EVALUATION OF EFFECT OF STIFFNESS AND ORIENTATION OF REINFORCEMENT ON THE SHEAR STRENGTH OF SAND

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***Abstract** - Reinforced soil is any soil system in which some reinforcing elements called inclusions are placed to improve its mechanical properties. The reinforcement restrains lateral deformation of the surrounding soil through soil-reinforcement interface bonding, increases its confinement and reduces its tendency for dilation which consequently increases the stiffness and strength of the soil mass. Soil-reinforcement interaction studies reported in literature are mostly concerned with the use of reinforcement in axial tension. Soil is relatively strong in compression and shear and is weak in tension. Large scale experimental study on soil-reinforcement interaction in the literature supported the conclusion that the improvement in soil strength attained from the bending stiffness of the reinforcement is always small as compared to the improvement obtained from the axial capacity of reinforcement. The objective of the current investigation is to evaluate the effect of orientation of reinforcement with respect to shear plane on the shear strength of soil using small size direct shear tests. A series of small size direct shear tests were conducted on clean, poorly graded medium grained sand under undrained condition. The two type of reinforcements were used; 25mm long black annealed reinforcement binding wire (glued with and particles to provide required friction), 3 in number embedded centrally in a single row (perpendicular to the direction of shear); 55 mm long and 25mm wide flexible wire mesh strips, 3 in number embedded centrally in the sand. The sand was tested in loose and medium dense states with reinforcement orientation (θ) varying from 0° to 40° with vertical. The reinforcements were only embedded in the sand and were not anchored to the shear box at any point.*

Key words: Sand, Reinforced Sand, Cohesion-less soils, soil-reinforcement Interactions, Rigid Reinforcement, Flexible Reinforcement, Orientation, Direct Shear Test.

1. INTRODUCTION

Reinforcing a soil mass by means of reinforcing elements, called inclusions, involves placement of inclusions in the regions of soil matrix where their presence will result in a favorable redistribution of stresses and strains. The inclusions cause an enhance in shear strength of the composite material and a decrease in its compressibility. Higher loads can be applied to the reinforced soil structure than an unreinforced one. The rapid development of geo-synthetics for soil reinforcing is a historic milestone in soil improvement techniques. Initially, reinforced earth structures were built with metallic strips, granular backfill and facing panels. This application demonstrated an economic and technical advantage over traditional retaining structures. Problems of corrosion in steel, coupled with the development of polymer material led to a rapid increase in the utilization of geo-synthetics in soil reinforcement. The characteristics of polymers, such as high tensile strength, and low installation costs made their function quite pleasing. Since geo-synthetic materials do not have much flexural stiffness, hence an increase in shear resistance is associated to the additional tensile strain mobilized in the reinforcement. Therefore, the efficiency of the reinforcement in providing an increase in shear resistance is highly relying upon the interference of the geo-synthetics with respect to the shear plane. The maximum efficiency should be expected when the orientation of the reinforcement coincides with the direction of the tensile strain of the soil. The rapid development of geo-synthetics for soil reinforcing is a historic milestone in soil improvement techniques. Initially, reinforced earth structures were built with metallic strips, granular backfill and facing panels. This application demonstrated an economic and technical advantage over traditional retaining structures. Problems of corrosion in steel, coupled with the development of polymer material led to a rapid increase in the utilization of geo-synthetics in soil reinforcement. The characteristics of polymers, such as high tensile strength, and low installation costs made their function quite pleasing. Since geo-synthetic materials do not have much flexural stiffness, hence an increase in shear resistance is associated to the additional tensile strain mobilized in the reinforcement. Therefore, the efficiency of the reinforcement in providing an increase in shear resistance is highly relying upon the interference of the geo-synthetics with respect to the shear plane. The maximum efficiency should be expected when the orientation of the reinforcement coincides with the direction of the tensile strain of the soil.

2. LITERATURAL REVIEW

McGowan, et al. (1978) obtained a similar result on plane strain cell test on sand containing a single layer of flexible reinforcement. Jewell recognized weakening to occur when the steel grid was placed along the direction of principal compressive strains in the unreinforced sand. This was attributed to a reduction in vertical effective stress. McGowan observed weakening of the sand when the reinforcement orientation approached the rupture band which developed in the sand alone. This was recognized to be the direction of zero-extension in the unreinforced sand. The weakening was linked to a lower bond between soil and reinforcement than soil alone.

Jewell et al. (1980) was the first to use the direct shear apparatus for the systematic study of soil-reinforcement interaction with a series of tests on grid and bar reinforcements. The study was concerned with studying the effects of tensile reinforcement on the mechanical behavior of sands. Jewell used the direct shear test and placed the reinforcement in the central plane. The reasons for choosing direct shear test were:

1. The reinforcement variables could be better controlled and examined in a unit cell test than in model or field studies of soil reinforcement systems.

2. The pattern of deformation is similar to that experienced by soil in which a rupture band develops, with the principal axes of stress, strain and strain increment free to rotate as is the case in model and field structures.

3. The overall shear strength of the sample is measured directly at the boundaries of the apparatus.

The performed test were monitored by boundary measurements as well as internal measurements by using a radiographic technique. He came to the conclusion that the optimum orientation for a relatively flexible reinforcement was approximately along the direction of principle tensile strain in the unreinforced soil. This indicated that the reinforcement functioned by limiting tensile strains in the sand.

Dyer, et al. (1985) advanced the work by using a photo elastic technique to investigate the stresses acting between the reinforcement and an artificial granular soil (crushed glass) in the direct shear test. The findings of Dyer (1985) were in agreement with McGowan (1978) and Jewell (1980) that the optimum orientation for a single flexible reinforcement in a plane strain unit cell test on cohesionless soil is indicated to be the direction of principal tensile strains in the unreinforced soil. At this orientation, the flexible reinforcement acts in tension and provides an additional means for the soil to resist loading as a result of limiting tensile strains in the soil.

Palmeira et al. (1987) has demonstrated that scale was not a problem when he constructed a large direct shear apparatus and tested a cubic soil sample of unit dimensions 1000mm. He demonstrated that the increase in the strength of reinforced soil depended upon the form, type and mechanical behavior of reinforcement. Palmeira concluded that the presence of the reinforcement can cause a 100% increase in shear strength. The reinforcement can limit severely the shear strains in the central region, in particular when the reinforcement orientation coincides with the direction of the minor principal strain.

Juran et al. (1988) the load transfer model was extended for the case of cohesive soil and was tested for its validity for the residual soil. Test results showed that the reinforcement inclusion significantly increases the ultimate shear strength. The composite soils system also fails at relatively larger shear displacement and in most of the cases the reinforced soil shows a strain hardening behavior. It was observed that the shear strength increases with the reinforcement orientation, and it was more effective when the orientation was 45° to the shear plane.

Basu et al (2007) wrote in his journal ―Design approach for geo-cell reinforced flexible pavements‖ that geo-cell is a comparatively new reinforcing material in civil industry. The unique three dimensional confinement of this material separates it from other geo-synthetic reinforcing material, such as woven geotextile, geo-grids, etc. The local soil or granular material show well structural properties when restricted in geo-cell with a suited style. The association of geo-cell in pavement layers make easier a better load transfer and decrement in vertical stresses below the pavement structure. Hence a large thickness reduction is possible by using this cellular confinement technology in flexible pavements

Hsieh et al. (2008) found that, in general, the shear strength obtained in shear boxes with large dimensions is more than that obtained with smaller shear boxes.

Vieira et al. in (2008) withstanding the fact that the conventional direct shear device can only accommodate small size specimens, which might impose serious limitations in terms of reproducing real conditions, direct shear strength for several interfaces obtained with the developed device were compared by with results achieved in a small (60 mm × 60 mm) conventional direct shear apparatus. The shear stress-shear displacement curves obtained with the large scale direct shear tests tend to exhibit peak shear strength, not evident in the results achieved with the conventional apparatus. The maximum shear strengths reached with two devices are relatively close however they were achieved for lower values of the normalized shear displacement in the larger box.

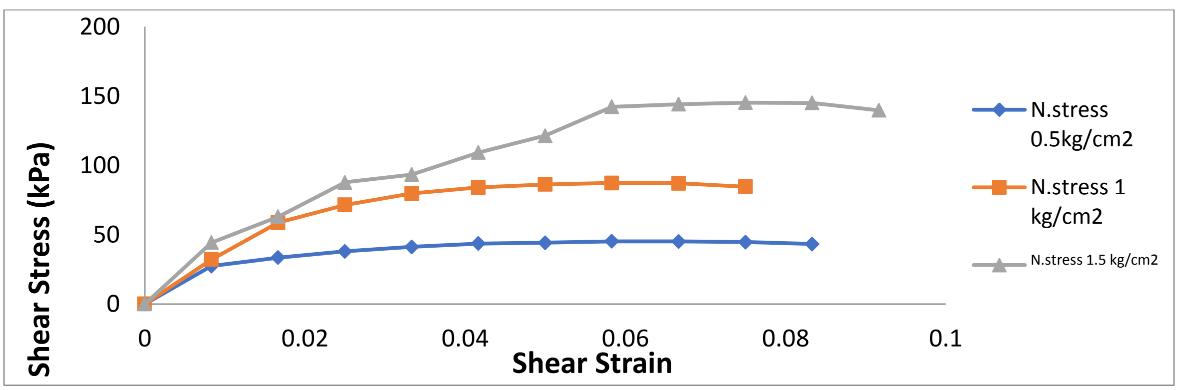
Wang et al. (2008) have evaluated the shear parameters of geo-cell reinforced soils using direct shear tests. Three different specimen's i.e. silty gravel, geo-cell reinforced silty gravel soil and geo-cell reinforced cement stabilizing silty gravel soil were tested. The shear stress-displacement behavior, the shear strength and the strengthening mechanism of geo-cell reinforced soils were evaluated .The comparisons of large -scale shear test responses with that from tri-axial compression tests were conducted, in order to evaluate the influences of testing method on the shear strength as well. The test results indicate that both the unreinforced soil and geo-cell reinforced soil give similar nonlinear responses in their shear-strain behavior. The geo-cell reinforced cement stabilized soil showed quasi-elastic characteristic when the normal stress was in the range of 1.0Gpa.The geo-cell reinforcement resulted in an increase of cohesion of sand by about 244%, while it resulted about 10 fold increase in cohesion in case of the cement stabilized soil. The friction angle does not undergo much of change.

Vieira, et al. (2013) concluded that the large scale device overestimates the shear strength of the soil geo-synthetic interface comparatively to the results obtained with the conventional direct shear apparatus. Notice, however, that the large scale direct shear device should represent more accurately the real behavior of the interface. Nevertheless, the differences between the results obtained with the two devices are not significant.

Rufaidah Shah, et al. (2017) concluded that the orientation of the reinforcement with respect to the shear plane has an important effect on the shear resistance of the soil and the use of small size apparatus was feasible as the results obtained were in not contradicting with the previous results in the literature, so the conclusions derived may be considered reliable. In order to examine the stress-strain characteristics of unreinforced and reinforced sandy soil a testing program was adopted out in a direct shear apparatus.

3. RESULT

i. DST Calculations of Unreinforced Test Sand

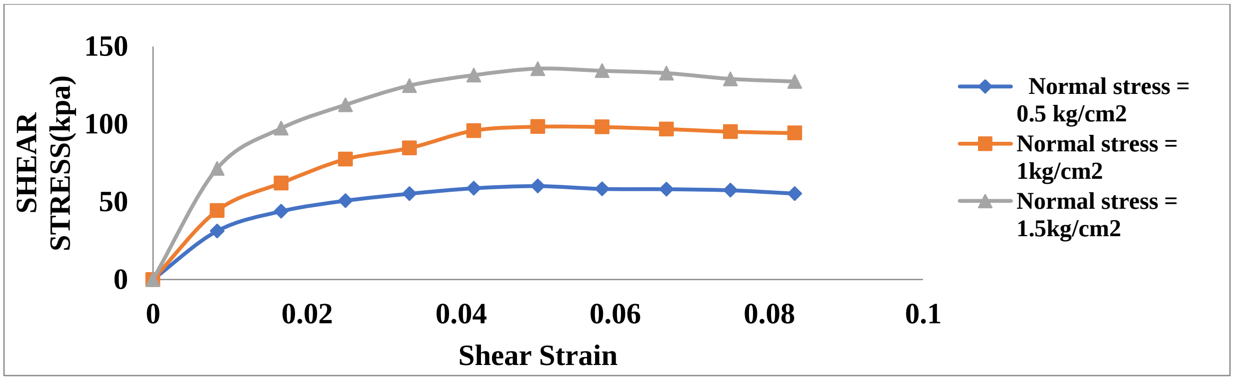


Graph 1: DST Calculations of Unreinforced Test Sand

Table 1: DST Peak results of Unreinforced Test Sand

Sample No	Normal stress (kPa)	Proving Ring Reading	Shear Load (N)	Shear Load (kg)	Shear Stress (kPa)
1	50	67	1627.2	162.7	45.2
2	100	115	3142.8	314.28	87.3
3	150	156	5230.8	523.08	145.3

ii. DST Calculations of Reinforced Test Sand @ 60% RD (Reinforced @ θ=0°)

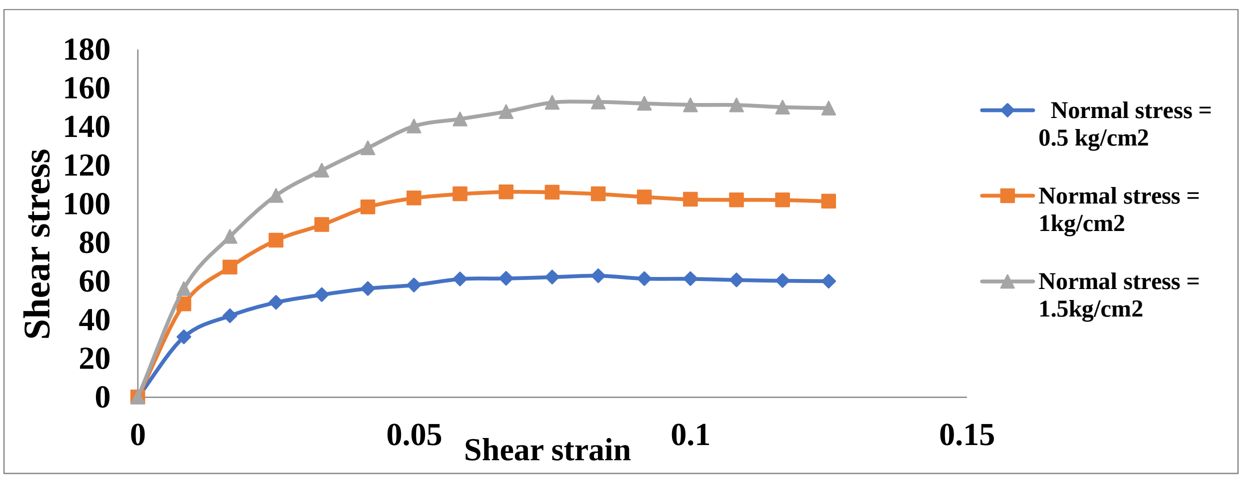


Graph 2: Boundary data from reinforced direct shear test on medium dense sand at θ=0°

Table 2: DST Peak results of reinforced Test Sand (Reinforced @ θ=0°)

Sample No	Normal stress(kg/cm²)	Proving Ring Reading	Shear Load (kg)	Shear Load (kg)	Shear Stress (kg/cm²)
1	50	68	2163.6	216.36	60.1
2	100	119	3538.8	353.88	98.3
3	150	163	4885.2	488.52	135.7

iii. DST Calculations of Reinforced Test Sand @ 60% RD (Reinforced @ θ=10

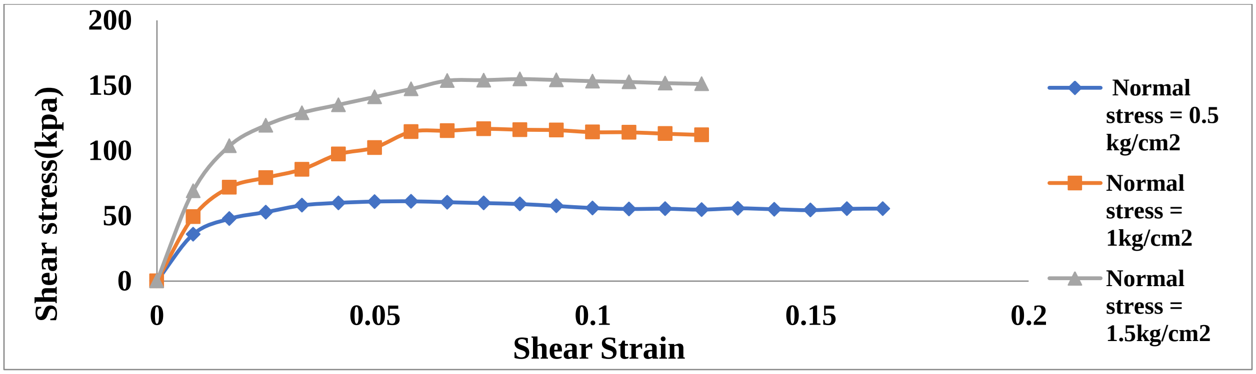


Graph 3: Boundary data from reinforced direct shear test on medium dense sand at θ=10°

Table 3: DST Peak results of reinforced Test Sand (Reinforced @ θ=10°)

Sample No	Normal stress(kg/cm²)	Proving Ring Reading	Shear Load (kg)	Shear Load (kg)	Shear Stress (kg/cm²)
1	50	73	2264.4	226.44	62.9
2	100	122	3826.8	382.68	106.3
3	150	181	5504.4	550.44	152.9

iv. DST Calculations of Reinforced Test Sand @ 60% RD (Reinforced @ θ=25°

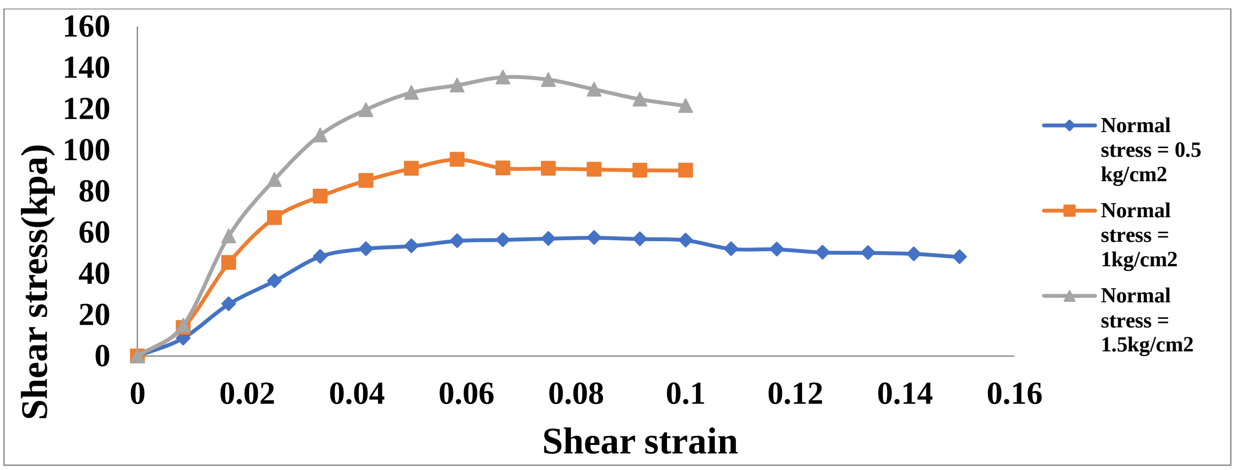


Graph 4: Boundary data from reinforced direct shear test on medium dense sand at θ=25°

Table 4: DST Peak results of reinforced Test Sand (Reinforced @ θ=25°)

Sample No	Normal stress(kg/cm²)	Proving Ring Reading	Shear Load (kg)	Shear Load (kg)	Shear Stress (kg/cm²)
1	50	75	2203.2	220.32	61.2
2	100	125	4201.2	420.12	116.7
3	150	165	5576.4	557.64	154.9

v. DST Calculations of Reinforced Test Sand @ 60% RD (Reinforced @ θ=40°)



Graph 5: Boundary data from reinforced direct shear test on medium dense sand at θ=40°

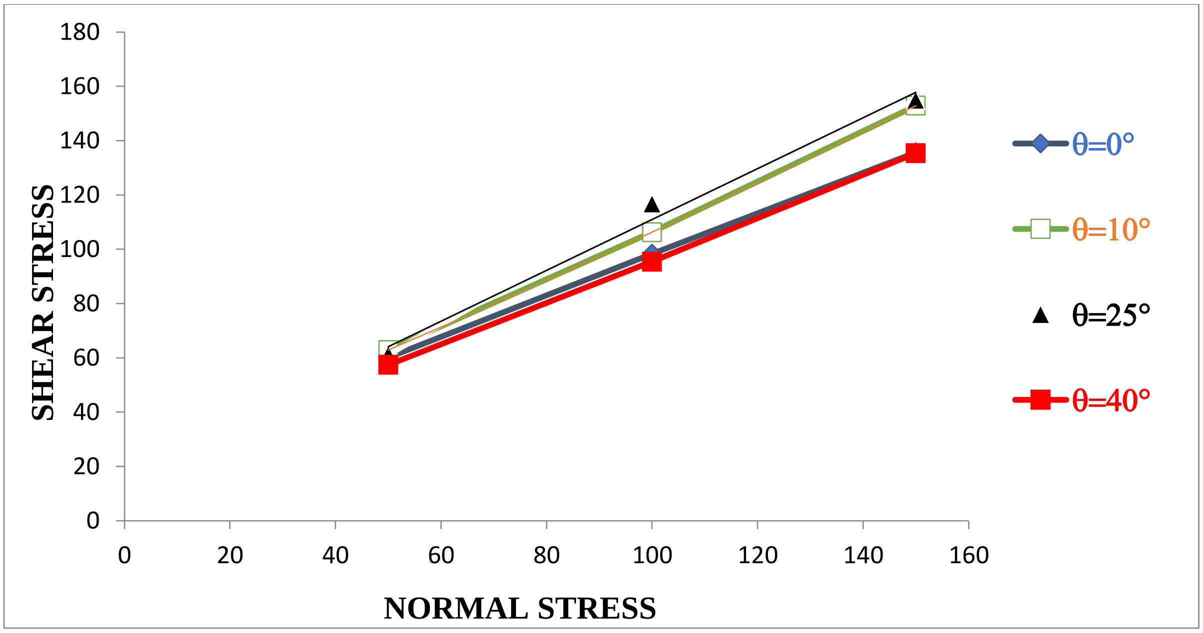
Table 5: DST Peak results of reinforced Test Sand (Reinforced @ θ=40°)

Sample No	Normal stress(kg/cm²)	Proving Ring Reading	Shear Load (kg)	Shear Load (kg)	Shear Stress (kg/cm²)
1	0.5	69	2066.4	206.64	57.4
2	1	111	3434.4	343.44	95.4
3	1.5	160	4874.4	487.44	135.4

vi. Undrained Shear parameters of reinforced medium dense sand for various orientations

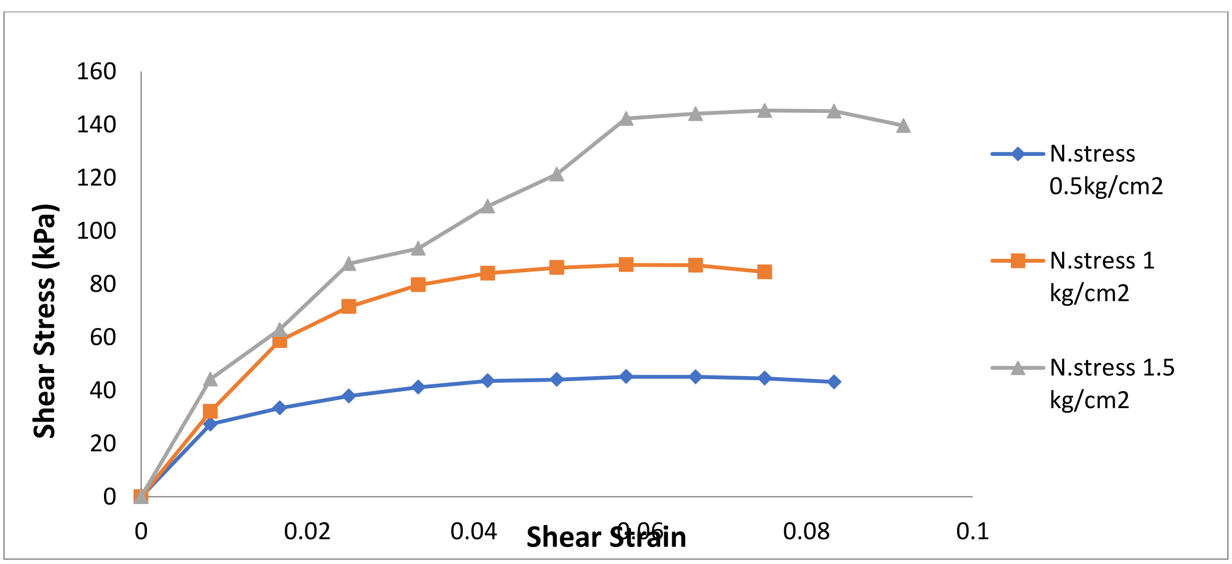
Table 6: Values for undrained shear parameters

Θ	**0°**	**10°**	**25°**	**40°**
***CR'* (kPa)**	**22.43**	**17.36**	**17.23**	**18.06**
***ΦC*(degrees)**	**37.08**	**41.98**	**43.13**	**37.95**



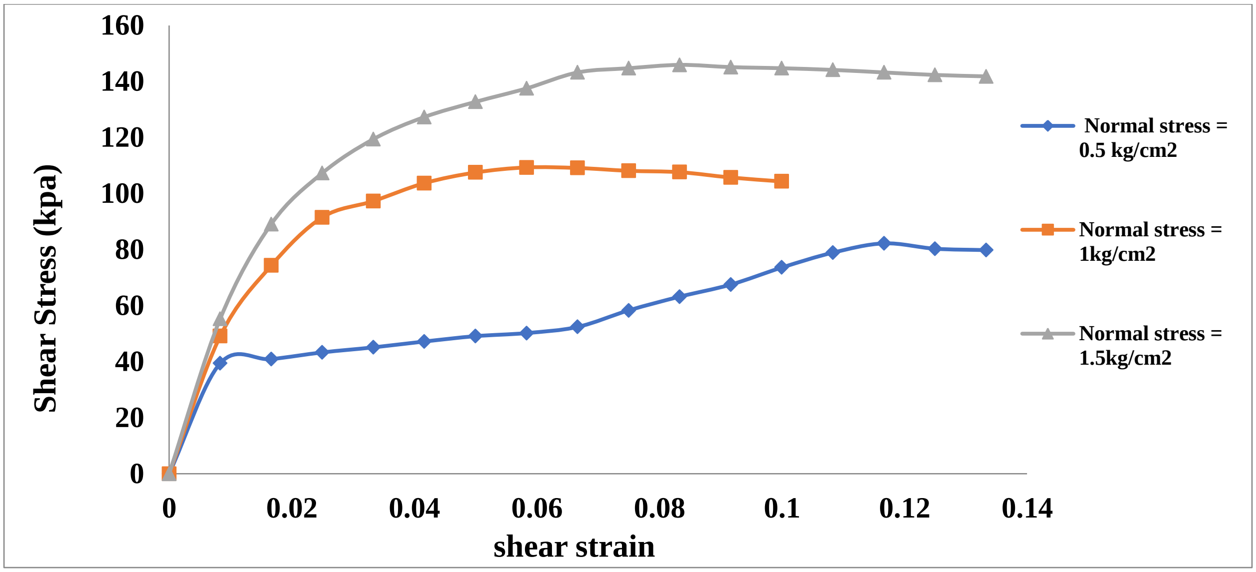
Graph 6: Mohr- failure envelop of reinforced sand for various orientations using rigid reinforcement.

vii. DST Calculations of Unreinforced Test Sand @ 60% RD



Graph 7: Unreinforced direct shear test on medium dense sand

viii. DST Calculations of Reinforced Test Sand @ 60% RD(Reinforced @ θ=25°)

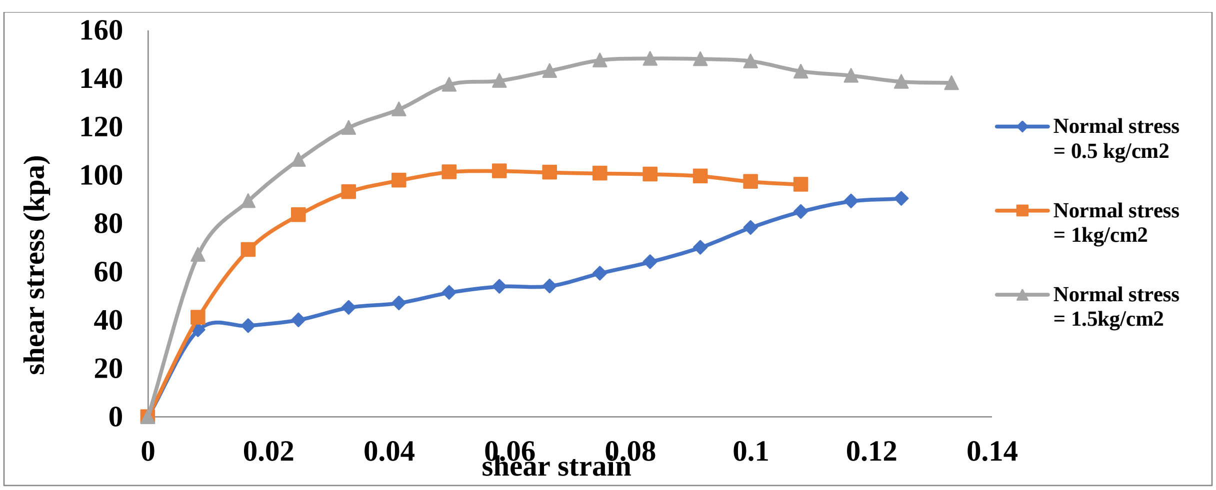


Graph 8: Boundary data from reinforced direct shear test on medium dense sand using flexible reinforcement θ = 25°

Table 7: DST Peak results of reinforced Test Sand (Reinforced @ θ=25°

Sample no	Normal stress(kg/cm²)	Proving Ring Reading	Shear Load (kg)	Shear Load (kg)	Shear Stress (kg/cm²)
1	0.5	111	2959.2	295.92	82.2
2	1	125	3934.8	393.48	109.3
3	1.5	163	5252.4	525.24	145.9

ix. DST Calculations of Reinforced Test Sand @ 60% RD (Reinforced @ θ=40°)



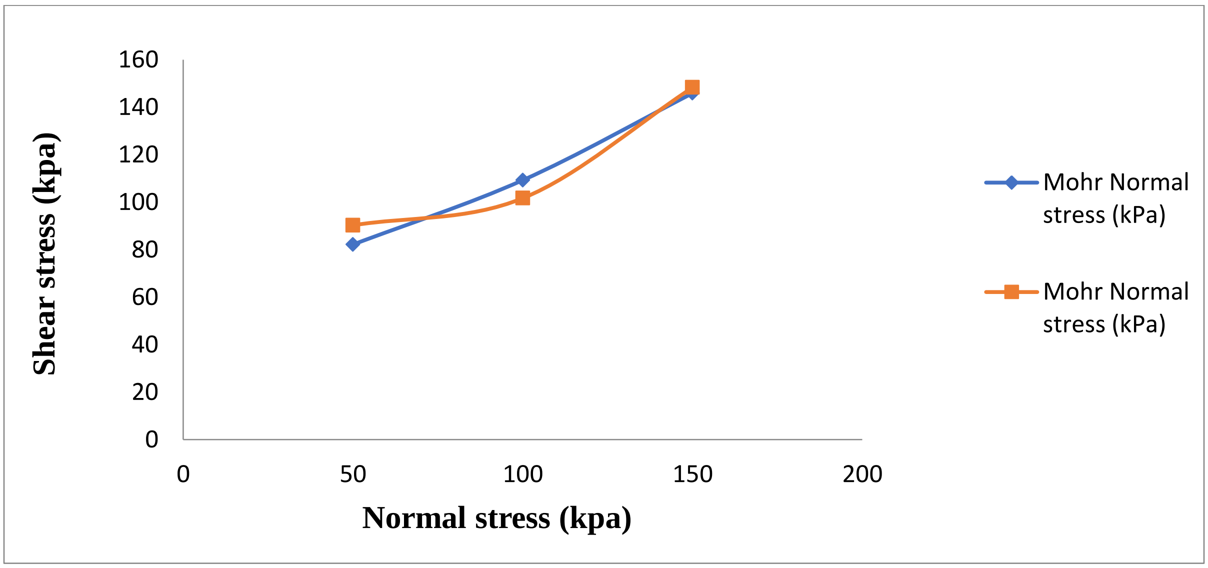
Graph 9: Boundary data from reinforced direct shear test on medium dense sand using flexible reinforcement *θ=40°*

Table 8: DST Peak results of reinforced Test Sand (Reinforced @ θ=40°)

Sample no	Normal stress(kg/cm²)	Proving Ring Reading	Shear Load (kg)	Shear Load (kg)	Shear Stress (kg/cm²)
1	0.5	108	3250.8	325.08	90.3
2	1	117	3661.2	366.12	101.7
3	1.5	166	5338.8	533.88	148.3

Table 9: Undrained Shear parameters of reinforced medium dense sand for various orientations using flexible reinforcement

θ	Unreinforced	25°	40°
C_R (kPa)	8.26	48.76	55.43
Φ_C (degrees)	44.7	32.49	30.11



Graph 10: Mohr-failure envelop of reinforced sand for various orientations using flexible reinforcement.

4. CONCLUSIONS

The following conclusions can be drawn from the experimental results:

1. The orientation of the reinforcement with respect to shear plane has a significant effect on the shear resistance of the soil.
2. The variation in the value of composite friction angle (φc) and development of apparent cohesion (c) due to the presence of reinforcement was observed. The attainment of overall maximum shear strength was observed when the reinforcement was oriented at about +25°.
3. Flexible reinforcement in comparison to Rigid reinforcement shows higher Shear strength
4. The value of apparent cohesion increases abruptly with flexible reinforcement than Rigid Reinforcement
5. It can also be concluded that the use of small size apparatus was feasible as the results obtained were in agreement with the previous findings in the literature so the conclusions derived may be considered reliable.

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