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Net Safe Bearing Capacity of Glass Fiber Reinforced Pilani Soil Under Surface Footing Conditions

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Abstract: Net safe bearing capacity of surface footing is important geotechnical design consideration. Soil in Pilani has negligible to zero cohesion and adequate angle of internal friction in it. If it is reinforced with fibers, it may enhance its net safe bearing capacity for surface footing condition as well as enhance its long term performance. This aspect has been studied in present study. E-glass fibers in strand form have been used as reinforcing agent. Cohesion and angle of internal friction required for net safe bearing capacity calculation of reinforced soil has been determined by conducting direct shear testing. Obtained experimental results have been discussed and analyzed. Practical significance of the study also has been described.

Index Terms: Angle of internal friction, Cohesion, Fiber reinforced soil, Net safe bearing capacity.

1. INTRODUCTION

From engineering point of view it is always desirable to enhance the strength of soil system by adding external agents into it. Reinforcing fibers have been successfully and effectively used in concrete and cement structures to obtain desirable strength related properties. Besides cement and concrete, these fibers can also be used as reinforcement in soils to enhance their strength. Variety of natural fibers have been used as strength enhancing agents in the soil matrix. Banana, jute and coconut fibers are some of the important ones. Lately variety of synthetic fibers have also been developed to act as reinforcing agents for the soil matrix [1]. Glass fiber is one such synthetic fiber. Glass fibers are extensible due to their low modulus. Maximum force in fiber is controlled by deformation in soil under these conditions. Adding glass fibers into matrix inhibits crack propagation and provides ductility. Presence of glass fibers holds the matrix together. Glass fibers are stiffer than matrix. Hence small amount of fiber added is adequate. They are broadly divided as E-glass and S-glass fibers.

Surface footing is a specific type of shallow foundation. Foundation slab of required cross-sectional dimension and of adequate thickness is constructed on labeled horizontal ground surface. For water table quite below ground surface, vertical loading & square cross-section of foundation, following equation is used to calculate net ultimate bearing capacity under local shear failure conditions as per IS: 6403-1981 (Code of Practice for Determination of Bearing Capacity of Shallow Foundations):

$$q_{nu} = (0.67)(1.3)cN'_c + (0.5)(0.8)(\gamma)(B)N'_\gamma \quad (1)$$

In above Equation (1), 'c' is cohesion and 'γ' is dry density of soil below footing base. 'B' is footing width. 'N'_c' & 'N'_γ' are bearing capacity factors for local shear failure, calculated based on angle of internal friction of soil below the base of surface footing. Cohesion and angle of internal friction is determined in the laboratory under appropriate drainage conditions. Experimentally obtained angle of internal friction has to be modified for local shear failure as per IS: 6403-1981 in order to calculate bearing capacity factors. In c-ϕ soil, if stress-strain curve is continuously rising even at strains of 10 to 20%, local shear failure is assumed. Bearing capacity factors to be used for local shear failure condition in Equation (1) based on modified angle of internal friction is read from Table 1 of IS: 6403-1981 using linear interpolation. Net ultimate bearing capacity is divided with factor of safety to get net safe bearing capacity. In present study, 3 has been taken as factor of safety. It is the maximum net intensity of loading that the soil can safely support without the risk of shear failure [2].

In Pilani, soil is freely draining. Water table is at considerable depth below ground surface. Worst condition in-situ water content in soil close to ground surface is around 10%. Its average in-situ dry density is 1.57 gm/cc. For a given surface footing of known cross-sectional dimension, if this underlying soil till required depth is reinforced with glass fibers (fiber orientation being perpendicular to labeled horizontal ground surface), it is expected to alter its cohesion and angle of internal friction value. Consequently, net safe bearing capacity will also change. This fact has been studied under experimental framework in the present study. Glass fibers used were of E-glass type.

2. EXPERIMENTAL DETAILS

For experimental purpose, soil of Pilani was taken from two different locations. One location was desert stretch and soil was taken from ground surface. The soil was sandy. Oven dried this soil (passing through 300 micron sieve and retained on 150 micron sieve, labeled as S_{150}) was taken. Second location was deep ditch, at a depth of 12 to 15 meters from ground surface. This soil was fine grained. Oven dried this soil, passing through 150 micron sieve & retained on 75 micron sieve, labeled as C_{75} as well as passing through 75 micron sieve & retained on pan, labeled as C_p was taken. In present study, weight composition of soil taken was $S_{150} = 50\%$, $C_{75} = 25\%$ & $C_p = 25\%$. Water content during testing was 10%.

Since soil of Pilani is freely draining, there is no accumulation of pore water pressure. Direct shear testing under drained conditions can be used to find cohesion and angle of internal friction value which is required in Equation (1). Hence direct shear testing has been conducted on reinforced soil in present study. Plan area of direct shear box used in experimentation was 6 cm × 6 cm. Sample height in the shear box was 5.5 cm with horizontal failure plane at mid-height in the shear box. For all the fiber contents tested in present study, based on experimental observation during direct shear testing, local shear failure was found to be applicable.

E-glass fibers were used as reinforcing agent in the present study. Fibers were taken from glass fiber woven mats. Fiber length was constant at 5 cm. Fiber orientation was perpendicular to horizontal failure surface. Furthermore, they were placed transverse to the sliding direction of direct shear testing. There were three layers of soil (having composition as described above), each having 2 cm thickness during direct shear testing. In between two soil layers, there was a layer of E-glass fiber strand. If one fiber strand was kept at the centre in between two soil layers, it resulted in a fiber content of 0.02%. Weight fraction of fiber in soil-fiber composite was obtained by taking ratio of total weight of fiber in the composite to total weight of composite and expressed on percentage basis. Fiber contents tested was 0%, 0.02%, 0.04%, 0.06%, 0.08%, 0.1% & 0.12%. Cohesion and angle of internal friction variation with fiber content obtained from direct shear testing has been shown in Table 1. For 0.04% fiber content, there were two fiber strands with equal spacing in between two soil layers. Similarly other fiber content samples were prepared. For surface footing of square cross-section with 5 meter dimension and in-situ dry density of 1.57 gm/cc, net safe bearing capacity using Equation (1) has also been calculated at tested fiber contents and shown in Table 1.

Table 1
Cohesion, angle of internal friction & net safe bearing capacity variation with fiber content

Fiber Content (%)	*Cohesion (T/m^2)*	*Angle of Internal Friction (deg.)*	*Net Safe Bearing Capacity (T/m^2)*
0	0.876	38.8	26.21
0.02	1.023	38.52	26.65
0.04	1.068	38.33	26.52
0.06	1.104	38.15	26.31
0.08	1.283	37.79	26.72
0.1	1.311	37.12	25.18
0.12	1.379	36.87	24.99

3. DISCUSSION OF EXPERIMENTAL RESULTS

From the results of present experimental study, it is clear that if soil is collected from aforementioned two places of Pilani and soil composition used similar to soil composition used in present study, it will have a cohesion of 0.876 T/m^2 and angle of internal friction of 38.8 degrees. If this soil is used as underlying soil (till required depth below ground surface), for surface footing of square type (5 meters × 5 meters plan area), its net safe bearing capacity will be 26.21 T/m^2 at 10% water content and 1.57 gm/cc dry density. As fiber content increases from 0% to 0.12%, cohesion was found to increase from 0.876 T/m^2 to 1.379 T/m^2 and angle of internal friction was found to decrease from 38.8 degrees to 36.87 degrees. Net safe bearing capacity was found to range from 24.99 T/m^2 to 26.72 T/m^2. Maximum value of net safe bearing capacity was found to be 26.72 T/m^2 at 0.08% fiber content. At this fiber content, cohesion in the composite was 1.283 T/m^2.

If cohesion in underlying soil is zero or negligible, there is possibility of crack formation in the underlying soil below surface foundation block in the long run. Underlying soil might settle affecting foundation block as well as the superstructure. If 0.08% fiber content is used in the experimented soil with fiber orientation perpendicular to the labeled horizontal ground surface with sufficient fiber length below ground surface it will have maximum net safe bearing capacity. Furthermore, it will have cohesion of 1.283 T/m^2, which is substantially higher than unreinforced condition cohesion of 0.876 T/m^2. Performance of underlying soil as foundation material will be much better in the long run in terms of crack formation.

With increasing weight fraction of glass-fibers in the composite, adhesion between soil particles and glass fibers increases resulting in better physical bonding between the two phases [3]. Apart from better physical bonding, increased adhesion between soil particles and glass fibers results in decrease in diffuse double layer thickness around soil particles. Combined effect of decrease in diffuse double layer thickness around soil particles and van der Waals attractive forces between soil particles due to better adhesion, enhances sticking tendency between soil particles. This results in increase in cohesion of the glass fiber reinforced soil composite. In the present study, cohesion of glass fiber reinforced soil composite was found to increase with increase in weight fraction of glass fibers.

When glass fibers are present in the soil matrix, the contact area between soil particles gets reduced [4]. Furthermore, if diameter of glass fibers is smaller compared to particle size of soil particles of the soil matrix, glass fibers tend to slip under external load. This causes actual physical contact between soil particles to decrease.

Consequently frictional resistance of the glass fiber reinforced soil composite is less. In the present study, glass fiber diameter was smaller than the particle size of the soil tested and therefore this phenomenon was applicable. In soils without glass fiber reinforcements, frictional resistance is either due to physical contact between the soil particles or due to attractive electrical forces of interaction between soil particles.

Due to reduction in contact area between soil particles, there is reduction in attractive electrical forces of interaction. This reduction in attractive electrical forces also reduces frictional resistance of the glass fiber reinforced soil composite [5]. In the present study, angle of internal friction (which is an indication of frictional resistance) of glass fiber reinforced soil composite decreased with increasing weight fraction of glass fibers.

4. CONCLUSIONS

As already explained, soil in present study was collected from two different places in Pilani. If this soil, in the composition as described in present study is used as underlying soil till required depth, for 5 meters square surface footing, it will have maximum net safe bearing capacity if reinforced with E-glass fibers with fiber content 0.08% based on the tested fiber contents in the range of 0% to 0.12%. Fiber orientation will be perpendicular to horizontal soil surface with fiber length as per required soil depth. The fibers will be in strand form. For 5 meters square underlying soil of required depth, there will be three equal soil layers of 5 meters length and 1.67 meters width with one fiber strand layer in between two soil layer with appropriate spacing between fiber strand to get 0.08% fiber content.

Although soil from two locations in Pilani has been used in present study, representative ground surface soil where surface footing has to be constructed can be reinforced with E-glass fibers (in the strand form) and corresponding laboratory investigation can be carried out (the way it was carried out in present study) to find out optimum required fiber content. Similar study can be carried out at other places also.

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