Experimental and Numerical Study of Reinforced Silty Clay Soil in Delta

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Abstract:-**Soil reinforcement is a recent and special field of soil improvement. It covers a range of techniques, which consists of placing inclusions in soil. The most studies devoted partly or totally the behavior of foundation on reinforced subgrade without regarding the basic characteristics of the reinforced soil. So, the paper presents an experimental investigation into the mechanical and compressibility properties of the reinforced silty clay samples by jute cloth Geotextile (JGT) at intermediate depth, also, the paper studied numerically the effect of JGT reinforcement on the bearing capacity of footing on silty clay soil using Plaxis software. The effects of the reinforcement on shear stress and shear failure were studied. The results indicated that the presence of such reinforcement has a considerable effect in increasing the shear strength of the reinforced samples, decreasing compressibility and increasing bearing capacity of foundations constructed on reinforced soil.**

Keywords: **Soil reinforcement, Jute cloth geotextile, Shear stress, Shear parameters, Compressibility, Bearing capacity, Plaxis.**

I. INTRODUCTION

Recently there has been a strong demand for the use of Geotextiles for improving mechanical properties of cohesive soils. Because these properties played important role in determination of the bearing capacity and settlement under foundations. Also, it were used in a wide range in computer programs. The bearing capacity problems of different foundations on reinforced soils are getting wider day by day with advent of the researchers to improve the foundation soil conditions. The techniques of soil reinforcement were done by including new materials into the soil in various forms as Multi membrane and grid which, including fabrics as geogrid, geocel and commonly geotextiles. The geotextile membrane can withstand only tensile forces. The most important kinds of fabrics are geotextile and geogrid. Geotextile is the name now universally adopted for fabrics used in geotechnical engineering. They have been used extensively in reinforcement of soil for foundation uses. For more than a decade geotextile fabrics have been used for subgrade stabilization of soft foundation soils. Applications of fabrics in civil engineering have been successfully developed and offer benefits in terms of economics, durability and performance. Fabrics play important role in geotechnical engineering works, especially highway and railroad, reinforced soil, stabilization of soil or rock slopes, drainage control, embankment, dams, and tunnels.

Fabrics are now commonly used as reinforcement material to improve the load bearing of various soils, soft soil and weak soils. The mechanism of load bearing of soil reinforcement with reinforcement depends on the interface friction between the reinforcement and the soil. Fabrics are also used as a reinforced material with earth structure. Otherwise, the use of fabric is one of the effective means of stabilization poor soils where they are used worldwide in many areas of civil engineering works.

Geosynthetics are now commonly used in many civil engineering applications and especially in solid and liquid hazardous waste containment and municipal landfills. Much work has been carried out during the past decades on the behavior of the reinforced earth retaining wall e.g.[1]. The application of soil reinforcement for improving the bearing capacity and the load settlement response of the foundations, the base for pavements and embankments on soft soil were studied.[2], proved that the presence of tensile reinforcing strips under footing increases and improves the bearing capacity of supporting soil and decreases the stress over weak layer.[3], [4],[5-6], [7], studied the method of improving the bearing capacity of footing model resting on sand subgrades reinforced by a variety of reinforcement. While [8-9]studied the application of the composite fabrics on soft ground and reinforced soil structure without determination of the mechanical or any characteristics of reinforced soil.

For extent[10] and [11] explained the improvement of the bearing capacity of strip footing by using geosynthtic reinforcement placed in horizontal manner. [12] investigated the suitability of using some natural material as reinforcement for sand. Generally, the basic concept of Reinforced Earth material is presented. This material results from the association of the two components having different moduli of elasticity. A stress applied to the mass will cause strain in the soil that will transmit the tensile load to the strips. The displacements are restrained in the direction of the strips causing the reinforced mass to behave like a cohesive anisotropy material. Hence, the concept of Reinforced Earth is based on a frictional earth-reinforcement interaction.

The last mentioned papers describe the results of the loading tests on a Varity of horizontal reinforced layers beneath the footing. It deals with the study the effect of the existence of reinforcement on the bearing capacity of any footing without considering the effect of the existence such reinforcement on the mechanical properties of the tested soil. So, the present paper aims to study and evaluate both the mechanical characteristics of reinforced alluvium soil in central delta by a jute cloth Geotextiles (JGT) and studied numerically the effect of JGT reinforcement on the bearing capacity of footing on reinforced soil using Plaxis software. Where a jute cloth is locally available and economy. The subsequent study involved soil characterization and reinforcement material evaluations to determine appropriate parameters for design and construction control for reinforced samples.

Site under investigation and sampling

The tested samples were taken from the alluvium soil in central Delta in Egypt. Where many borings showed that there is a layer of alluvium or a thick silty clay covered the middle Delta. The percentage of silt in soil samples ranged between 69% to 75%. In general a layer of silty clay in Delta with thickness range from 1 to 6m at depth range from 2 to 11 m in all parts in central Delta. All samples were taken at intermediate depth of 3m below the ground surface.

Testing Program

A complete laboratory program is performed on each sample as following:

1. Hydrometer analysis. The grain size distribution curve for the tested samples are shown in Fig. (1). The sample is classified as silty clay with trace of sand (8% sand : 70% silt
: 22% clay)
2. Atterberglimits, which mean the determination of the water content, liquid limit, plastic limit and plasticity index. The consistency values were determined according to ASTM specification respectively as follows: wc=33%, LL=37, PL=15and PI=22. The initial void ratioeo was found to be 0.9248 at bulk density 18.5 kN/m^3 and specific gravity (GS = 2.68).
3. Direct shear tests for both unreinforced and reinforced samples to study the effect of the existence of the reinforcement on the shear parameters of the tested sample and induced shear stresses. The apparatus used in these tests is the shear box apparatus.
The box is square (6 cm x 6 cm) in section by (2 cm) thick and it is split horizontally at level of the center of the soil specimen, the lower half of the box is rigidly held in position in a container. Where, a series of direct shear tests at different normal stresses were carried out for both reinforced and unreinforced sample.The samples were reinforced by reinforced elements at the middle part of the plan of failure in direct shear to simulate the actual state in the field. All tests were carried out at submerged state and at bulk density of 18.5 kN/m^3.
4. Consolidation tests for both unreinforced and reinforced samples to determine the basic compressibility characteristics. The convential oedometer was used. It consists of a consolidation cell of diameter (11 cm), brass rings diameter (7.5 cm) and height (1.9 cm). Porous plate machine to fit into the ring, bottom porous plate of diameter (7.5 cm) and a loading cap. A series of the consolidation tests were carried out at submerged state for both reinforced and unreinforced samples, the samples were reinforced by reinforced elements at the middle depth or on the halve of the odometer ring.

Reinforced elements

The adopted reinforcement element is a woven type jute cloth. Its physical and strength properties were determined in the laboratory using standard methods of ASTM for Geotextiles The thickness, mass per unit area and breaking strength or failure strength were measured as 1.25 mm, 0.35 kg/cm^2 and 10.9 N/mm respectively. The failure strength at elongation 14.5%.

II. EXPERIMENTAL RESULTS

Fig. 3-4 shows the shear stress versus shear displacement curves at the three-stress level of normal stress for specimens with and without reinforcement. The same is true for the residual shear strength. It has been found that the peak shear strength increases with normal stress for both reinforced and unreinforced samples. The increase in the shear strength leads to decrease in the shear displacement as illustrated in the last figures.

The existence of the reinforcement at the interface in the direct shear was distinctly reduced the shear displacement because such reinforcement was induced additional shear strength. In addition, the shear modulus of the reinforced samples exhibits no change under various normal stress, but larger than that under zero normal stress and without reinforcement. On the other hand, the maximum shear displacement at peak shear strength for reinforced sample falls within a narrow range, with an increase in normal stress from 15 kN/m^2 to 55 kN/m^2. the shear displacement falls from 0.4cm to 0.33cm. Generally, with a few exceptions, both the peak and residual shear strengths are larger for specimens with reinforcement than those without reinforcement.

Basically, two types of failure were encountered, that is, peak failure and slippage failure. A peak failure was distinguished in the unreinforced soil by the sliding between the particles of the samples, which located between the upper and lower part in the direct shear. A slippage failure was distinguished by occurrence of splitting or rip off between the reinforcement material and the soil. The slippage failure related to applied normal stress, type of soil and interface friction ofthe reinforcement.

Shear stress versus normal displacement

In all tests, before the initial failure, that is, yield point, the vertical displacement was very insignificant or slightly increased. But thereafter, it followed two pattern of behavior depending on the types of failure. As applied stress in the specimens reached its yield point, the vertical displacement began to increase and continued to increase until peak failure occurred. This is clarified and confirmed by the figure. 4, which show the relationship between the shear stress and the vertical displacement at a given normal stress. It was expected that the existence of the layer of reinforcement decrease the vertical displacement, where the reinforcement prevented soil particles vertical movement i. e. reducing the settlement. Also, it has been found that, when the applied stress in unreinforced samples reached the peak failure strength and the failure occurred the general trend of vertical displacement was decreased until the development of the residual stress then it became constant except for slight variations. On the other hand, for the reinforced sample the vertical displacement generally continued to increase until the test was completed because the soil not reached to failure. Also, the variation in the vertical displacement was decreased in unreinforced soil sample. The variation of the magnitude of the vertical displacement was also affected by the magnitude of the normal stress, soil type and reinforcement type.

Failure curves for reinforced and unreinforced soils

Fig. 5 show the shear stress versus normal stress curves for both reinforced and unreinforced samples. The linear regression was used to analyze the test data to study the effect of the reinforcement on the shear parameters of tested samples. It can be indicated that the failure curves can be adequately represented by a straight line. The slope of this line corresponds to the internal friction angle and its coordinate at the origin corresponds to the apparent cohesion. As shown in fig. 5, the shear parameters results of the unreinforced sample were, angle of internal friction (ϕ=15°) and cohesion (C = 24 kN/m^2).

On the other hand, the existence of the reinforcement increased and improved the mechanical parameters of the tested sample where, the reinforcement had a considerable effect on increasing the shear strength of soil due to frictional interaction between the soil and inclusions. In the other way, for the reinforced samples, it can be observed that the expected values of the angle of internal friction (ϕ=20°) and cohesion (C = 31 kN/m^2). That means the reinforcement had a distinctly effect on the mobilization of addition shear strength where the angle of intemal friction was increased by (33%) and the apparent cohesion also increased by (29%) of its initial values.

III. CONSOLIDATION TEST RESULTS

Variation of void ratio vs vertical stress

The results of consolidation test are usually presented in the form of voids ratio versus logarithm of effective pressure. These results are presented through fig.6 for both reinforced and unreinforced samples. It is clearly seen that the void ratio decreases as the vertical stress increases for two cases. That is backed to the pore water pressure dissipation. The existence of the reinforcement sharply decreases the void ratio with the comparison of unreinforced sample.

It has been found that at the pressure 100 kN/m^2 the void ratio sharply decreased for each case because the reinforcement decreased the settlement. Also, the compression index Cc of the reinforced samples was less than unreinforced samples that because, the inclusions decreases the compressibility of the tested soil. For extent, the value of the coefficient of compressibility a_v for the unreinforced sample was found to be (a_v= 0.00098 rn^2/kN) and the coefficient of volume change (m_v= 0.00049 m^2/kN).And the modulus of elasticity of the ordinary samples (E = 2040 kN/m^2). But for the reinforced samples it has been noticed that values of the compressibility factors (av = 6.65 x 10^{-4}m^2/kN and mv = 0.00035 m^2/kN) were decreased due to reinforcement effect. It was expected that the inclusions decrease the settlement and increase the modulus of elasticity of the reinforced samples (E = 2850 kN/m^2). i. e. the reinforcement improved the compressibility of soil to sustain any deformation and reduces the stresses within the soil.

Effect of the reinforcement on the drained properties

In order to study the effect of the reinforcement on the coefficient of permeability of the tested sample. The relationship between the settlement and log time for both reinforced and unreinforced sample was plotted in fig. 7. It noticed that the settlement of all samples increases with time and the existence of reinforcement decreased the settlement. That means the reinforcement decreased the flow and drainage of water in samples. Otherwise, the coefficient of consolidation (Cv) can be obtained at degree of consolidation (U = 50%). The extracted values of Cv for both unreinforced and reinforced sample were (3.675 mm/min and 2.05 mm/min). And the corresponding coefficient of permeability were found (K = 3x10^{-8} cm/sec) for unreinforced sample and (K =1.35x10^{-9} cm/sec) for reinforced sample). It concluded that the reinforcement played an important role in controlling the flow of the water through the reinforced samples, it can decrease the coefficient of permeability and delay the consolidation process. These reasons were reflected on decreasing the resulting settlement.

Numerical study

A plane strain elasto-plastic finite element method program (PLAXIS 8.6) [13] was used in the finite element analysisto study the effect of adding jute cloth Geotextile (JGT) inclusions to the silty clay on the behavior of centrally loaded footing on the top of reinforced soil. Full modeling of soil, reinforcing elements, footing and loading are performed using commercial FEM package PLAXIS Version 8.6.

Numerical Model Setup

The soil was modeled using well-known Mohr-coulomb model which has been considered as a first order approximation of real soil behavior. This elasto-plastic model requires the parameters shown in Table 1.

Table 1. Soil Properties

Unit weight	18.5 KN/m^3
Young's modulus [E_{ref}]	2040 KN/m^2
Poisson ratio [υ]	0.4
Cohesion [c]	24 KN/m^2
Angel of internal friction [ϕ]	15°
Dilatancy angle [Ψ]	0°

The jute cloth geotextile (JGT) was modelled using elasto-plastic constitutive model with the parameters shown in Table 2.

Table 2. JGT Properties

EA	**1000 KN/m**
Np	**10.9 KN/m**

Where: EA: Axial/Normal Stiffness

Np: Ultimate tensile strength of JGT

The footing was modelled as a rigid plate element. The geometry of the model is shown in fig. 8 where u is the depth of first layer of reinforcement from the bottom of footing and was chosen to equal 0.25 footing width B (u=0.25B). The vertical spacing between geotextiles layers were equal to 0.25B. The length of geotextile layers L is equal to six times the footing widthB (L = 6B). The maximum no. of geotextiles layers is three.

An interface element between the soil and the Geotextile had the typical value of R_{inner} =0.85 is used. The boundary conditions are assumed such that the vertical boundaries are free vertically and constrained horizontally while the bottom horizontal boundary is fully fixed as shown in fig. 9. Figs. 10-11 show the deformed mesh of the model and vertical displacement after application of footing load in case of reinforced soil with 3 layers of geotextiles.

IV. RESULTS AND DISCUSSION

The results are presented on the relation between the stresses under the footing in (KN/m^2) versus its associated settlement in (cm).fig. 12 shows the relationship between the footing stress versus settlement in case of unreinforced soil and reinforced soil with 1,2 and 3 layers of geotextiles respectively. From fig. 12 it was observed that geotextile reinforcement improves the ultimate bearing capacity of footing. The improvement reaches an increase in bearing capacity by a maximum percentage of 84% in case of using 3 layers of reinforcement. Also, it was noted that the increase in bearing capacity is not associated with a decrease in settlement for the same stress value.

V. CONCLUSIONS

1. Based on direct shear test it was concluded that reinforcement had a considerable effect on increasing the angle of internal friction and the apparent cohesion. The percentage increase was about 33% for angle of internal friction and 29% for cohesion.
2. The presence of the reinforcement was modified the failure pattern from peak failure to slippage failure
3. Based on the consolidation tests, it has been found that the presence of the layer of reinforcement at the middle of sample decreased the compressibility parameters. Also, the reinforcement has a remarkably effect on decreasing the coefficient of volume change and increases the modulus of elasticity which leads to decreasing the settlement
4. The inclusion of the reinforced soil decreasing the coefficient of the permeability which means, that the use of such reinforcement delays the consolidation process.
5. Based on the results of finite element model it was concluded that placement of reinforcement layers at an appropriate location in the body of clay soil resulted in a significant increase in the bearing capacity of footing.
6. The improvement reaches an increase in bearing capacity by a maximum percentage of 84% in case of using 3 layers of reinforcement.
7. The most beneficial effect of geotextile reinforcement on the bearing capacity is realized when the first layer is placed at a depth of about 0.25(u=0.25B) below the bottom of the footing.
8. Reinforcements placed below a depth B measured from the bottom of the foundation do not have any influence on the ultimate bearing capacity of a foundation.
9. Geotextile reinforcement do not have much influence on the foundation settlement at ultimate load. For the present tests, the ultimate load occurred at an average settlement of about 0.22B which is large.

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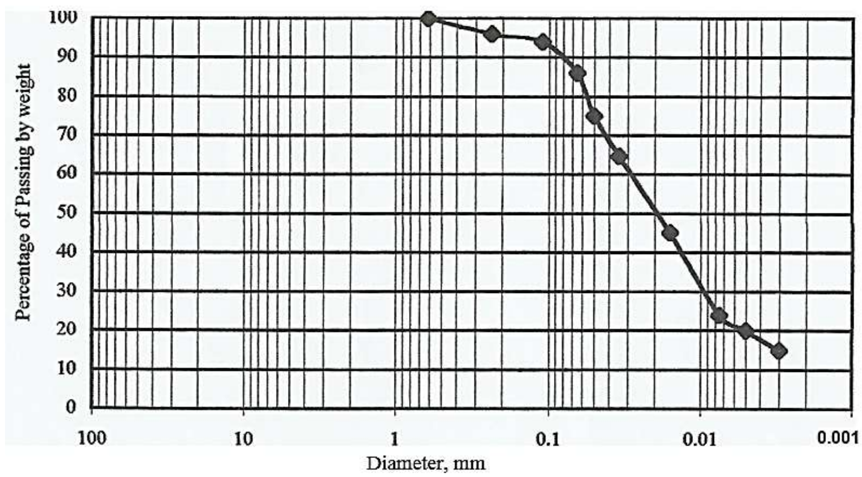

Fig. 1 Grain size distribution curve from Hydrometer test for the tested sample

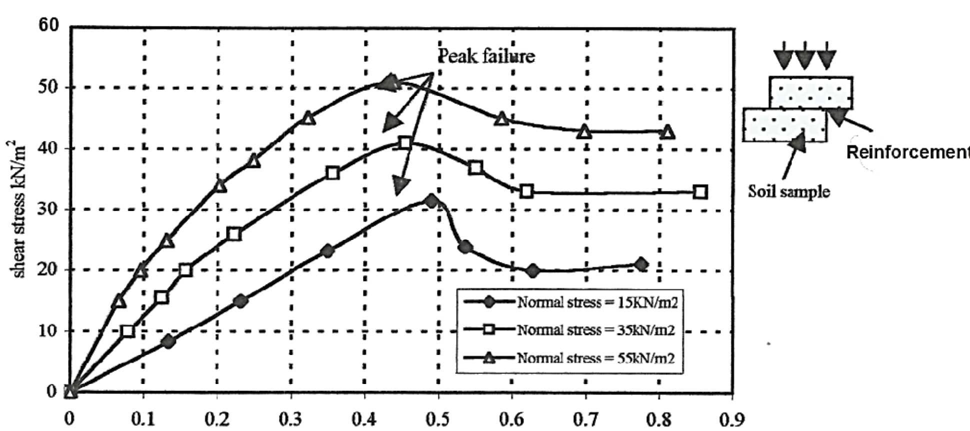

Fig.2 Shear stress versus shear displacement curves at three levels of normal stress for unreinforced soil

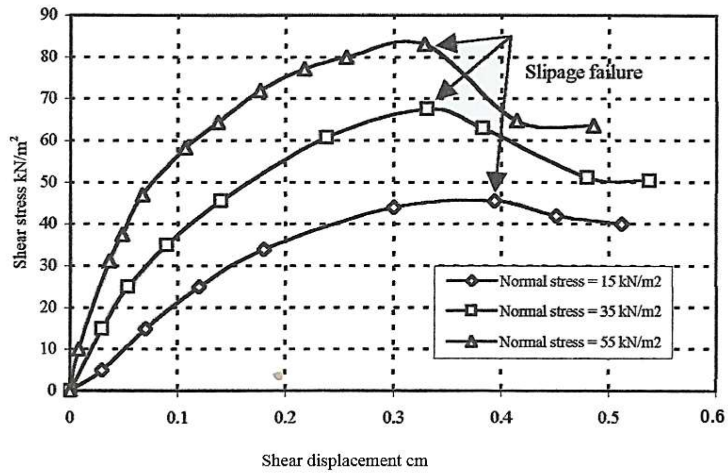

Fig.3 Shear stress versus shear displacement curves at three levels of normal stress for reinforced soil

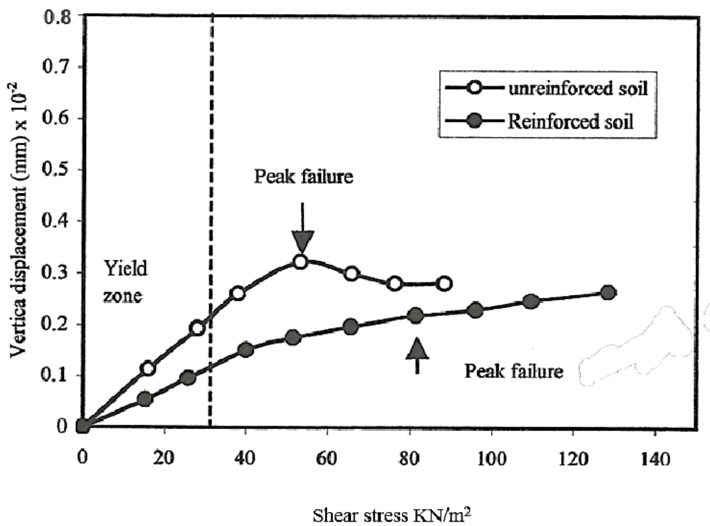

Fig.4 Shear stress versus vertical displacement at the same normal stress for reinforced and unreinforced soil

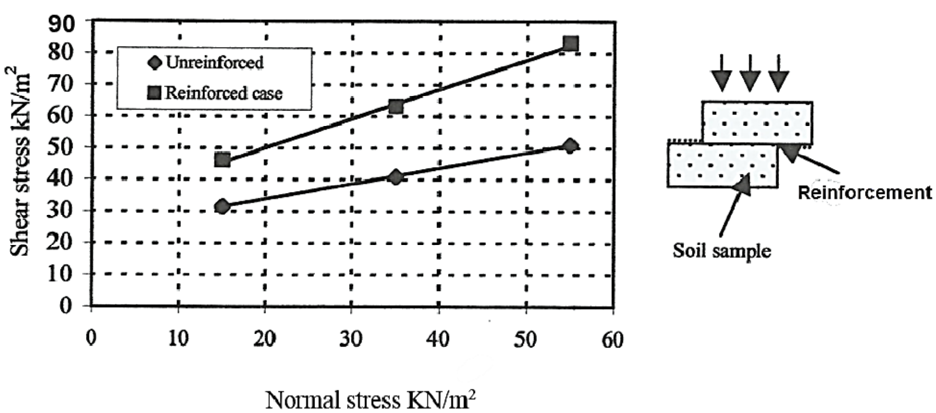

Fig.5: Failure curve for reinforced and unreinforced soils

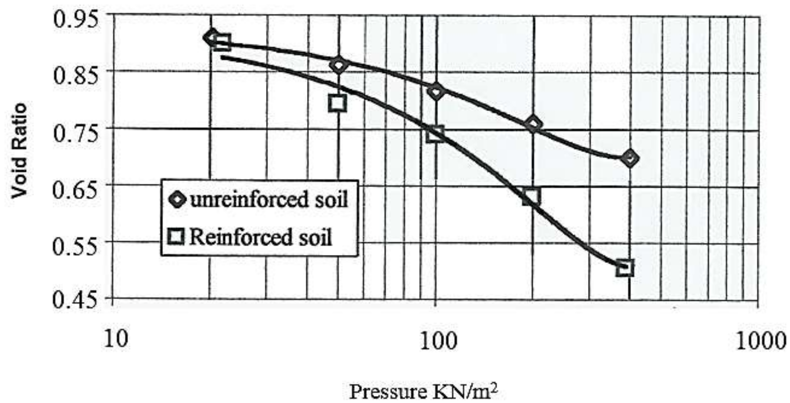

Fig.6: The relationship between the void ratio and pressure for reinforced and unreinforced soils.

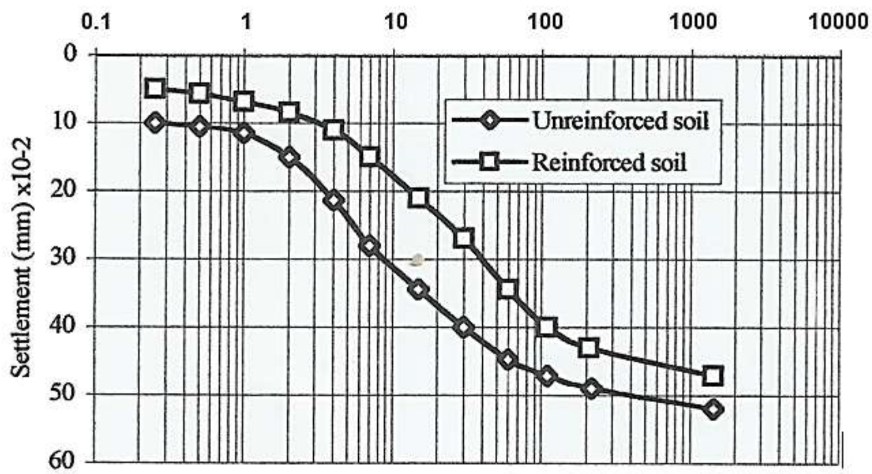

Fig.7 Settlement - log time curve for reinforced and unreinforced soils at normal stress 100 KN/m^2

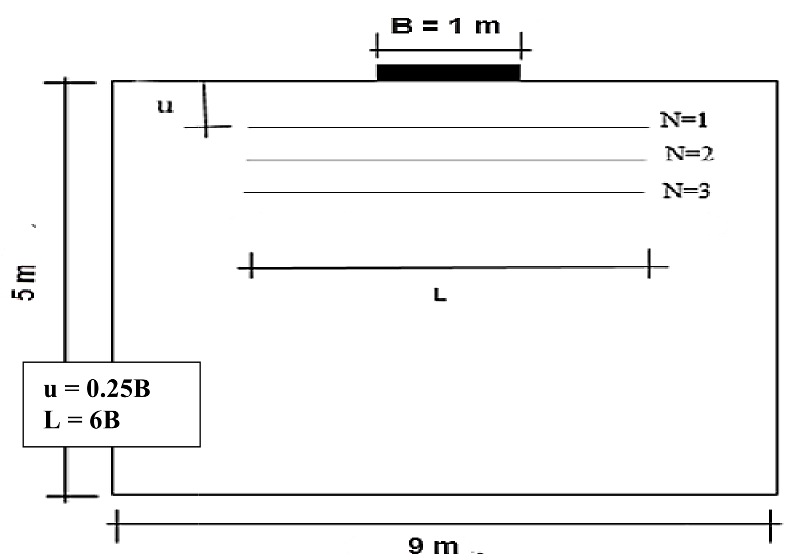

Fig.8Geometry of finite element model

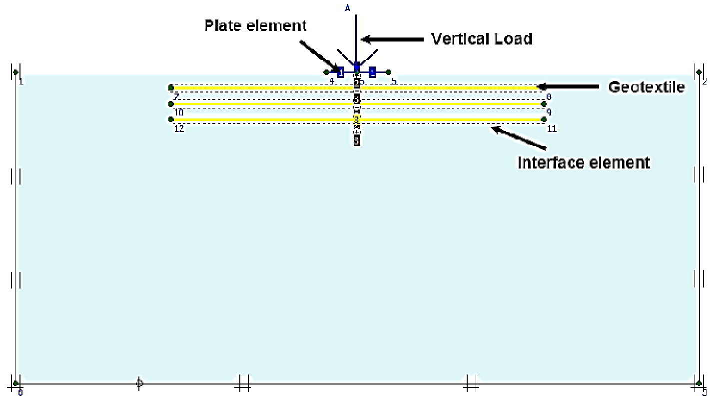

Fig.9Finite element model showing the load and boundary conditions

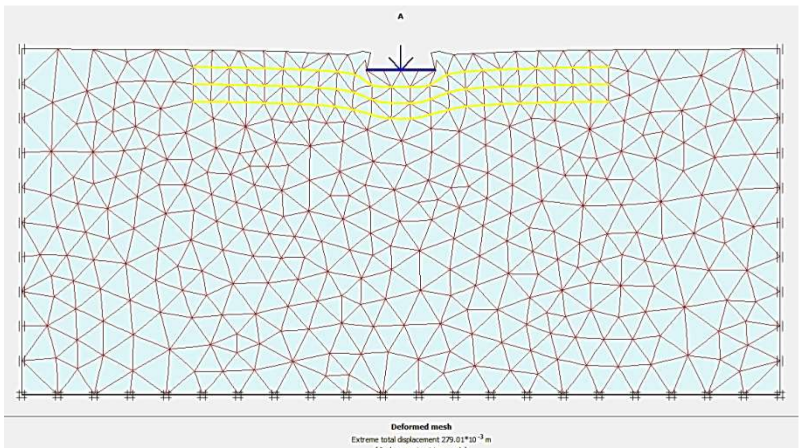

Fig. 10 Deformed mesh

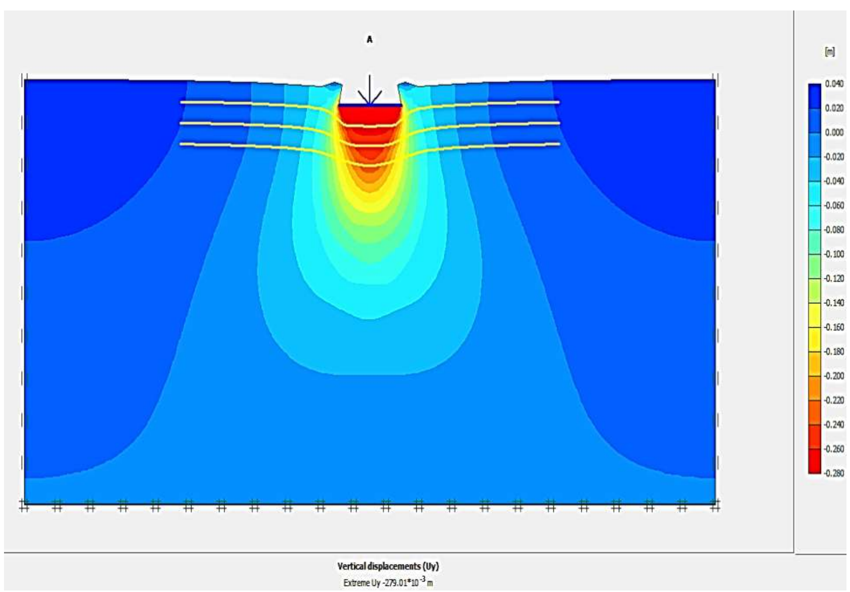

Fig. 11 Vertical Displacement (U_y)

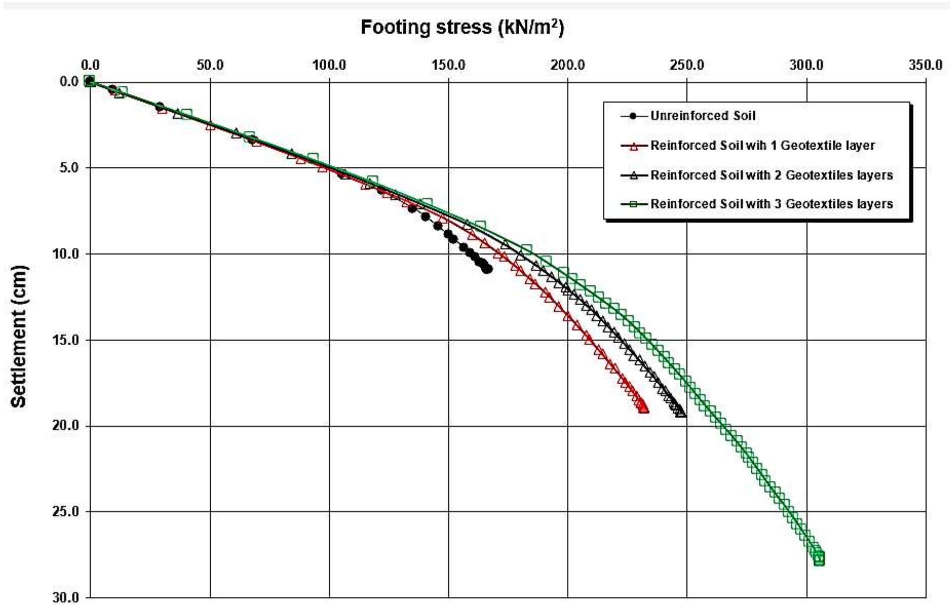

Fig. 12 the relationship between the footing stress versus settlement in case of unreinforced soil and reinforced soil