# Evaluation of Stiffness Modulus of Soil Reinforced with Glass Fiber

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***Abstract*— This paper presents the effects of glass fibers on the shear strength parameters of clayey soil. To study the effect, clayey soil was mixed with three different glass fiber contents (0.5%, 1.0% and 1.5%) of aspect ratio of 30, 45 and 60. The natural physical properties of clay soil such as specific gravity, angle of internal friction, OMC, MDD and shear strength/stiffness were obtained in accordance with Indian Standard codes. The clayey soil was mixed with glass fibers at different percentages by dry weight of the specimens and with three different aspect ratios (l/d).Series of triaxial test was carried out to study the behaviour of unreinforced and reinforced clayey soil. After studying the results, it clearly showed that the shear strength/stiffness and angle of internal friction of clayey soil increased with increasing the fibers length and fibers content.**

***Key Words: Triaxial test; L/D ratio; angle of internal friction (φ); Shear strength; Glass fiber content.***

## I. INTRODUCTION

Reinforced soil is the latest technique used for ground improvement, the concept of reinforced soil was first given by Vidal of France in 1966. Since then the researchers all over the world working on this concept to make reinforced soil economical and strong. Use of reinforced soil in geotechnical structures such as foundations, retaining walls, embankments, pavements etc. The main function of reinforcing the soil matrix is to increase the strength (shearing strength) and reduce its deformation. The primary advantages of randomly distributed fibers are the absence of potential planes of weakness that can develop parallel to oriented reinforcement (Maher and Gray 1990). All over the world many investigator have worked on fiber-reinforced soil using synthetic as well as natural fibers. Some of them are Rosa L. Santoni, Jeb S. Tingle and Steve L. Webster (2001), Kameshwar Rao Tallapragada, Anuj Kumar Sharma and Tarulata Meshram (2009), Mousa F. Attom and Adil K. Al-Tamimi (2010), Amin Chegenizadeh and Hamid Nikraz (2012), Shivanand Mali and Baleshwar Singh (2013), H. P. Singh and M. Bagra (2013), Rabindra kumar kar, Pradip Kumar Pradhan and Ashutosh Naik (2014), S. Yari, A. Bagheri and M. Yousefi Rad (2014), Shivanand Mali and Baleshwar Singh (2014), Himadri Baruah (2015), Dinesh Kumar, R. Shanmuga and G. Kalyan Kumar (2015), Dimpa Moni Kalita, Indrani Mili, Himadri Baruah and Injamamul Islam (2016). The technique of soil reinforcement using glass fiber is being widely used at present in a civil engineering projects and is fast replacing the conventional ground improvement techniques. Glass fiber has generally had long life as compared with natural fiber and it is non biological degradation. Presently the glass fiber is extensively used in civil engineering applications and thereby the cost of construction can be brought down to a great extent. In present study, we are motivated to study the strength behaviour of randomly distributed glass fiber (c-φ) reinforced soil, at different aspect ratio.

## II MATERIALS

The clayey soil sample was collected at natural ground surface from Ambala cantt region. The required properties of clayey soil sample were determined Indian standard codes as shown in tables 1. Sample is clayey in nature.

Table 1: Properties of samples

| S. No. | Description | Sample |
|---|---|---|
| 1 | Fines (%) | 53.7 |
| 2 | Sand (%) | 46.3 |
| 3 | Liquid Limit (%) | 32.5 |
| 4 | Plastic Limit (%) | 20 |
| 5 | Plasticity Index (%) | 12.5 |
| 6 | Flow Index | 29 |
| 7 | Toughness Index | 0.68 |
| 8 | Classification | CL |
| 9 | Compaction test | OMC = 12%, MDD = 20.40kN/$m^3$ |

*Glass fiber*

Glass fiber has been procured from Science market Ambala cantt. Haryana, India and were divided into basis of size 10 mm, 15 mm and 20 mm for its inclusion in various percentages (0.5, 1.0 and 1.5% by dry weight) to clayey soil. The physical properties of glass fiber are given in Table 2.

Table 2**:** Properties of Glass fibers

| Description | Glass fiber |
|---|---|
| Length (mm) | 10 mm, 15 mm and 20 mm |
| Diameter (mm) | 0.35 |
| Tensile strength (GPa) | 2.30 |
| Tensile modulus (GPa) | 76 |
| Ultimate strain | 0.018 |

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Fig 1: Glass fiber.

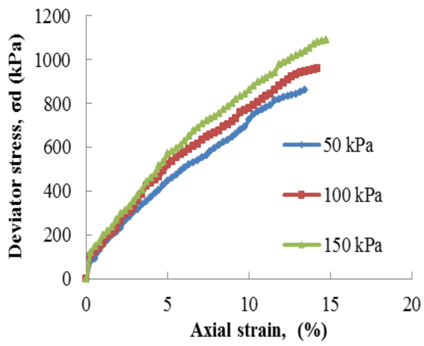


Figure 2: Deviator stress – axial strain plots of unreinforced clayey soil

A glance of the figure indicates that under a constant confining stress, $\sigma_d$ the deviator stress increases with the increase in the axial strain. The peak/maximum deviator stress is attained at an axial strain of about 14.20% which is independent of the confining stress. Though, higher the confining stress, higher is the deviator stress. Figure 3 shows the plots of deviator stress-axial strain from triaxial tests under confining stress of 50 kPa on glass fiber reinforced clayey soil at an aspect ratio of 30 and at different fiber contents from 0% to 1.5%.

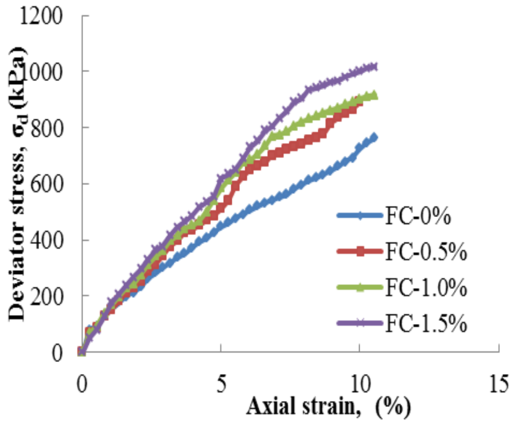


Figure 3: Variation of deviator stress vs. axial strain plots at $\sigma_3$= 50kPa (L/d=30)

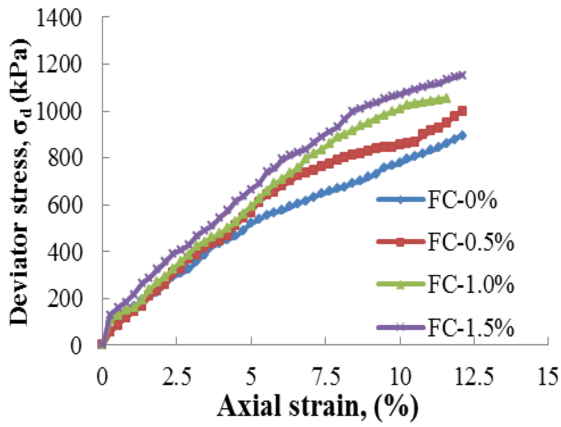


Figure 4: Variation of deviator stress vs. axial strain plots at $\sigma_3$= 100kPa (L/d=30)

## III EXPERIMENTAL PROGRAMME

*A.Triaxial Test*

In deep foundations, confining pressures play the significant role in changing the behaviour of soils. Similarly in high rise earth dams, the confining pressures are of very high magnitude. Triaxial test is the only test to simulate these confining pressures. the composite material of clayey soil and glass fiber was mixed homogenously at 12% optimum moisture content (OMC). Glass fiber reinforced clay was compacted in five different layers in a cylindrical mould of 100 mm diameter and 120 mm high to a standard Proctor's maximum density. Then the specimen was extracted for triaxial test. The series of Unconsolidated Undrained (UU) triaxial tests were conducted on samples prepared by glass fiber mix clayey soil with three different aspect ratio i.e. l/d ( 30, 45 and 60) and with three different fiber content ( 0.5%, 1.0% and 1.5%) at a constant strain rate of 1.2mm/min as per Indian Standards Specifications IS 2720 (Part II): 1993. Three different confining pressures (50 kPa, 100 kPa and 150kPa) were used during testing. Three unreinforced and reinforced specimens were tested for each combination of variables.

## IV. RESULTS AND DISCUSSION

*A. Effect of aspect ratio on stress-strain behavior*

Figure 2 shows the typical deviator stress-axial strain plots from triaxial tests on unreinforced clayey soil at the Proctor's maximum dry density, $\Upsilon_{dmax}$ of 20.40 KN/m$^3$ under confining stress of 50 kPa, 100 kPa and 150 kPa.

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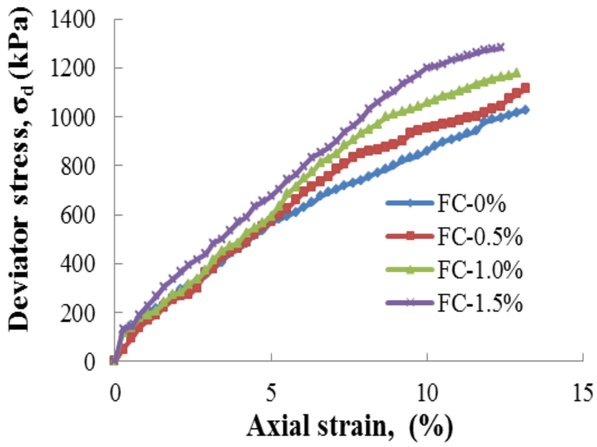


Figure 5: Variation of deviator stress vs. axial strain plots at $\sigma_3$= 150kPa (L/d=30)

All the samples were prepared at the Proctor's maximum dry density of 20.40 KN/m$^3$. For the sake of comparison, test results of unreinforced clayey soil have been plotted. Similar curves under confining stresses, $\sigma_3$ of 50 kPa, 100 kPa and 150 kPa have been plotted in the Figures 3 to Figure 5 respectively.Figure 6 shows the plots of deviator stress-axial strain from triaxial tests under confining stress of 50 kPa on glass fiber reinforced clayey soil at an aspect ratio of 45 and at different fiber contents from 0% to 1.5%.

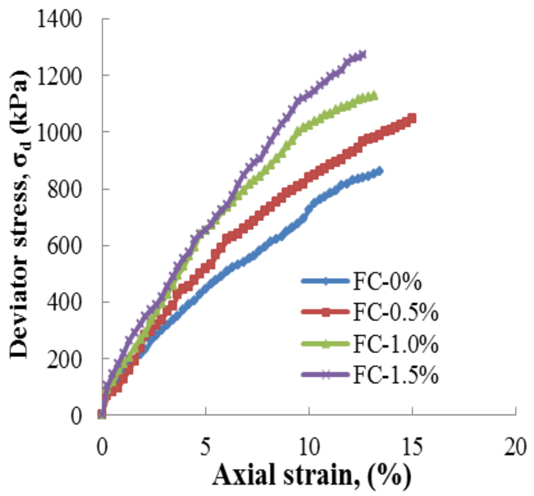


Figure 6: Variation of deviator stress vs. axial strain plots at $\sigma_3$= 50kPa (L/d=45)

All the samples were prepared at the Proctor's maximum dry density of 20.40 KN/m$^3$. For the sake of comparison, test results of unreinforced clayey soil have been plotted. Similar curves under confining stresses, $\sigma_3$ of 50 kPa, 100 kPa and 150 kPa have been plotted in the Figures 6 to Figure 8 respectively.

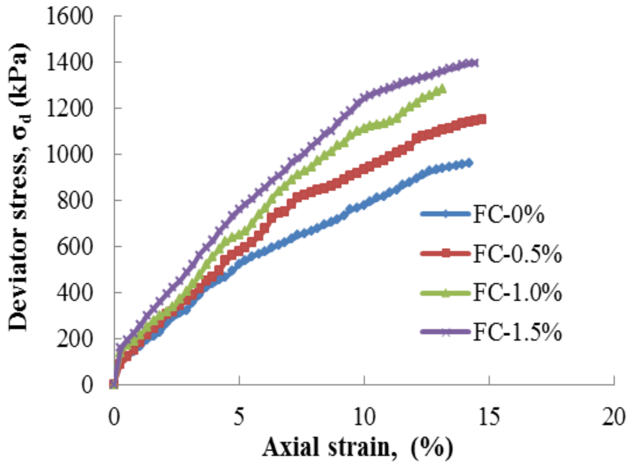


Figure 7: Variation of deviator stress vs. axial strain plots at $\sigma_3$ = 100kPa (L/d=45)

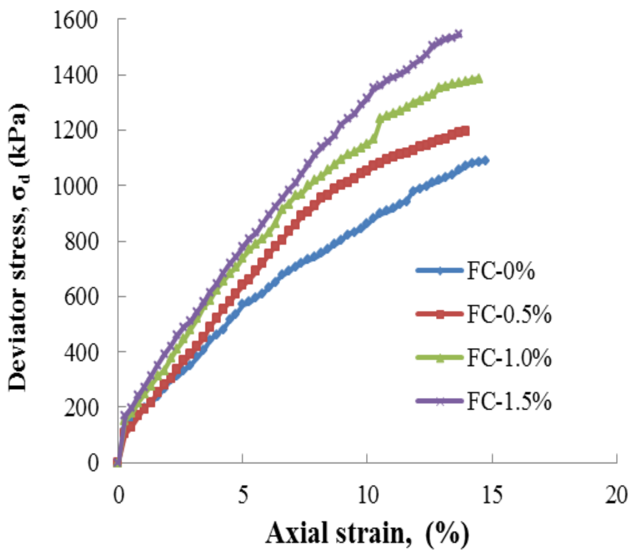


Figure 8: Variation of deviator stress vs. axial strain plots at $\sigma_3$ = 150kPa (L/d=45)

A glance of the Figure 6 indicates that the deviator stress-axial strain plots of fiber reinforced clayey soil do not exhibit any peak stress. Also, the deviator stress-axial strain curves of fiber reinforced clayey soil do not indicate the decreasing trend for any value of fiber content and confining stress. The deviator stress continuously increases with increase in axial strain. Similar stress-strain behavior of clayey soil reinforced with glass fiber is observed for high confining stresses as shown in Figure 7 to Figure 8. Figure 9 shows the plots of deviator stress-axial strain from triaxial tests under confining stress of 50 kPa on glass fiber reinforced clayey soil at an aspect ratio of 60 and at different fiber contents from 0% to 1.5%.

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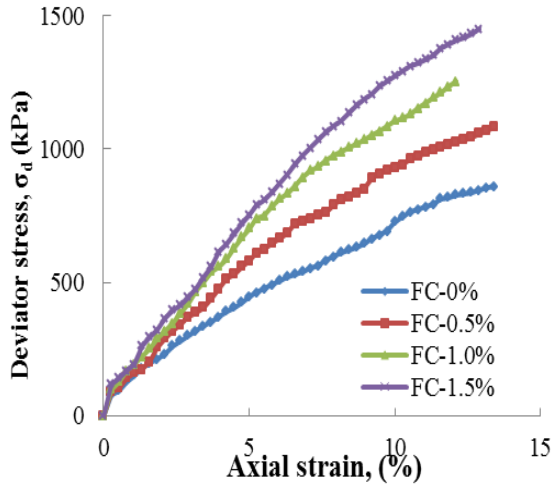


Figure 9: Variation of deviator stress vs. axial strain at $\sigma_3$=50kPa (L/d=60)

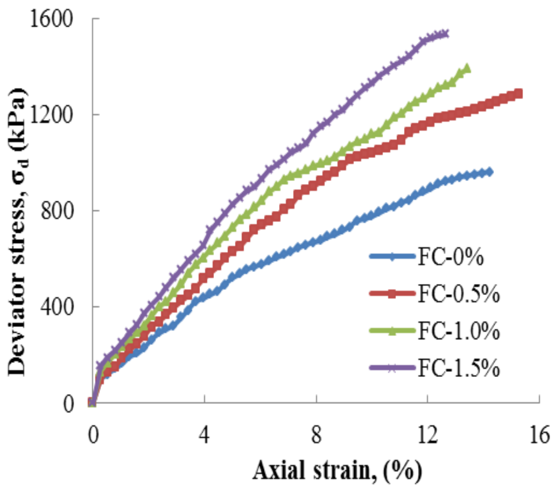


Figure 10: Variation of deviator stress vs. axial strain at $\sigma_3$=100kPa (L/d=60)

All the samples were prepared at the Proctor's maximum dry density of 20.40 KN/m$^3$. For the sake of comparison, test results of unreinforced clayey soil have been plotted. Similar curves under confining stresses, $\sigma_3$ of 50 kPa, 100 kPa and 150 kPa have been plotted in the Figures 9 to Figure 11 respectively.

A glance of the Figure 10 indicates that the deviator stress-axial strain plots of fiber reinforced clayey soil do not exhibit any peak stress. Also, the deviator stress-axial strain curves of fiber reinforced clayey soil do not indicate the decreasing trend for any value of fiber content and confining stress. The deviator stress continuously increases with increase in axial strain. Similar stress-strain behavior of clayey soil reinforced with glass fiber is observed for high confining stresses as shown in Figure 10 to Figure 11.

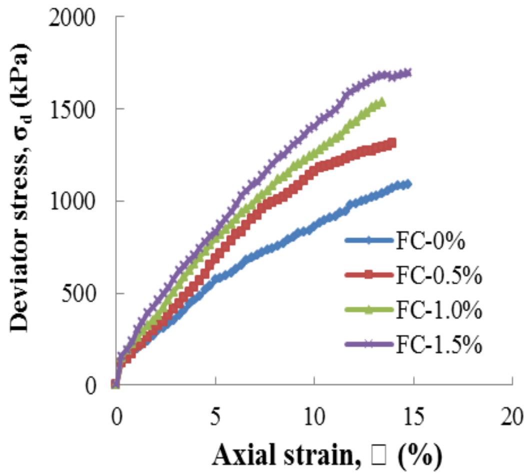


Figure 11: Variation of deviator stress vs. axial strain at $\sigma_3$=150kPa (L/d=60)

Table 4: Stiffness Modulus of Reinforced Soil (L/d=30)

| Fiber Content (%) | Confining Pressure (kPa) | L/d=30 Stiffness Modulus ($\sigma_d$/€) | L/d=30 Average Stiffness Modulus | L/d=30 Increase in Average Stiffness modulus |
|---|---|---|---|---|
| 0 | 50<br>100<br>150 | 6405<br>6757<br>7400 | 6854 | - |
| 0.5 | 50<br>100<br>150 | 6847<br>7456<br>7773 | 7358 | 504(7%) |
| 1.0 | 50<br>100<br>150 | 7407<br>7921<br>8801 | 8043 | 1189(11%) |
| 1.5 | 50<br>100<br>150 | 8413<br>8761<br>9641 | 8923 | 2069(30%) |

Table 5: Stiffness Modulus of Reinforced Soil(L/d=45)

| Fiber Content (%) | Confining Pressure (kPa) | L/d=45 Stiffness Modulus ($\sigma_d$/€) | L/d=45 Average Stiffness Modulus | L/d=45 Increase in Average Stiffness modulus |
|---|---|---|---|---|
| 0 | 50<br>100<br>150 | 6405<br>6757<br>7400 | 6854 | - |
| 0.5 | 50<br>100<br>150 | 6974<br>7775<br>8566 | 7771 | 917(13%) |
| 1.0 | 50<br>100<br>150 | 8233<br>9719<br>9892 | 9281 | 2427(35%) |
| 1.5 | 50<br>100<br>150 | 10079<br>9647<br>11294 | 10340 | 3486(51%) |

Table 6: Stiffness Modulus of Reinforced Soil (L/d=60)

| Fiber Content (%) | Confining Pressure (kPa) | L/d=60 | | |
|---|---|---|---|---|
| | | Stiffness Modulus ($\sigma_d$/€) | Average Stiffness Modulus | Increase in Average Stiffness modulus |
| 0 | 50<br>100<br>150 | 6405<br>6757<br>7400 | 6854 | - |
| 0.5 | 50<br>100<br>150 | 7509<br>8394<br>9390 | 8431 | 1577(23%) |
| 1.0 | 50<br>100<br>150 | 10060<br>10350<br>11430 | 10613 | 3759(54%) |
| 1.5 | 50<br>100<br>150 | 11233<br>12137<br>11506 | 11625 | 4771(69%) |

Table 7: Shear Strength Parameter (L/d=30)

| Fiber Content | L/d=30 Shear Strength Parameters (c and φ) | | | |
|---|---|---|---|---|
| | C (kN/m$^2$) | Φ (Degree) | % Increase in (c) | % Increase in (φ) |
| 0 | 22 | 28 | - | - |
| 0.5 | 24 | 30 | 9 | 7 |
| 1.0 | 26 | 31 | 18 | 11 |
| 1.5 | 28 | 33 | 27 | 18 |

Table 8: Shear Strength Parameter (L/d=45)

| Fiber Content | L/d=45 Shear Strength Parameters (c and φ) | | | |
|---|---|---|---|---|
| | C (kN/m$^2$) | Φ (Degree) | % Increase in (c) | % Increase in (φ) |
| 0 | 22 | 28 | - | - |
| 0.5 | 28 | 29 | 27 | 4 |
| 1.0 | 33 | 32 | 39 | 14 |
| 1.5 | 33 | 35 | 39 | 25 |

Table 9: Shear Strength Parameter at (L/d=60)

| Fiber Content (%) | L/d=60 Shear Strength Parameters (c and φ) | | | |
|---|---|---|---|---|
| | C (kN/m$^2$) | Φ (Degree) | % Increase in (c) | % Increase in (φ) |
| 0 | 22 | 28 | - | - |
| 0.5 | 36 | 32 | 64 | 14 |
| 1.0 | 36.5 | 35 | 66 | 25 |
| 1.5 | 37.5 | 37 | 71 | 32 |

*B.Effect of fiber content*

Based on the results of triaxial compression tests performed on reinforced soil at different fiber content varying from 0.0% to 1.5% for aspect ratio 30, 45 and 60, the computed values of stiffness modulus and shear strength parameters of reinforced soil are shown in Table 4-6 and Table 7-9 respectively. It is observed that from Table 4 the stiffness modulus of reinforced soil increase with increase in confining pressure, fiber content and change in aspect ratio. The results of column 3, column 6 and column 9 of Table 4 shows the values of stiffness modulus of reinforced soil corresponding to a different confining pressures for aspect ratio 30, 45 and 60 respectively. Colum 4, column 7 and column 10 of Table 4 show the average value of stiffness modulus for aspect ratio 30, 45 and 60 respectively. It is clear from the values of stiffness modulus that it increases with the increase in confining pressures and this aspect can be observed for all the fiber contents and all the aspect ratio. This is due to the fact that under higher confining pressures soil samples are more confined and more resistant to deformation which results into higher deviator stress at failure. It is further observed that the average increase in stiffness modulus of reinforced soil increase with the increase in fiber contents and this trend is observed for all aspect ratio i.e. 30, 45 and 60. For instance the average stiffness modulus of unreinforced soil is 6854. When 0.5% glass fiber having aspect ratio 30 is added to the soil, the stiffness modulus of soil increases to 7358 i.e. improvement in stiffness modulus of soil is 7% due to 0.5% inclusion of glass fiber. Similar trend is observed from the results of Table 4 for fiber contents of 1.0% and 1.5% also and the maximum improvement in average stiffness modulus of soil is 69% for fiber content of 1.5% of aspect ratio of 30. For 45 fiber length the improvement in average stiffness modulus of soil is 50% and similarly for 60 aspect ratio the improvement in average stiffness modulus of soil is 69%. The significant increase in average stiffness modulus of soil due to addition of glass fiber improves the load-settlement characteristics of soil and the amount of immediate settlement would be reduced significantly.

It is observed from Table 7-9 that the shear strength parameters (c and φ) of reinforced soil increase in fiber content and this aspect can be observed for all aspect ratio i.e. 30, 45 and 60. Column 2 and column 3 show the values of cohesion (c) and angle of internal friction (φ) of reinforced soil for aspect ratio of 30. The results of column 2 and column 3 of Table 7-9 show the amount of percentage increase in (c) and (φ) values of soil due to inclusion of glass fiber of aspect ratio 30. The results of column 4 and column 5 clearly show that the percentage increase in (c) value and (φ) value are 9%, 18%, 27%, and 7%, 11%, 18% respectively for fiber contents of 0.5%, 1.0% and 1.5%. Similar trend is observed from the results of column 8 and column 9 for aspect ratio 45 and here corresponding percentages increase in (c) and (φ) values are 27%, 39%, 39% and 4%, 14%, 25% respectively. The significant increase in shear strength parameters of soil due to addition of glass fiber improves the load carrying capacity of soil and glass fiber reinforced soil can be used as foundation soil for supporting heavier loads of civil engineering structures. Similar trend of results was observed by H.P.Singh and M.Bagra (2013).

The increase in stiffness modulus and shear strength parameters of soil due to inclusion of glass fiber is due to the fact that randomly oriented discrete inclusions incorporated into soil mass improves its load deformation behaviour by interacting with the soil particles mechanically through surface friction and also by interlocking.

### *C.Effect of fiber length*

It is clear from the tests results of Table 4 and Table 5 that the value average stiffness modulus and shear strength of soil increases with the change in glass fiber length. The result of column 5, column 8 and column 11 of Table 4 show the increase in average stiffness modulus of reinforced soil for aspect ratio of 30, 45 and 60 respectively. The percentage increase in stiffness modulus of reinforced soil due to 0.5% fiber content is 7% for aspect ratio 30 of glass fiber. And in case of 45 and 60 aspect ratio of glass fiber, the percentage increase in stiffness modulus of reinforced soil due to same fiber content i.e. 0.5% is 13% and 23%, and this aspect can be observed for all the fiber contents i.e. is 1.0% and 1.5%. It is further observed from Table 4 that the maximum percentage increase in stiffness modulus of reinforced soil for aspect ratio of 60 and at fiber content of 1.5% is 69% which is very much substantial and would reduce the immediate settlement of soil significantly. Similar trend of increase in shear strength parameters (c and φ) of soil due to inclusion of glass fiber is observed from Table 5 also.

## V.CONCLUSION

Based on the experimental results of this study the following conclusions are drawn:-

1. Based on the present study it is concluded that preparation of identical samples of glass fiber reinforced soil beyond 1.5% of fiber content was not possible and hence maximum fiber content is 1.5%.
2. The value of stiffness modulus of reinforced soil increases with increase in aspect ratio and fiber content, the maximum percentage increase in stiffness modulus is 30% over virgin soil for aspect ratio 30 and at fiber content of 1.5%. Similarly increase in stiffness modulus was noticed at aspect ratio 45 and 60 at fiber content 1.5% is 51% and 69% respectively.
3. The maximum increase in the values of (c) and (φ) are 27% and 18% respectively over virgin soil at fiber content 1.5% for aspect ratio 30
4. The stiffness modulus of reinforced soil increases with increase in fiber length and its maximum percentage increase is 69% over virgin soil for aspect ratio 60 at fiber content of 1.5%.
5. The shear strength parameter (c and φ) increase in aspect ratio. The maximum value of (c) and (φ) are 71.00% and 32.00% respectively for aspect ratio 60 at fiber content of 1.5%.
6. The effect of fiber content and aspects ratio increases the shear strength parameters which are useful in geotechnical engineering structures. Increase in strength/stiffness of weak and soft soils will performed better as compared with unreinforced soil.
7. Use of glass fiber provided stiff surface for construction point of view and randomly mix glass fiber can lead to a lot of saving in money and becomes economical. Because it is long life due to its unique property of non-biodegradable in nature.

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