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Laboratory and analytical investigation of sleeve reinforced stone columns

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ABSTRACT: A laboratory investigation was carried out in which natural and sleeve reinforced stone columns were tested in triaxial compression. These tests were performed in a large diameter (0.25m) triaxial compression machine under saturated drained conditions. Two types of polymer sleeves and two types of granular materials were investigated. A hyperbolic stress-strain model was used to predict the experimental results to a good degree. Highly dilative granular material was best suited to develop the hoop stresses in the reinforcing sleeves even at small vertical strains.

1 INTRODUCTION

The load-deformation response of a granular column in triaxial compression is similar to that in the field and is to a large extent a function of the confining stress. In the field the confinement is supplied by the surrounding soil and under continued loading the column will either fail by excessive bulging or by shear. In the triaxial apparatus the confinement is applied by the cell pressure. In this experimental investigation the load carrying capacity was increased considerably by confining the granular column material within geogrid sleeves. The addition of these cylindrical sleeves or jackets also minimized the lateral bulding of the columns.

Two commercially available geogrids were investigated. The horizontal shaped ribs or elements of the geogrid sleeve mobilized additional confinement stresses on the column material through the generation of hoop stresses. Two series of tests were performed. The first series investigated the load-deformation response of the two granular materials under triaxial compression. The results from these tests served as control data. In the second series the same two granular materials were tested but the granular specimens were confined by the geogrid sleeves in addition to the applied confining pressures. The various aspects of this investigation will be presented in the following sections.

2 EQUIPMENT

The triaxial test apparatus was able to accommodate specimens of 0.25 in diameter and 0.50 m in height. The specimens were compacted in a mold mounted on a vibratory table. The granular material was vibrated to the specified density under a surcharge load of 13.8 kPa. For sleeve reinforced specimens the cylindrical geogrid was placed inside the steel mold with the rubber membrane being placed between the grid and the mold. The compacted and sealed specimens were transferred to the triaxial apparatus. All the parameters during a test were monitored by electronic transducers and the signals were collected and analysed by a data acquisition system attached to a computer. The data could either be analysed by the computer or down loaded for further analysis.

3 MATERIAL

Two granular aggregates were investigated as column material. A well graded crushed limestone aggregate (denoted as granular A) was compacted by vibration to 18.5 kN/m^3 corresponding to 85% of modified Proctor density. The largest particles were 20 mm and the size at 50% passing (D_{50}) was 5.5 mm. The second material was a uniform size crushed limestone aggregate of particle size 10 mm.

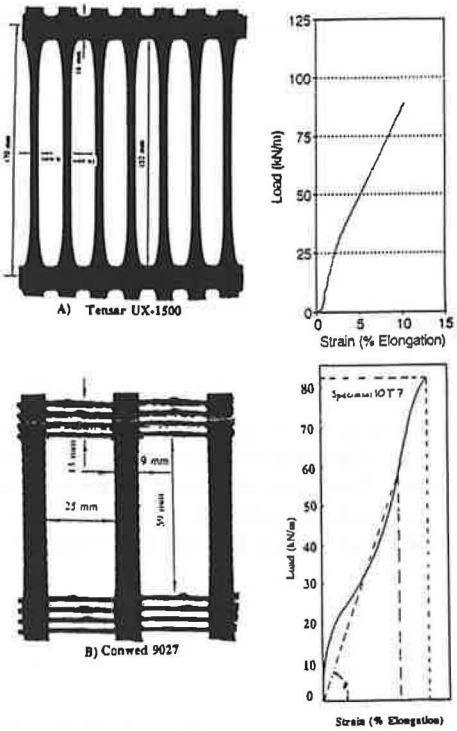

Fig.1. Geometry and modulus of geogrids

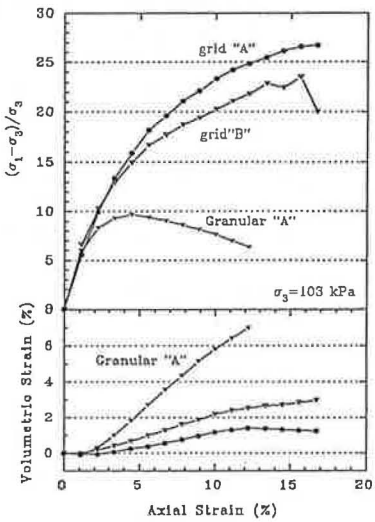

Fig.2. Well graded stone column behaviour (with and without sleeve reinforcement)

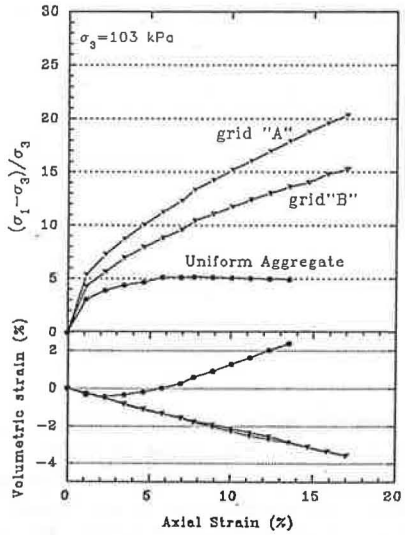

Fig.3. Uniform graded stone column behaviour (with and without reinforcement)

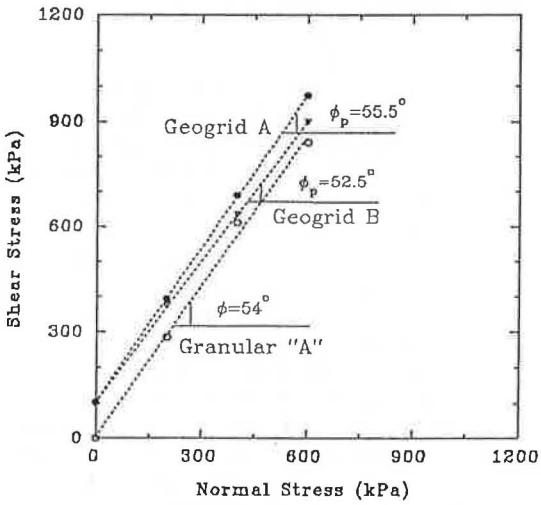

Fig.4. Strength envelopes (well graded soil)

The maximum and minimum densities were 17.2 and 14.2 kN/m^3 respectively. Both materials showed no cohesion intercept on a Mohr-Coulomb plot and yielded angles of shearing resistances of 43° for the well graded soil and 33° for the uniform aggregate.

Two geogrids were used as cylindrical sleeves. Grid A was an extruded uniaxial polyethylene mesh with longitudinal apertures. The tensile strength was 88.3 kN/m and the modulus was about 7.5 kN/m at 10% of elongation. Geogrid B was a knotted or woven polypropylene mesh. The geometry and load-strain characteristics of the two meshes are shown in Figure 1. The geogrid sleeves were of cylindrical shape 0.25 m in diameter and 0.50 m in height. The connection or joint for the cylindrical sleeve was made with high strength polyester cord. This type of connection was tested in tension and was found to be non-yielding and stronger than the geogrid itself. It should be noted that the strong axis of the geogrid sleeves was aligned in the circumferential direction in order to sustain the hoop stresses.

4 ANALYTICAL MODEL

A hyperbolic stress-strain simulation was used to predict the load-deformation behaviour of the soil specimens under triaxial compression. This method was proposed by Duncan and Chan (1970) and was modified by the authors to include the effects of the sleeve reinforcement. The parameters for the constitutive model were obtained independently for the two soils and for the two geogrids. Thus the model was found to be adequate to model the behaviour of the sleeve reinforced granular column under loading conditions as discussed in the next section.

5 TEST RESULTS AND DISCUSSION

Figure 2 shows typical normalized stress-strain relations for the well graded aggregate specimens with and without sleeve reinforcement. Similar plots are given in Figure 3 for the uniform graded aggregate. The well graded unreinforced specimen exhibited a peak deviator stress value. The uniform aggregate specimen reached a maximum stress value at about 6 to 7% of axial strain without exhibiting any decrease in stress values. In contrast all reinforced specimens exhibited strain hardening. Even at termination of testing at about 17% of axial strain, the deviator stress was still increasing (Figures 2 and 3). In one case only (Figure 2), the horizontal ribs of the geogrid B (knotted grid) started to break at about 13% of axial strain resulting in a sudden drop of deviator stress. A comparison of volume change behaviour between reinforced and natural specimens indicates that the geogrid sleeve reduced the dilation during shear markedly. For the uniform aggregate, the reinforced specimens continued to contract at a constant rate with increasing axial strain. For the well graded reinforced aggregate the dilation was reduced by more than 50% compared to the natural aggregate.

A comparison of the friction angles of unreinforced and sleeve reinforced columns are shown in Figures 4 and 5 for the well graded and the uniform aggregates respectively. The friction angle for the reinforced columns were calculated at axial strains corresponding to the peak deviator stress of the unreinforced column. The global friction angle for reinforced colums are the same as for the corresponding natural aggregate. The strength increase due to the sleeves is shown as an "apparent" cohesion intercept. Therefore, the strength for the sleeve reinforced columns can be estimated from the following relation.

$$S - C'_R + \sigma' \tan \phi_R$$

where C'_R is the "apparent" cohesion due to the reinforcing sleeve; σ' is the effective normal stress and ϕ_R is the angle of shearing resistance of the composite which can be taken as equal to that of the granular material (Figures 4 and 5).

Figure 6 shows the comparison of results using the hyperbolic stress function and the experimental stress-strain response for the well graded soil reinforced with the extruded uniaxial geogrid (geogrid A). A similar comparison is given in Figure 7 for the same granular material but with a sleeve made from geogrid B. The agreement is quite good. The comparison for the uniform aggregate and geogrid B is given in Figure 8. Again the analytical model is able to predict the stress-strain behaviour of the experimental curve quite well. It should be kept in mind that the input parameters for the constitutive model were obtained from separate and independent tests on the granular column material and the geogrids. The model can also accommodate parameters simulating soil confinement if the reinforced columns or piles were constructed in a natural soil deposit.

CONCLUSIONS

The experimental results from this laboratory test program validated the concept of applying polymer sleeves to stone columns. The application of

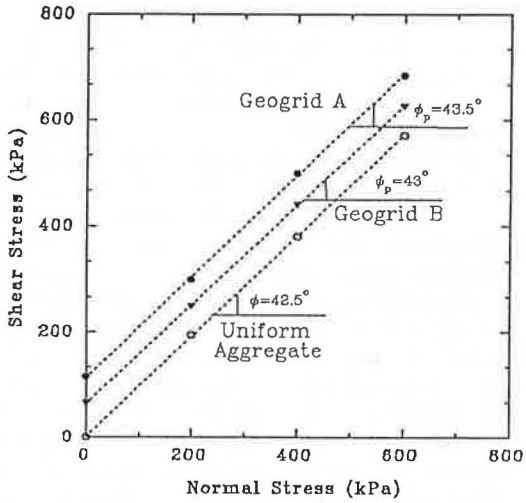

Fig.5. Strength envelopes (uniform graded soil)

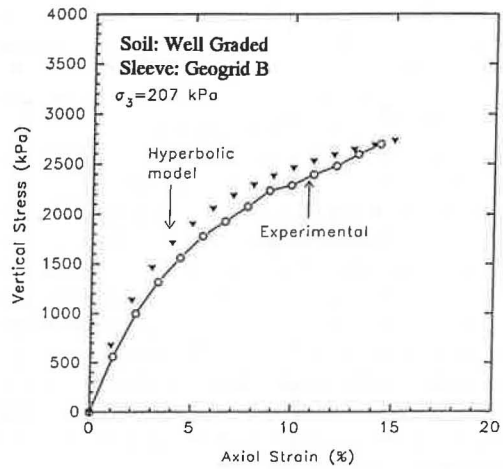

Fig.7. Constitutive and experimental behaviour (well graded soil and geogrid B)

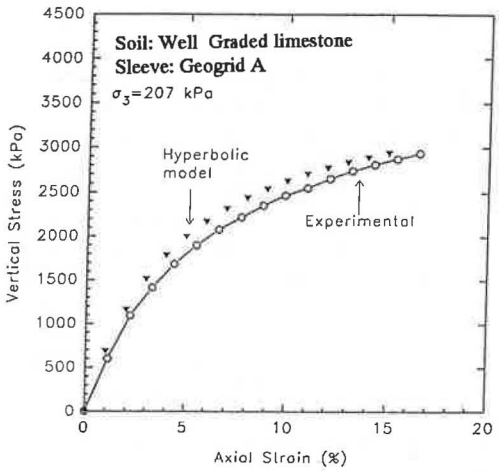

Fig.6. Constitutive and experimental behaviour (well graded soil and geogrid A)

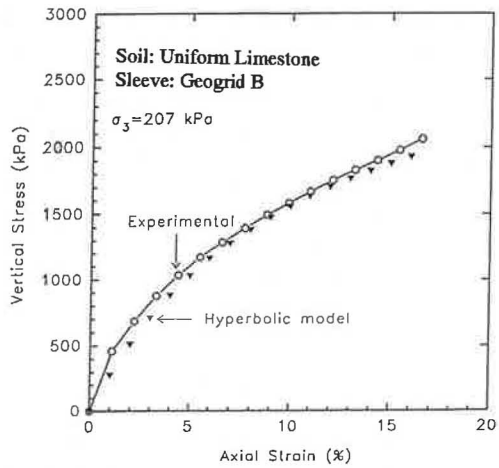

Fig.8. Constitutive and experimental behaviour (uniform graded soil and geogrid B)

geogrid sleeves will increase the stiffness of this system considerably. In addition the lateral deformation of these columns are decreased.The use of well graded and well compacted column material will dilate and thereby mobilize the tensile strength of the sleeve.

The reinforced composites exhibited the same angle of shearing resistance as the corresponding unreinforced columns for the two granular materials tested. Therefore, it can be concluded that for the range of confining pressures investigated, the strength of the sleeve reinforced column can be estimated from a modified Coloumb strength equation.

REFERENCES

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