maximum value of $\Delta\sigma_n$ equal to 200 kPa [see Fig. 2(a)], 2.67 times higher than the average value. The difference in value of $\Delta\sigma_n$ at position 4 of location I in case of half width specimen and the average value of maximum $\Delta\sigma_n$ for location I in case of full width specimen (200 -

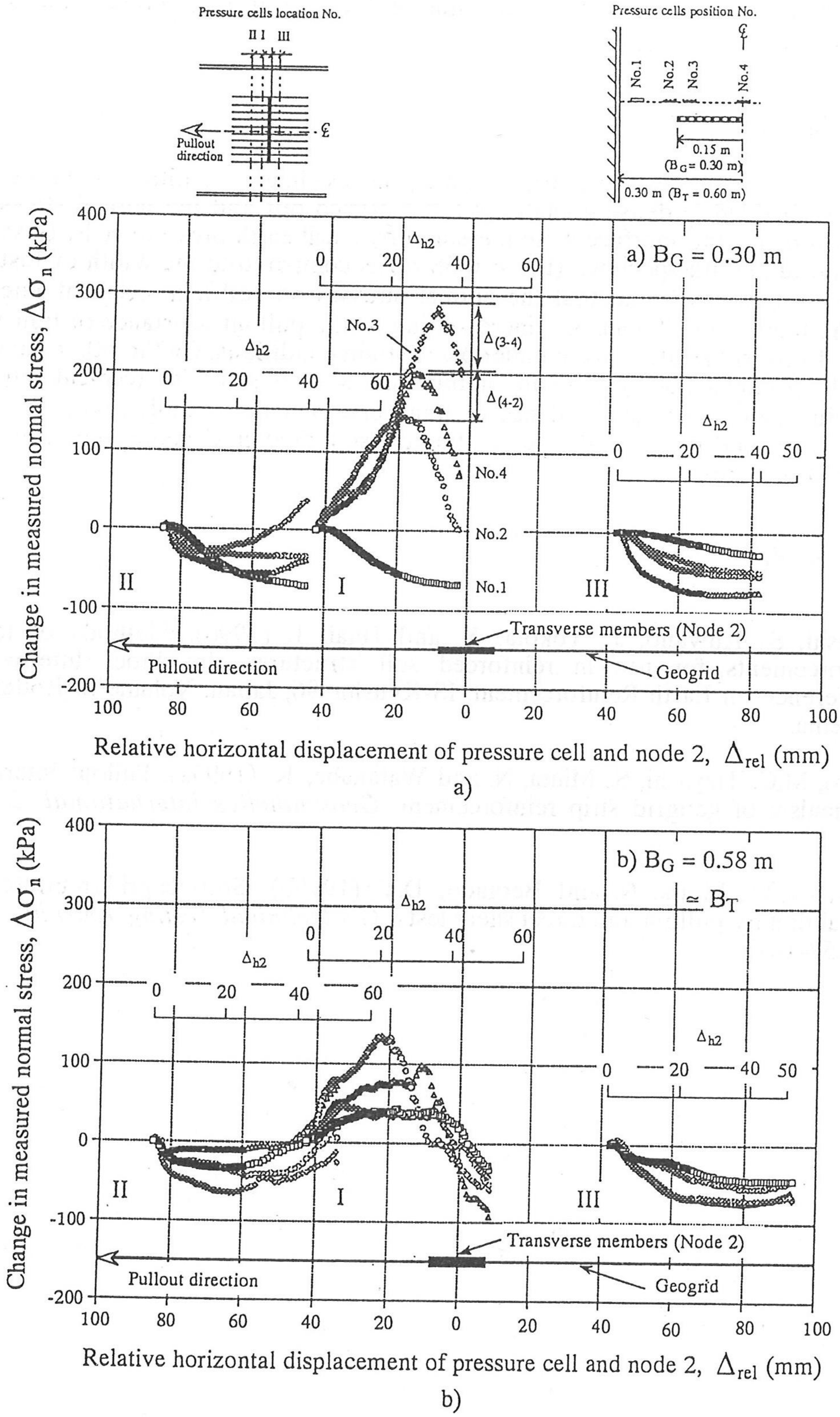


Fig. 2 Increase in normal stress versus Δ_{rel} for (a) $B_G = 0.3$ m; (b) $B_G = 0.58$ m

75 = 125 kPa) indicates the increase in value of $\Delta\sigma_n$ due to edge effect alone under true 3-D interaction mechanism.

CONCLUSIONS

A series of pullout tests on strip polymergrid specimens of different widths and strengths embedded in dense granular soil was carried out and the normal stresses at the soil-reinforcement interface were measured by small earth-pressure cells. Based on the tests on full width specimen (B_G = 0.58 m) as compared to the width of test box (B_T = 0.60 m), it was found that the normal stresses on soil-reinforcement interface around the transverse rib members increase due to the pullout resistance of transverse members of geogrid reinforcement under plane strain conditions. On the other hand, for half width specimen (B_G = 0.30 m), normal stresses on soil-reinforcement interface increase due to the pullout resistance of transverse members coupled with the edge effect of strip reinforcement due to restrained soil dilatancy under the true three dimensional condition.

REFERENCES

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