Strength evaluation of wet reinforced silty sand by triaxial test

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Abstract: Conventional investigations on the behavior of reinforced and unreinforced soils are often investigated at the failure point. In this paper, a new concept of comparison of the behavior of reinforced and unreinforced soil by estimating the strength and strength ratio (deviatoric stress of reinforced sample to unreinforced sample) at various strain levels is proposed. A comprehensive set of laboratory triaxial compression tests was carried out on wet (natural water content) non-plastic beach silty sand with and without geotextile. The layer configurations used are one, two, three and four horizontal reinforcing layers in a triaxial test sample. The influences of the number of geotextile layers and confining pressure at 3%, 6%, 9%, 12% and 15% of the imposed strain levels on sample were studied and described. The results show that the trend and magnitude of strength ratio is different for various strain level. It implies that using failure strength from peak point or strength corresponding to the axial-strain approximately 15% to evaluate the enhancement of strength or strength ratio due to reinforcement may cause hazard and uncertainty in practical design. Hence, it is necessary to consider the strength of reinforced sample compared with unreinforced sample at the imposed strain level. Only one type of soil and one type of geotextile were used in all tests.

Keyword: Triaxial test, soil reinforcements, geotextile, wet soil, strength, imposed strain

1. Introduction

Due to necessity of cost-saving, the reinforced soil has been widely used in geotechnical engineering applications such as construction of road and railway embankments, stabilization of slops, improvement of soft ground, and so on. Numerous papers have investigated the beneficial effects of soil reinforcement to increase the strength (McGown et al. [1], Gray and AL-Refeai [2], Athanasopoulos [3], Krishnasawamy and Isacc [4], Chandrasekaran et al. [5], Haeri [6], Latha and Murthy [7], Xie [8], etc) using triaxial, direct shear, and plane strain tests. Athanasopoulos [3] carried out a series test using direct shear test in order to study the effect of particle size on the mechanical behavior of geotextile reinforced sand. The results conducted that dilatancy behavior of the reinforced sand was affected by aperture ratio (defined as the ratio of the geotextile aperture size to the average sand particle size). Krishnasawamy and Isacc [4] performed cyclic triaxial tests to evaluate the liquefaction potential of sand with and without reinforcement. The results showed that the reinforced sand can be a promising solution to increase the safety against liquefaction. Chandrasekaran et al. [5] presented the results of the triaxial tests on both 100 and 200 mm diameters dry samples with woven and non-woven geotextiles. The results of tests showed that the deviatoric stress and axial strain at failure are increased with decreasing in distance of geotextile layers for both size samples. Haeri et al. [6] carried out triaxial compression tests in order to determine stress-strain and dilation characteristics of geotextile-reinforced dry beach sand. The results demonstrated that geotextile inclusion increases the peak strength, axial strain at failure, and ductility.

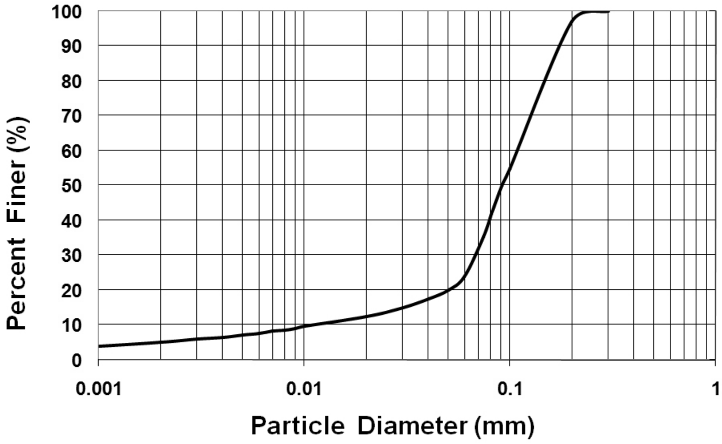

Fig.1 Particle size distribution curve for Bandarabbas silty sand

Table 1 Physical properties of sand

Description	Value
Coefficient of uniformity, C_u	11.0
Coefficient of curvature, C_c	4.45
Effective grain size, D_{10} (mm)	0.01
D_{30} (mm)	0.07
Medium grain size, D_{50} (mm)	0.09
D_{60} (mm)	0.11
Maximum void ratio, e_{max}	1.0
Minimum void ratio, e_{min}	0.54
Specific gravity, G_s	2.68
Angle of internal friction (degree) (triaxial test, RD=65%, $\omega = 15\%$)	36.0

Latha and Murthy [7] presented the results of triaxial compression tests on sand reinforced with different types of geosynthetics in different layer configurations to study the effect of quantity of reinforcement and tensile strength of the geosynthetic material on the mechanical behavior of the reinforced sand.

Current research works mainly emphasize on the strength of reinforced soil at failure point, whereas considering the strength of reinforced sample compared with unreinforced sample at the imposed strain level can show the new concept for strength of reinforced soil. The main purpose of this research is to investigate the behavior of reinforced and unreinforced soil at various strain levels. Hence, a comprehensive set of laboratory triaxial compression test was carried out on wet (natural water content) non-plastic beach silty sand with and without geotextile. The influences of the number of geotextile layers and confining pressure at different strain levels on strength and strength ratio were studied and described in this paper.

2. Test Material

2.1. Sand

Relatively uniform, clean, non-plastic silty sand from shores of the Persian Gulf in the city of Bandarabbas located in the south of Iran was used in this study. Fig. 1 shows the

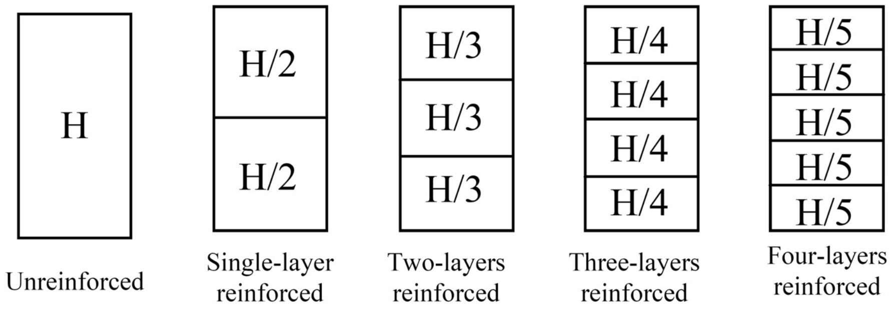

Fig. 2 Geotextile arrangements for triaxial tests

grain size distribution of soil. The property of the soil, which is classified as SM in Unified Soil Classification System, is tabulated in Table 1.

2.2. Geotextile

The geotextile used in this research, was made by an Iranian company. This type of geotextile is non-woven with weight of 120 gr/m²; nominal thickness of 1.2 mm and effective opening size of 0.12mm. The ultimate tensile load at break strain of 114% was measured approximately 594 N.

3. Testing Apparatus and Procedure

A standard triaxial compression apparatus (ELE Co.) was used for testing. The samples had a diameter of 38 mm and a height of 76 mm. The experimental data were collected by an automatic data acquisition system. For all of the tests, a strain rate of 0.35% per minute was used and all of the tests were continued up to a strain level of 20%. Corrections for the membrane effect and changes in the cross-sectional area of the sample were considered and implemented in the analysis of the experimental results.

In order to prepare the samples for testing, they were compacted in several layers. The layer compaction was by tamping technique applying undercompaction concept [9]. The weight of wet silty sand in each layer was measured and compacted carefully with a tamper consisting of a circular disk (with a diameter slightly less than the mold). This method has the advantage to obtain almost same density throughout the layers consistently. After compacting and leveling each layer of soil, the geotextile layer (with a diameter slightly less than the sample) was placed horizontally on the surface of layer. The number of layers for preparation of the specimen was selected between zero and four depending on the geotextile arrangement (Fig. 2). For all of the samples a relative density of RD=65% (equal to relative density in beach) and natural water content of ω=15% were used.

4. Experimental Program

A total of 28 laboratory triaxial compression tests in different series were planned and carried out. The first 8 tests were repeated carefully to examine the performance of the triaxial apparatus, the accuracy of the measurements, and the repeatability of the system, which proved to be quite satisfactory. The next 20 tests were scheduled to be performed under confining pressures of 50, 100, 300, and 500 kPa for without geotextile and four number of geotextile layers of 1, 2, 3, and 4. The geotextile arrangements for triaxial tests are shown in Fig. 2. These arrangements show that the height of the

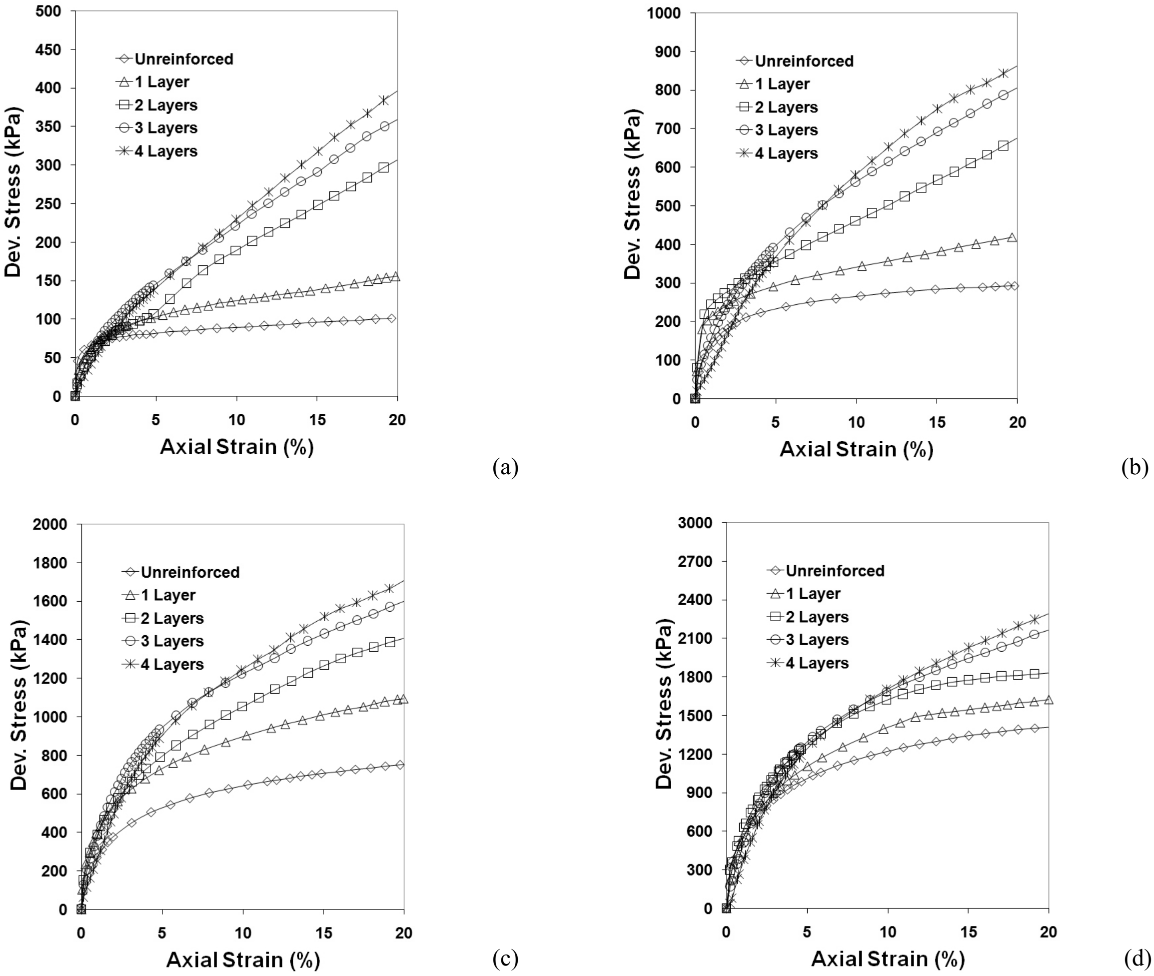

Fig.3 Stress-axial strain curves for reinforced samples under various confining pressure
(a) 50 kPa; (b) 100 kPa; (c) 300 kPa; and (d) 500 kPa

layers is equal.

5. Results and Discussions

The typical stress-strain curves for unreinforced and reinforced sample under confining pressure of 50, 100, 300 and 500 kPa with different number of geotextile layers have been shown in Figs. 3a-d. These figures indicate that the reinforcement increases the deviatoric stress and shear strength of the samples considerably, compared with unreinforced samples. This matter is essentially due to the increase in confinement; geotextile layers cause an internal confinement in reinforced samples, which has been explained by an increased confinement concept by Yang [10]. It can be observed that, there was no pronounced failure points in stress-strain behavior; as increasing the number of reinforcements resulted in more ductility of the samples as clogging developed in shear band within specimens. The figures also show that the beneficial effect of geotextile to enhance the strength of reinforced samples appear in high strain, while in low strain; geotextile layers does not have beneficial effect (in some cases of reinforcement for low strain level, the stiffness of sample decreases). It means that, the high strain levels should be imposed to

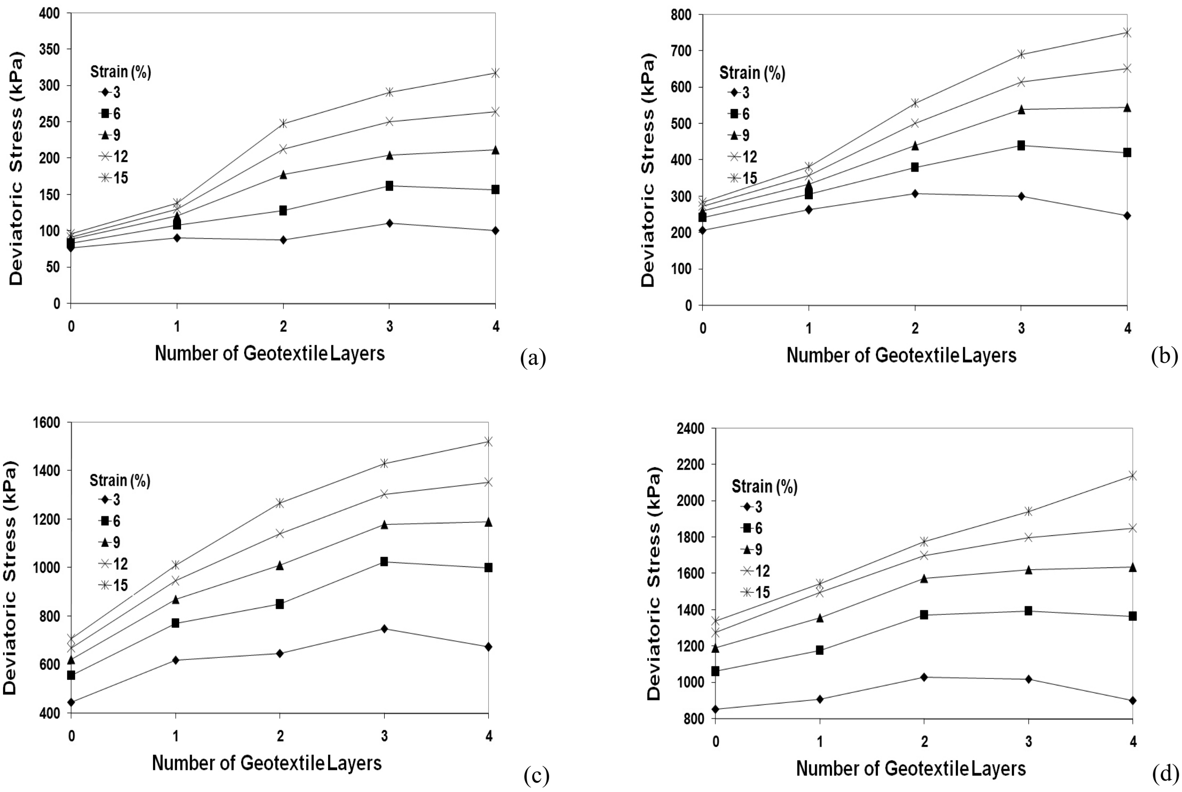

Fig.4 Deviatoric stress values versus number of reinforcement under various confining pressure at different strain levels (a) 50 kPa; (b) 100 kPa; (c) 300 kPa; and (d) 500 kPa

appear the effect of geotextile layers to increase the strength of samples. These comparisons indicate that the imposed strain level on the samples play an important role to increase the strength of the reinforced samples compared with unreinforced sample.

5.1. The Effect of the Number of Geotextile Layers on Strength at Different Strain Levels

Figs. 4a-d show the plots of deviatoric stress values versus number of geotextile layers (N), at different strain level of 3%, 6%, 9%, 12% and 15% and for different values of confining pressure of 50, 100, 300 and 500 kPa. It reveals that with increasing the number of geotextile layers, deviatoric stress (σ_d) increases up to a specific value of N (this value of N varies with strain level) and after that either the value becomes almost constant (or decreases) or the increase in σ_d is insignificant. The nature of the curves may be classified into two groups; one for strain level $\varepsilon \geqq 9\%$ and the other for $\varepsilon \leqq 9\%$. For the first group (higher strain levels) geotextile inclusion increases the deviatoric stress, significantly. It means that the geotextile layers cause an internal confinement. Moreover, for the first group, the rate of increase of with increase of N is more compared to that for the second group (lower strain levels) where the rate of increase of σ_d is not very significant. Also for lower values of strain (ε<9%) the value of σ_d after reaching the maximum values started decreasing. In this case for different values of confining pressure the optimum number of reinforcement layers is up to 2 or 3 layers.

In order to evaluate the effects of the strain level on the strength of the reinforced soil, strength ratio parameter in specific strains is introduced which is defined as:

$$\text{Strength Ratio} = \frac{(\sigma_d)_{\varepsilon_i}^{rein.}}{(\sigma_d)_{\varepsilon_i}^{unr.}} \tag{1}$$

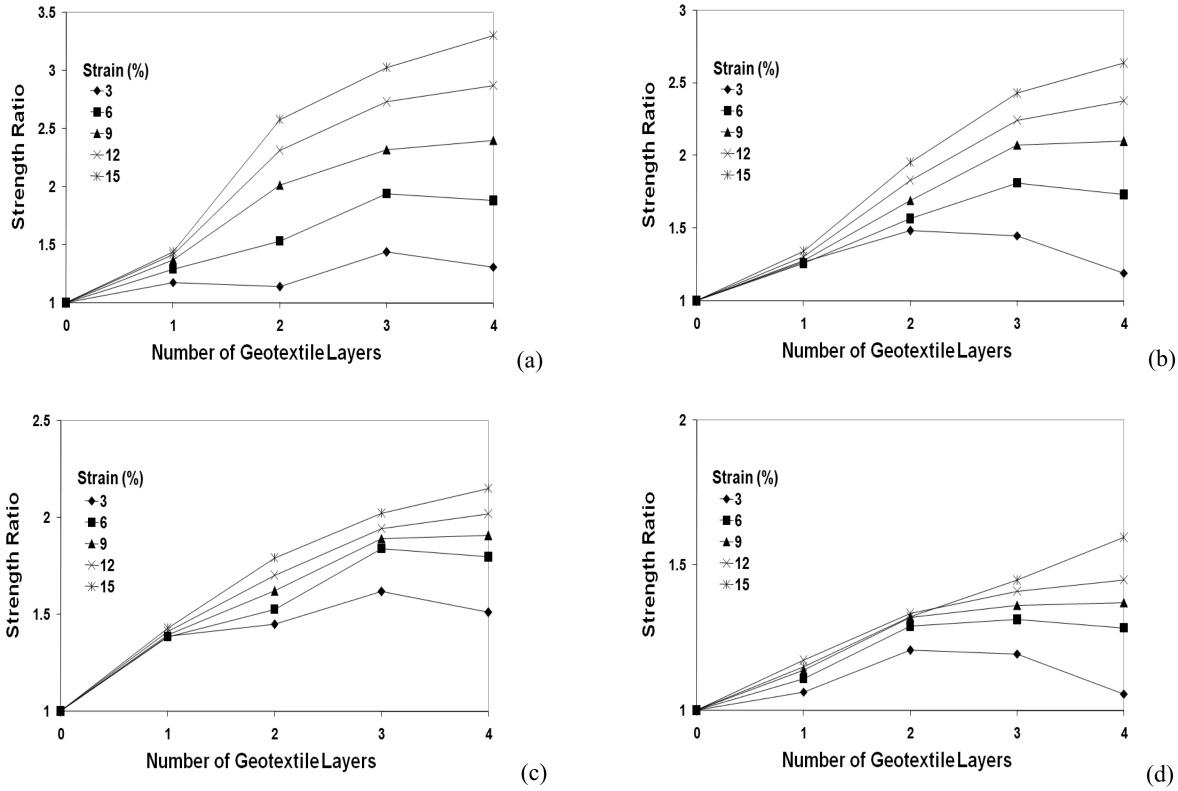

Fig. 5 Strength ratio values versus number of reinforcement under various confining pressure at different strain levels (a) 50 kPa; (b) 100 kPa; (c) 300 kPa; and (d) 500 kPa

Where $(\sigma_d)_{\varepsilon_i}^{rein.}$ and $(\sigma_d)_{\varepsilon_i}^{unr.}$ are the deviatoric stress for reinforced and unreinforced sample at any strain level, respectively. According to this definition, strength ratios in specific strain under different experimental cases can be calculated, as shown in Figs. 5a-d. These figures show the similar trend of the curves for strength ratio versus N for different values of strain and different values of confining pressure. The graphs indicate that, there is a substantial increase in strength ratio due to increase the number of reinforcement layers, irrespective of confining pressure. Also, the percent increase is more clearly for high strain level. For example, in two-layers of reinforcement under confining pressure of 50 kPa, the strength ratio increase about 158% (strength ratio =2.58) for strain level 15%, whereas there is only 53% (strength ratio =1.53) increase under strain level 6%. Hence, the strength ratio (or strength) of reinforced soil compared with unreinforced soil should be considered at the specific level of strain which defined as allowable value to design.

5.2. The Effect of Confining Pressure on Strength at Different Strain Levels

Deviatoric stress of samples at different values of strain level versus various confining pressure for one, two, three and four layers of reinforcement are depicted through Figs. 6a-d. These figures indicate that strength of reinforced sample increase with increasing confining pressure irrespective of reinforced layers or strain level. The stress paths are clearly bilinear or curve. The break in the bilinear or curve occurs at around 100 kPa confining pressure irrespective of reinforced layers or strain level. This behavior and the measure of the breakage point corroborate earlier triaxial results on geotextile reinforced sand reported

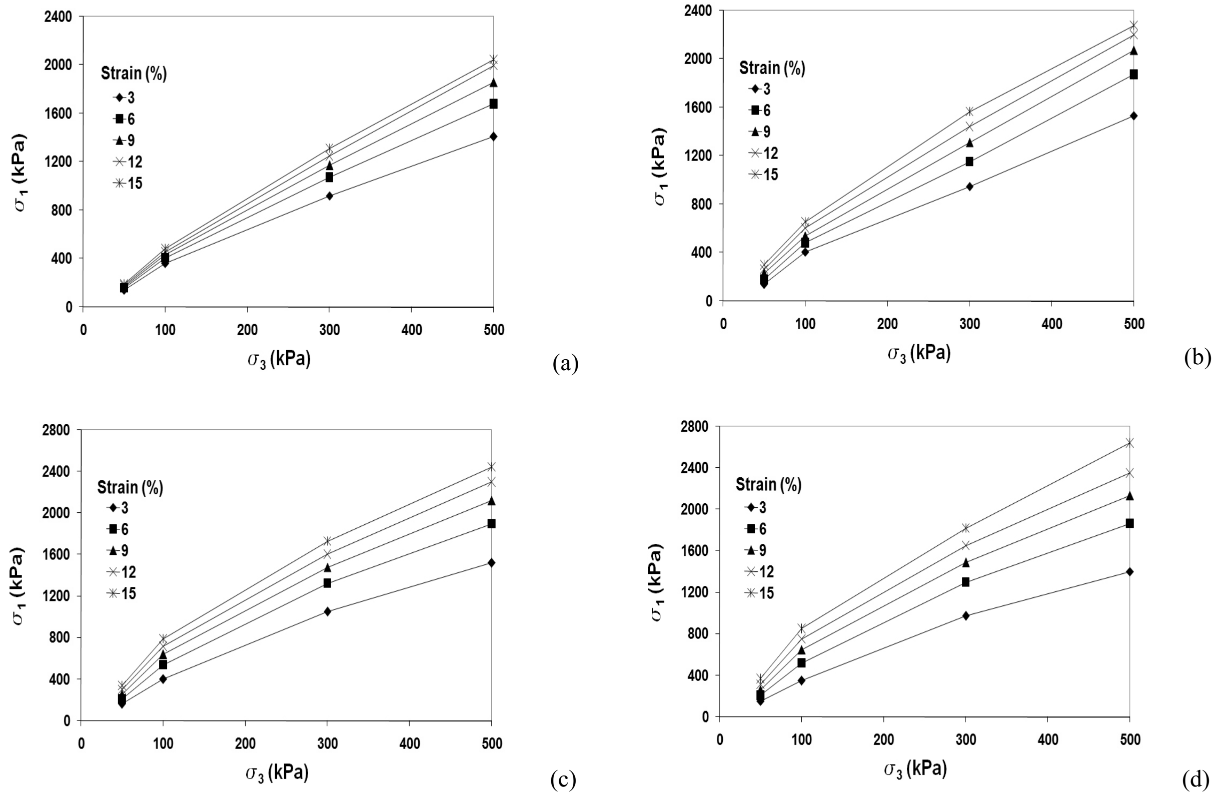

Fig.6 Strength values versus confining pressure for various number of reinforcement at different strain levels
(a) N=1; (b) N=2; (c) N=3; and (d) N=4

by Gray and Al-Refeai [2], Haeri et al. [6] and Gray et al. [11] at failure point.

Figs. 7a-d show the variation of strength ratio versus confining pressure for different values of strain and different values of reinforced layers. It illustrates that, For number of reinforced layer greater than one and higher value of strain ($\varepsilon \geqq 9\%$), the strength ratio decreases with an increase in confining pressure. Consider, for example in two-layers of reinforcement and 9% strain level, the strength ratio increase about 102% (strength ratio =2.02) under confining pressure of 50 kPa, whereas there is only 31% (strength ratio =1.31) increase under confining pressure of 500 kPa. The reason could be the decrease in interaction between the geotextile and soil correlated with increasing in confining pressure. On the other hand, it indicates that the reinforcement at high confining pressure (at the high depth below the ground surface) is not very effective. This behavior at high strain values ($\varepsilon \geqq 9\%$) corroborate earlier triaxial results of geotextile reinforced sand reported by Haeri et al. [6] at the failure point.

For number of reinforced layer greater than one and low value of strain ($\varepsilon \leqq 6\%$) it reveals that the strength ratio increases with increase in confining pressure for up to 100 or 300 kPa value of confining pressure and after that the value decreases. This fact implies that there is an optimum depth (corresponding to confining pressure) to soil reinforcement in low strain level.

It is clarified that using failure strength from peak strength or strength corresponding to the axial-strain approximately 15% (Lambe and Whitman, [12]) to evaluate the effect of reinforcement on strength (or strength ratio) without considering the imposed strain level

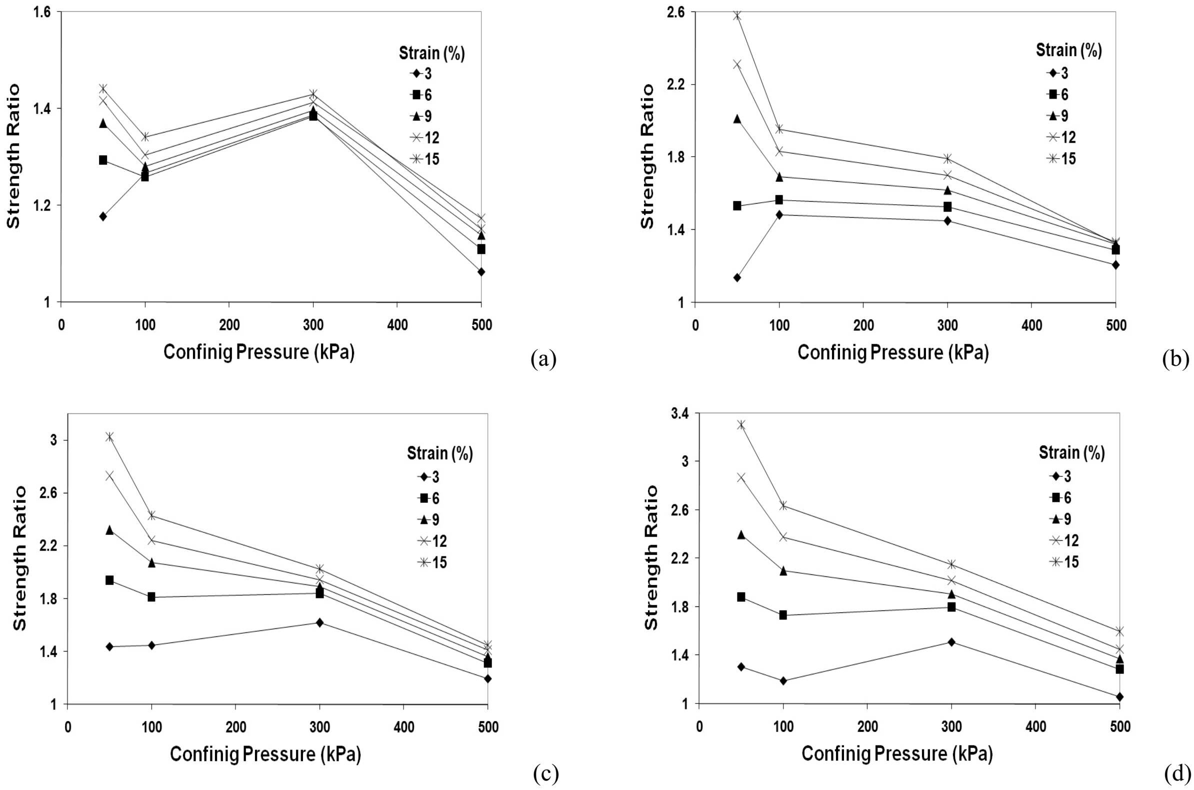

Fig.7 Strength ratio values versus confining pressure for various number of reinforcement at different strain levels (a) N=1; (b) N=2; (c) N=3; and (d) N=4

on the soil can be caused hazard and uncertainty in practical design. Hence, it is necessary to consider the strength (strength ratio) exactly in imposed strain level. Finally, for the one layer of reinforcement was not found the significant conclusion related to the strain level and confining pressure.

6. Practical Applications

The important aspect of specifying a maximum strength for a given soil by reinforcing is to be able to select a suitable relative density of soil, number of reinforced layers at any confining pressure. All of the researchers have investigated the effect of reinforcement on strength of soil at failure strain. As can be known, in engineering application the value of strain (or settlement) should be limited to the value of allowable strain. Hence the comparison of reinforced and unreinforced soil should be considered at different values of strain level. The results of this study indicate that considering the level of strain which is imposed on the specimen play an important role on the behavior of reinforced soil and influence of reinforcement. However, the obtained results can be applied in making initial estimates of strength of the wet reinforced silty sand in this study and other having similar grading and characteristics.

Although the results obtained in the present paper are encouraging to consider the role of strain on strength value of reinforced soil. It should be noted that as the triaxial specimens are too small to represent physical modeling of a reasonable prototype, the results obtained from these tests may not be representative of in situ performance and were used in context of the comparative study. Obviously additional research on larger scale tests together field tests would be required to extend the results to in situ conditions. Study of the behavior of soil reinforced with different value of water content to consider the various strain level in a larger scale is the subject of upcoming research by the authors.

7. Summary and Conclusions

In this paper the role of strain level on strength of wet reinforced non-plastic beach silty sand has been explored using triaxial compression tests. Soil alone and soil reinforced with one, two, three and four layers of geotextile under four different confining pressures tested. The results show that the number of layers of reinforcement, confining pressure and strain level are key factors affecting strength values of the reinforced soil. These can change the strength value in range of 25-325%.

For number of reinforced layer greater than one and strain higher than 9%, the strength ratio decreases with an increase in confining pressure. This value decreases from 325% to 40%. It indicates that the reinforcement at high confining pressure (at the high depth below the ground surface) is not very effective. Also, there is an optimum depth (corresponding to confining pressure) to soil reinforcement in low value of strain ($\varepsilon \leqq 6\%$) and number of reinforced layer greater than one, as the strength ratio increases with increase in confining pressure and after that the value decreases.

The above results show that the trend and magnitude of strength ratio can be changed for various strain level. It implies that using failure strength from peak point or strength corresponding to the axial-strain approximately 15% to evaluate the strength ratio due to reinforcement may cause hazard and uncertainty in practical design. Consequently, it should be considered the strength ratio at the imposed strain level.

8. References

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