Evaluation of the confining effect on geogrid pullout test under unloading-reloading history

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ABSTRACT: This paper presents an evaluation of the soil-geogrid interaction mechanism. The soil dilative phenomenon occurs due to the three dimensional bearing resistance at the transverse elements and the node embossments. The confining effect is evaluated under unloading-reloading process. Since the past studies show that seismic stability of the geogrid reinforced soil walls depends upon the pullout resistance between geogrid and backfill material after certain damage, e.g. residual deformation and generation of slip line in the backfill. Seismic stability of the geogrid reinforced soil walls having slip line in the reinforced area should be evaluated from the results of the pullout test which take account of damage process. In order to understand about mechanism of pullout test under seismic activities, unloading-reloading process was applied to simulate the geogrid being pushed back and forth under earthquakes. Results reveal that unloading-reloading decreases pullout resistance of geogrid at the peak values and at the residual parts however it has little impact before the peaks. The interaction between geogrid and soil during the shearing is analyzed by the Particle Image Velocimetry (PIV) method. This study will help to evaluate damaged degree of the geogrid reinforced soil walls after earthquakes.

1 INTRODUCTION

Stress distribution along reinforcement contains two components, frictional resistance and passive resistance Bergado et al. (1992). The frictional resistance depends on the surface area between geogrid and soil, the friction angle between geogrid and soil, and effective normal stress at the interface. The passive resistance is considered similar to bearing capacity mechanism. The failure mechanism is based upon the Terzaghi-Buisman bearing capacity equation for a strip footing as described by Colin Jones (1996). Peterson and Anderson (1980) provided a bearing capacity failure mechanism shown in Figure 1. Passive resistance depends on area of transverse elements, effective vertical stress and friction angle of soil. Experiment has shown the existence of confining effect which is independent of tensile force of geogrid. The confining effect is a factor of reinforcing effects related to soil dilatancy.

Yasufuku and Ochiai (2004) reported an existence of confining effect in an element test, Figure 2.

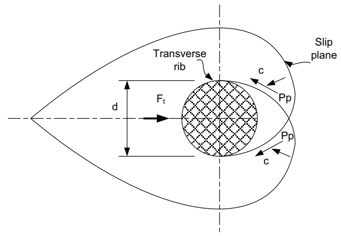


Figure 1. Failure plane for bearing resistance after Peterson and Anderson (1980)

F_t: Pullout resistane, d: Diameter, P_p: Passive resistance, c: Cohesion

In this study, a special pullout test was designed to carry out the pullout test with different geogrid types. The square and circle geogrid types were tested. To understand and stimulate geogrid working mechanism under seismic activities, unloading-reloading was applied during the pullout test by pushing the geogrid back and forth. The interaction between geogrid and soil especially at the transverse ribs was analyzed by the Particle Image Velocimetry (PIV) method to understand about the interaction mechanism during unloading-reloading process.

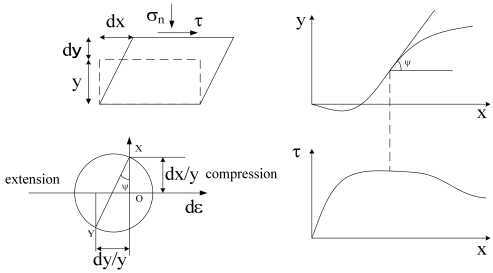


Figure 2. Dilatancy angle at peak values (Yasufuku & Ochiai, 2004)

2 PULLOUT TEST

2.1 *Test apparatus*

Figure 3 shows the schematic diagram of pullout test apparatus with dimensions of 300 mm (width) x 202 mm (height) x 400 mm (length).

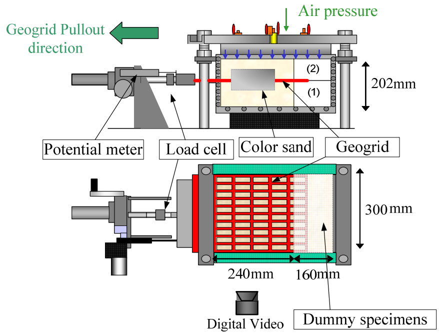


Figure 3. Pullout test apparatus

Two dummy specimens were put inside the box to reduce the frictional area between geogrid and soil making the contact length of 240 mm. The test apparatus was mainly made of steel except the longitudinal sidewalls which were made of hard transparent plastic plates. Color sands were attached at the observation square at the box side with an area of 134 mm (width) x 80 mm (height), where distance from left side of the box to the square was 30 mm, to observe the deformation at the interface between geogrid and sand by a digital video camera.

Dry Toyoura sand was poured through a sieve to make the soil homogeneous and the density (D_r=80%) was controlled by the vertical dropping height of 170 mm above the surface. Air pressure bag was used to apply a constant uniform vertical pressure from the top of the box. The tests were operated by pulling the geogrid out at a constant speed of 1 mm/min through a screw jack controlled by a motor. The pullout force was measured by a tension load cell and the pullout displacement of geogrid was measured by a displacement gauge. The pullout tests were finished at 55 mm of pullout displacement because of the limitation in the stroke of the jack.

2.2 *Materials*

Toyoura sand, which is available in Japan, was used in all pullout tests. The properties of sand are D_{50} (mm): 0.19; U_c : 1.56; e_{max} : 0.973; e_{min} : 0.609; e : 0.682; ϕ (°): 42

Two types of geogrid made of polycarbonate, a square geogrid (SG), a circle geogrid (CG) and a polycarbonate plate (P) are shown in Figure 4.

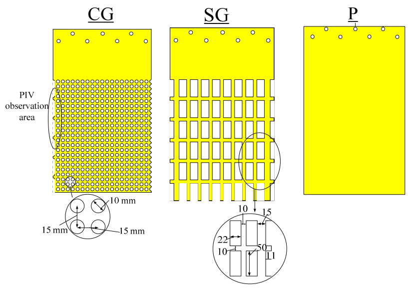


Figure 4. Polycarbonate types

Pullout testing procedure was described in details by Nguyen et al. (2008)

3 RESULTS AND DISCUSSIONS

3.1 *Pullout tests*

The overburden air pressure used for these tests were $\sigma_v = 5$, 20, 35 kPa. To achieve zero pullout resistance in unloading, the geogrid was pushed back slightly at the jack. In no unloading-reloading (NUR) pullout test, the peak values were learnt to carry out the next step – pullout test with unloading-reloading (UR) process.

The UR steps were implemented at 3 stages: before the peak value, at the peak value and at the residual part as shown in Fig 5. The whole process is presented through successive steps: O-A-B-C-D-E-F-G-H (for example, $\sigma_v = 35$ kPa). UR process before the peak values is O-A-B-C. The process at the peak value is C-D-E and one more time at the residual part is F-G-H.

Before the peak values, the UR did not affect the pullout resistance however it reduced the pullout resistance at the peak and residual parts. The amount of decrease differed with geogrid types. Reduction in pullout resistance before and after UR process, e.g. τ_p at C and τ_r at E in Fig 5, was computed in the form of $\left(\tau_p - \tau_r\right)/\tau_p\,(\%)$. In these tests, the decreases at peak value of CG, SG and plate were 5%, 10% and 5% respectively.

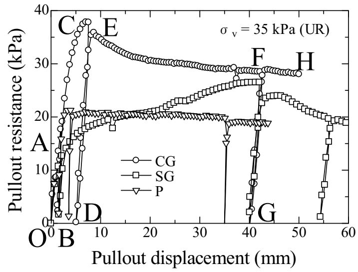


Figure 5. Pullout resistance vs pullout displacement; Unloading-reloading process

3.2 *Particle Image Velocimetry (PIV) analysis*

The interaction between geogrid and soil especially at the transverse ribs was analyzed by the Particle Image Velocimetry (PIV) method to understand about the mechanism during unloading-reloading process. The color area was captured by a digital camera. Images were studied about the movement of sand around the geogrid. The interaction between soil and geogrid includes frictional resistance, passive resistance and confining effect. The whole unloading-reloading procedure with $\sigma_v = 35\text{kPa}$ and circle geogrid is analyzed and shown in the figure 5. The two observed nodal points N:23 and N:38 are shown in Figure 6.

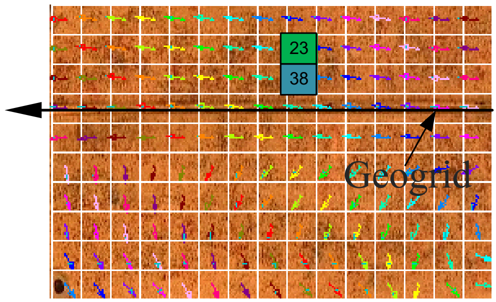
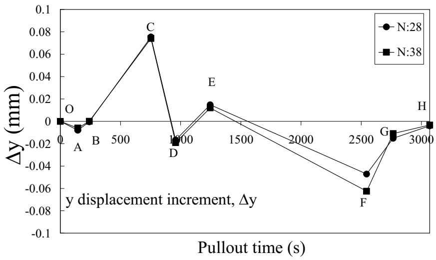


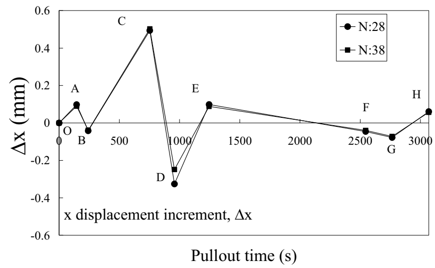
Figure 6. Position of nodal points 23 and 38 during pullout test of circle geogrid under $\sigma_v = 35$ kPa with unloading-reloading process

Figure 7 shows x and y direction displacement analysis of the nodal points 23 and 38. Δx denotes a displacement increment in x-direction from the previous step, e.g. Δx_c is Δx from B to C. If the value of Δx is positive then it means the soil particle moves in the same direction as a pullout direction. If Δx is negative, the soil particle moves in the opposite direction to a pullout direction. Δy indicates a displacement increment in y-direction from the previous step. If Δy is positive then it means the soil particle moves upward and soil shows volume increase or dilative behavior. If Δy is negative, the soil particle moves downward and soil shows volume decrease or contractive behavior

E.g.
$$\Delta x_A = x_A - x_O$$
$$\Delta x_B = x_B - x_A$$



a) Increment of soil particle in y-direction



b) Increment of soil particle in x-direction

Figure 7. Increments of particles from O~H steps, Unloading-Reloading process, 35 kPa

As shown in Figure 7b on Δx, it is observed that from O→A, when geogrid is pulled out to the left soil particle move also to the left with the geogrid. When unloaded from A→B, geogrid is pushed back to the right and the soil particles also move to the right. Soil particles show large displacements in the pullout direction to the peak, C. At peak, unloading step pushes soil particles a big displacement toward the opposite pullout direction (from C→D). After peak, the shear zone is formed around geogrid's surfaces therefore soil particles show small displacement even under unloading-reloading process (F to G).

In the Δy graph of Figure 7a, soil shows at the beginning as values of Δy at A and B are negative. However at peak C, soil shows the most dilative behavior. These are similar to the soil dilatancy behavior as reported by Yasufuku & Ochiai (2004) in Figure. 2. In the residual state, once the shear zone is formed, soil just shows contractive behavior even under unloading-reloading process.

Figure 8 shows positions of the two nodal points N:23 and N:38 and their x & y displacement trajectory respectively of CG pullout under $\sigma_v = 35$ kPa during UR process.

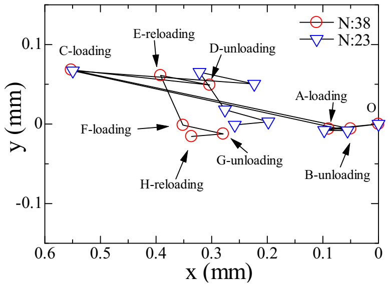


Figure 8. Trajectory of nodal point 23 and 38 during pullout test of circle geogrid under $\sigma_v = 35$ kPa with unloading-reloading process;

It is seen that at the beginning to peak, step A→C, two particles moved almost equally in a large x-displacement along with geogrid's pullout direction. The maximum displacements were achieved at the peak value C. After the peak, the two particles started to move separately in same behaviors during the whole pullout test. Even when geogrid was pulled in a very large displacement of 50 mm, these two particles stayed almost at the same places. It indicated that after peak, a shear zone around geogrid's surfaces was formed and soil was divided into layers. During shearing these layers slipped on each other. Before the shear zone was formed, the UR process did not affect the pullout resistance because soil was uniform and the UR did not change soil position. But after the shear zone formed the UR disturbed the shear zone reducing the pullout resistance.

4 CONCLUSIONS

A series of pullout tests with different opening geogrids, unloading-reloading step and using PIV analysis were carried out. From this study the following conclusions are drawn:

1. The unloading-reloading reduces pullout resistance at the peak and residual part however it shows very little effect before peak.
2. The amount of reduction after unloading-reloading process depends on the geogrids' opening and stiffness.
3. The maximum displacement of soil is achieved at peak. At residual part, unloading-reloading process does not affect much on the horizontal displacement of soil.
4. After the peak value, the shear zone is formed around geogrid's surfaces and soil is divided into layers. These layers slip on each other during the shearing at residual part.

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