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Bearing capacity of geotextile-reinforced sand with varying fine fraction

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Abstract. Use of geotextile as reinforcement material to improve the weak soil is a popular method these days. Tensile strength of geotextile and the soil-geotextile interaction are the major factors which influence the improvement of the soil. Change in fine content within the sand can change the interface behavior between soil and geotextile. In the present paper, the bearing capacity of unreinforced and geotextile-reinforced sand with different percentages of fines has been studied. A series of model tests have been carried out and the load settlement curves are obtained. The ultimate load carrying capacity of unreinforced and reinforced sand with different percentages of fines is compared. The interface behavior of sand and geotextile with various percentages of fines is also studied. It is observed that sand having around 5% of fine is suitable or permissible for bearing capacity improvement due to the application of geosynthetic reinforcement. The effectiveness of the reinforcement in load carrying capacity improvement decreases due to the addition of excessive amount of fines.

Keywords: bearing capacity; compaction; fine; geotextile-reinforced sand, soil-geotextile interface friction and adhesion

1. Introduction

Geosynthetic reinforcements are effectively used as a construction material to increase the bearing capacity and reduce the settlement of foundation resting on weak or poor soils. It can be used for many geotechnical constructions like foundations, retaining walls, embankments etc. Many researches have been conducted to study the behavior of footing resting on geosynthetic-reinforced bed (Binquet and Lee 1975, Andrawes *et al*. 1983, Guido *et al*. 1985, Sakti and Das 1987, Love *et al*. 1987, Das 1989, Khing *et al*. 1994, Manjunath and Dewaikar 1994, Adams and Collin 1997, Das *et al*. 1998a, b, 2001a, b, Boushehrian and Hataf 2003, Patra *et al*. 2005, Basudhar *et al*. 2007, 2008, Sharma *et al*. 2008, Latha and Somwansh 2009, Lavasan and Ghazavi 2012).

Most of the available studies on geosynthetic-reinforced soil are conducted either on pure sand or clay. Very limited studies are conducted to study the effect of fines on behavior of geosynthetic-reinforced and unreinforced sands. Studies have been conducted to show the effects

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of fines on the different properties of sands such as undrained shear strength, liquefaction resistance and pore pressure generation, mechanical properties, compressive strength (Salgado *et al*. 2000, Polito and Martin 2001, Bloomfield and Ware 2004, Ni *et al*. 2004, Naeini and Baziar 2004, Sadek and Saleh 2007, Derakhshandi and Rathje 2008). Studies are also conducted to find the effects of fines on compaction characteristics of sand (Bloomfield and Ware 2004, Kim *et al*. 2004, Deb *et al*. 2010). Babi *et al*. (2000) conducted CBR tests and concluded that within the limits of 0 to 10% by mass, fine stone particles have positive effect on the bearing capacity improvement. It is further concluded that fine clay particles content higher than 5% by mass is not acceptable as for higher percentages of fines the bearing capacity decreases. Thus, it is observed that most of the studies on effect of fines are conducted for unreinforced soil and are mainly concentrated to show the effect of fines on various properties of sand. The size of individual particles has an important influence on the behaviour of soils. In the field, getting pure sandy soil sometimes is difficult and in such cases the soil is a mixture of sand and some percentages of fines (silt or clay or both). Thus, it is necessary to study the behavior of unreinforced and geosynthetic-reinforced sand mixed with fines. The main objective of this study is to investigate the effects of fines on the behavior of geotextile-reinforced and unreinforced sands. The effect of fines on the effectiveness of geotextile reinforcement in bearing capacity improvement is also studied.

2. Experimental studies

The necessary details of the materials used, experimental set-up, tests conducted and the experimental procedures are outlined in the following sections.

2.1 Materials

Sand, fine and geotextile were used for the experimental investigations. Sand particles passing through 4.75 mm sieve and retained in 0.075 mm sieve were used for the tests. The grain size distribution of the sand is shown in Fig. 1. From the particle size distribution curve of sand, the Coefficient of Uniformity (C_u) and Coefficient of Curvature (C_c) values have been determined and presented in Table 1.The properties of sand have also been presented in Table 1. Soil with particle size less than 0.075 mm has been used as fine. The grain size distribution of the fine is shown in Fig. 1. The properties of the fine have been presented in Table 2. A woven type polypropylene geotextile was used as reinforcement. Table 3 shows the properties of the geotextile reinforcement.

2.2 Compaction characteristics of the soil mix

To investigate the effect of fines on compaction behavior of sand, standard proctor tests were carried out on sand mixed with different percentages of fines (5%, 10%, 20%, 30%, and 40% by mass). Maximum dry unit weight ($\gamma_{d\max}$) at optimum moisture content was obtained from the tests. Fig. 2 shows the variation of maximum dry unit weight with percentage of fines. It is observed that as the fine percentage increases (up to 21%) the maximum dry unit weight value also increases and after that it decreases due to addition of fines. This is because of the fact that due to the addition fines into the coarse-grained sand, the void spaces are being occupied by the added fines which increase the density of the sand. However, after a limiting value of 21%, the void spaces are filled with more fines and the sand particles are replaced by excess fines. As the maximum dry unit

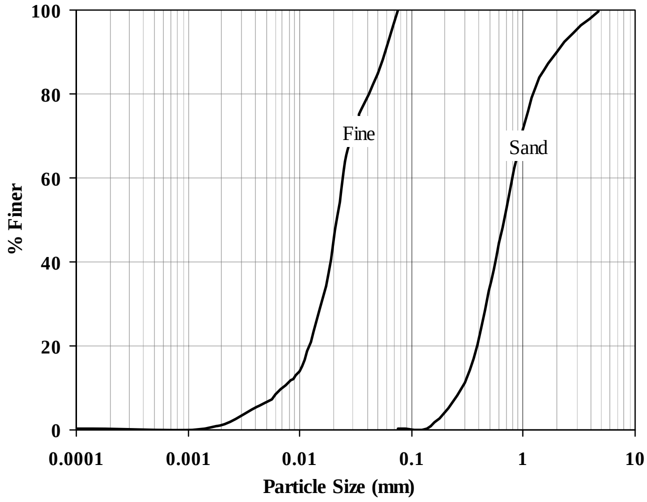

Fig. 1 Grain size distribution of sand and fine

Table 1 Properties of sand

Parameters	Values
Specific gravity	2.7
Maximum dry unit weight	17.3 kN/m^3
Minimum dry unit weight	14.8 kN/m^3
Internal friction angle (ϕ) at 65% relative density	42°
Bulk unit weight at 65% relative density	16.35 kN/m^3
Uniformity coefficient (C_u)	2.9
Coefficient of curvature (C_c)	1.0

Table 2 Properties of fine

Parameters	Value
Specific gravity	2.55
Liquid limit (%)	49.7
Plastic limit (%)	23.6
Plasticity index	26.1
Optimum moisture content (OMC) (%)	22.5
Maximum dry unit weight ($\gamma_{d\max}$)	15.2 kN/m^3
Undrained cohesion (at OMC and $\gamma_{d\max}$)	27.5 kPa

Table 3 Properties of geotextile

Parameters	**Value**
Pore size	< 0.075 mm
Thickness	0.29 mm
Weight	261 gm/m^2
Ultimate tensile strength	12.8 kN/m
Strain at maximum strength	15%

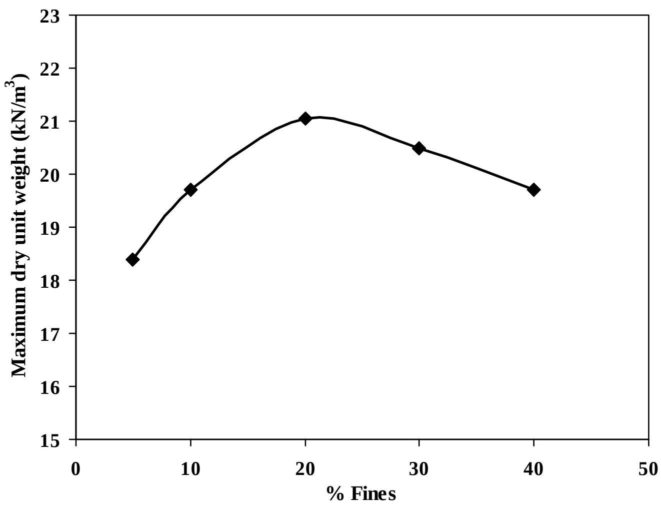

Fig. 2 Variation of maximum dry unit weight with fines

weight of pure fine soil (15.1 kN/m^3) is lower than the maximum dry unit weight of pure sand (17.3 kN/m^3), the $\gamma_{d\max}$ value decreases with the addition of excessive fines (more that 21%) into the sand. Deb *et al*. (2010) studied the effect of fines on compaction characteristics of poorly graded sand and similar results were obtained. A correlation between the required amount of the fines to attain the maximum dry unit weight and uniformity coefficient of sand (C_u) has been suggested by Deb *et al*. (2010). According to the suggestion, as the C_u value of the sand increases from 1 to 6, the amount of fine requited to attain maximum dry unit weight decreases linearly from 32% to 9% (by mass). From the suggested relationship, the calculated required amount of fine is around 23% (as in the present study, the C_u value of the sand is 2.9) and from the present study the observed value is around 21%.

2.3 Geotextile-soil interface properties

To determine the interface properties (adhesion and friction) between the geotextile and mixed soil, modified direct shear tests were conducted for different percentages of fines (5%, 10%, 20%, 30% and 40% by mass) according to the procedure adopted by Anubhav and Basudhar (2010). In the modified direct shear test, a Perspex block was placed into the lower half of the direct shear box and the upper half of the box was filled with sand (with and without fines). The geotextile was placed at the interface between the Perspex block and soil. The traditional direct shear tests were also conducted to determine the cohesion and friction values of the mixed soil without geotextile reinforcement (unreinforced soil). Figs. 3 and 4 show the variation of cohesion (or adhesion) and friction angle (or interface friction angle) with percentage of fines, respectively for both unreinforced and reinforced conditions. It is observed from the Fig. 3 that for unreinforced case, as the amount of fine increases the cohesion (*C*) value also increases up to 30% of fines, whereas beyond that it decreases due to addition of fines. This is due to that fact that the direct shear tests were performed at optimum water content (OMC) to achieve maximum bulk unit weight. The OMC value is in between 8%-10% up to 30% fine, but when the fine content is more than 30%, the OMC value increases and for pure fine soil it is 22.5%. Thus, as the fine content increases the cohesion value also increases (up to 30%). However, beyond the 30% fines, as the fine content increases amount of water in the soil also increases to achieve the maximum bulk unit weight and cohesion value decreases. For pure fine soil, the undrained cohesion value is 27.5 kPa (at OMC and $\gamma_{bulkmax}$). The degree of saturation of the mixed soil at its OMC is around 90% when more than 10% fines are added. Thus, the effect of water on cohesion value of the soil is more as the percentage of fine increases. The unit weight of the mixed soil also decreases as more fines are added (more than 21%). For reinforced case, as the fine amount increases the adhesion between soil and reinforcement ($C_a = \alpha C$, where α is the adhesion factor and C is the cohesion value of the unreinforced soil) value also increases up to 30% of fine and after that it decreases slightly. However, the increment or reduction of the adhesion value with fines is not much significant as compared to the increment or reduction of the cohesion value of the unreinforced soil with fines. For example, in case of unreinforced soil the cohesion value is increased by 19 times as the amount of fine increases from 5% to 30%, whereas for reinforced soil the increment of interface adhesion is only 5 times due to similar increment of fines. The reduction of cohesion value is 43%

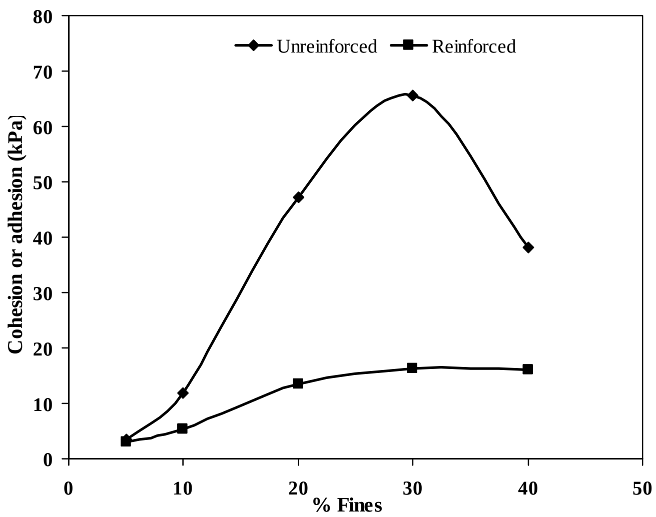

Fig. 3 Variation of cohesion and adhesion with fines

when amount of fine increases from 30% to 40%, whereas the reduction of adhesion value is only 1.2% due to similar increment of fines. Thus, effect of fines on the cohesion value of the unreinforced is more significant as compared to the interface adhesion value of the soil and geotextile. However, at 5% fines the reinforcement-soil adhesion value is almost same as compared to the cohesion value of unreinforced soil and beyond that the reinforcement-soil adhesion value is lower than the cohesion value of unreinforced soil.

Fig. 4 shows the variation of friction angle (ϕ or δ, where ϕ is the friction angle of the unreinforced soil and δ is the angle of friction between the soil and geotextile) value with

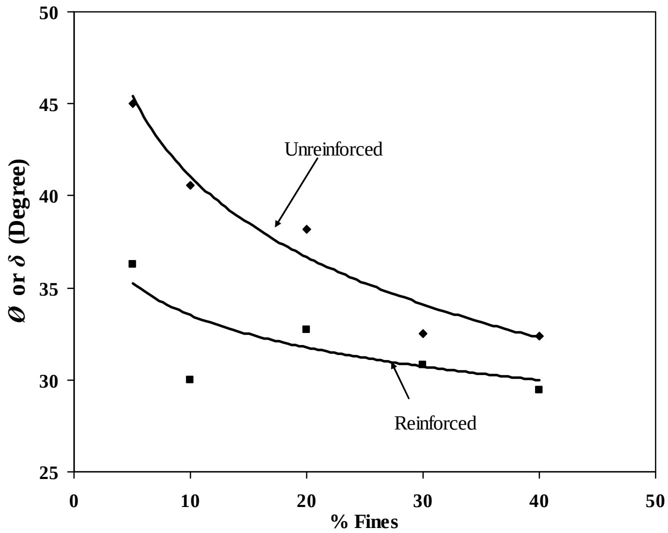

Fig. 4 Variation of ϕ and δ with fines

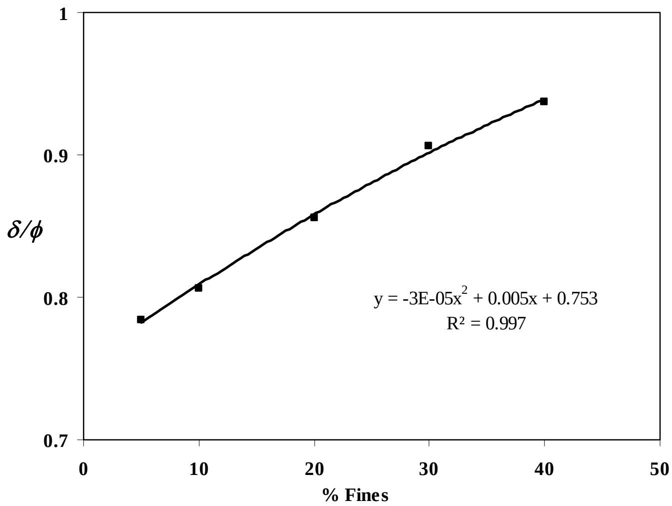

Fig. 5 Variation of δ/ϕ with fines

percentage of fine. The difference between ϕ and δ decreases as the amount of fine increases in the sand. The effect of fines on the interface friction angle between soil and reinforcement is not so significant as compared to the friction angle of the unreinforced soil. For example, the friction angle of the unreinforced soil is decreased by 29% as the amount of fine increases from 5% to 40%, whereas the reduction is 15% in case of interface friction angle due to similar addition of fines. For pure sand at 65% relative density, the ϕ and δ values are 42° and 28°, respectively. Thus, it can be said that ϕ value of mixed soil is slightly more as compared to the pure sand at 65% relative density if small percentage of fine is added (up to 10%) whereas, addition of more fine reported lower ϕ value as compared to the pure sand at 65% relative density. This is due to the fact that the density of soil with 5% fine is more than the density of the pure sand (at 65% relative density). Thus, the friction angle of the sand with 5% fine is more than the friction angle of pure sand. However, as the amount of fine increases the friction angle value of the mixed soil decreases and soil with more than 10% fine, the friction angle of the fine mixed sand is less than the friction angle of pure sand (at 65% relative density). Based on the obtained results (Fig. 4), an equation is proposed in non-dimensional as (from Fig. 5)

$$\frac{\delta}{\phi} = -0.00003 f^2 + 0.005 f + 0.753 \tag{1}$$

where f is the amount of fines in percentage (≥ 5%) and ϕ and δ are in degree. However, the equations are presented based on the observed experimental results from one type of sand, fine and geosynthetic reinforcement. More experiments are required with different types of materials to propose generalized equation.

2.4 Model test setup

An experimental test setup was developed for model testing purpose to show the effect of fines on the behavior of geotextile-reinforced sand. A steel tank having dimension 1.2 m (length) × 1 m (width) × 0.5 m (height) was used to conduct the model tests. LVDT was used for measuring the deflection under various loading conditions. For measuring the applied load, a proving ring was used with a least count of 6.5 kg. For the model tests, an iron square footing of dimension 150 mm × 150 mm and thickness 10 mm was used. The depth of the soil sample for each test was taken as 500 mm. To achieve the required density, the soil was compacted. Total 8 numbers of tests were carried for 0%, 5%, 10%, 20% fine mixed with sand (by mass). For each soil sample, unreinforced and reinforced both the tests were conducted. Single layer of geotextile was placed at 75 mm (0.5B, where B is the width of the foundation) depth from the bottom of the footing [as it is reported that placement of single reinforcement layer at 0.5B depth gives maximum improvement (Basudhar *et al*. 2008). Sufficient length of the reinforcement was used (more than 6B) for development of adequate friction between the reinforcement and soil. Fig. 6 shows the schematic diagram of the model test setup.

2.5 Sample preparation for model test

For both unreinforced and reinforced cases, dry sand of specified properties was used for 0% fine condition. Compaction was done to achieve 65% relative density. For preparation of 5%, 10%, 20% fine mixed soil, initially dry sand was taken and percentage wise fine soil slurry was mixed with the dry sand. Corresponding to each fine percentage, required water was added to achieve

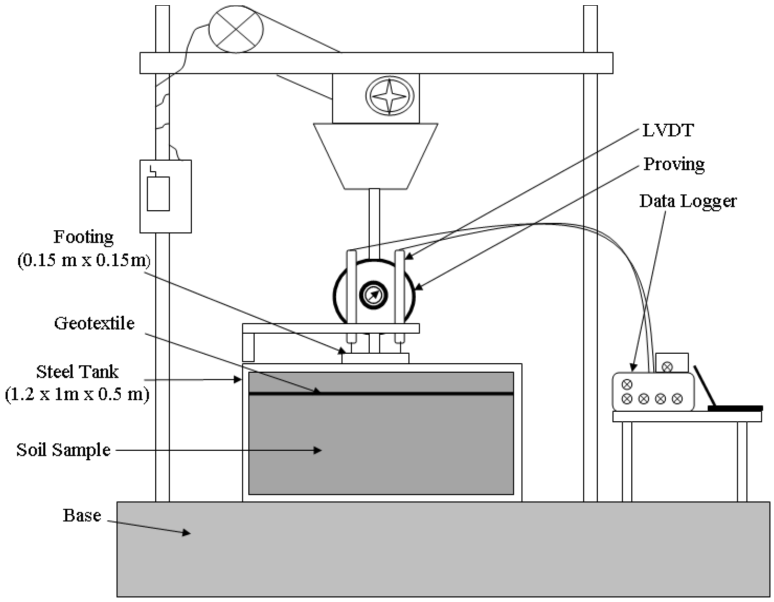

Fig. 6 Scehmetic diagram of model test setup

optimum moisture content as the mixed soils were tested at OMC. Soil layers were compacted for both unreinforced and reinforced case.

2.6 Test procedure

For zero percentage fine, dry sand was placed inside the tank and compaction was done in five layers with a layer thickness of 100 mm. For rest of the tests, soil sample was prepared by mixing of required percentage of fines (5%, 10% and 20% by mass) and water (at OMC) with sand. The mixed soil sample was placed into the tank by 100 mm thick layer (in 5 five layers) and compacted to achieved required maximum bulk unit weight. The square footing (0.15 m × 0.15 m) was placed on the soil sample. Loading (under constant stress) was applied on the footing and measured by the proving ring. The settlement was measured by the LVDT which was placed on the top of the footing. Tests were done for four cases as: (i) unreinforced and reinforced dry sand at 65% relative density; (ii) unreinforced and reinforced sand with 5% fine; (iii) unreinforced and reinforced sand with 10% fine; and (iv) unreinforced and reinforced sand with 20% fine.

3. Results and discussion

Figs. 7 and 8 show the load-settlement curves of unreinforced and geitextile-reinforced sand mixed with various percentages of fines. To investigate the effect of fines on the improvement characteristics of geotextile-reinforced sand, the ultimate load carrying capacity of the soil for each test has been determined and reported in Fig. 9. Since no definite failure point is observed in all the load-settlement curves, the ultimate load carrying capacity of the soil is determined by load corresponding to the intersection point of the tangents drawn from initial and end straight portion of the load-settlement curve as suggested by Lee *et al*. (1999). It is observed from the figure that as the amount of fine increases the ultimate load carrying capacity of the unreinforced and reinforced soil increases (up to 10% of fines). This is due to the fact that for 5% fines, maximum value of friction angle is achieved and cohesion value is also increased (as compared to pure sand), whereas as the fine content (> 5%) increases cohesion value increases significantly (up to 30%), but ϕ value decreases not as significantly as compared to the increment of cohesion value. The density of the sand also increases as the amount of fine increases (up to 21% fine). Thus, the load carrying capacity of the mixed soil increases as the amount of fine increases (up to 10% of fine). In case of

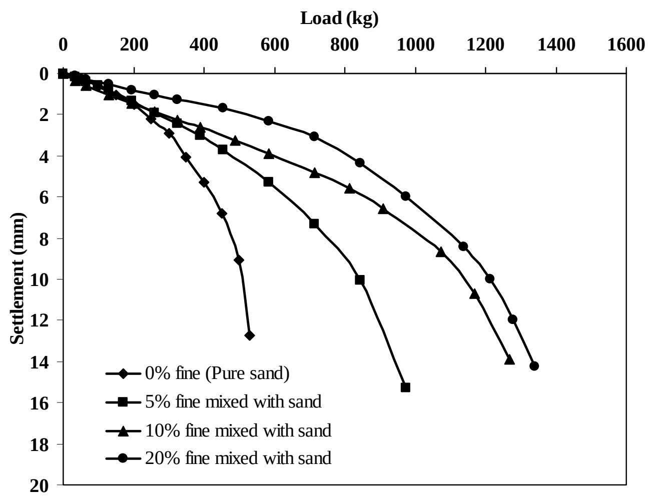

Fig. 7 Load-settlement curves of unreinforced sand with various percentages of fines

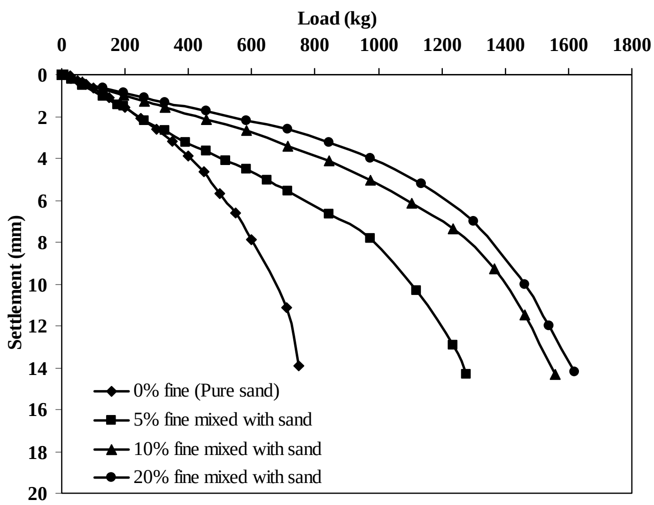

Fig. 8 Load-settlement curves of reinforced sand with various percentages of fines

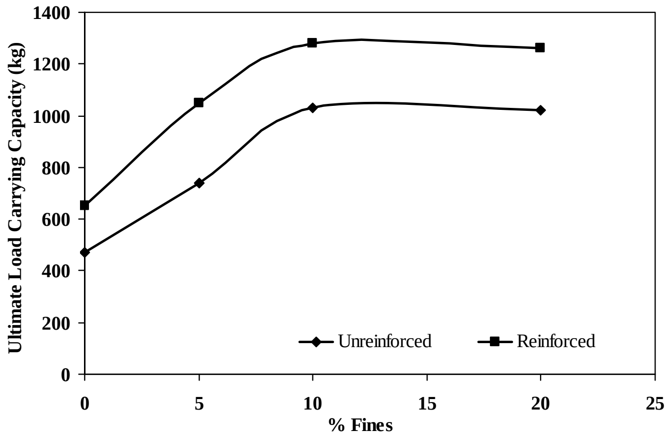

Fig. 9 Variation of ultimate load carrying capacity with fines

5% and 10% fine mixed soil, almost 90% of maximum bulk unit weight is achieved in the model tank, but in case of 20% fine mixed sand around 86% maximum bulk unit weight is achieved. Thus, almost same maximum bulk unit weight is achieved for 10% and 20% mixed soil and not much improvement in the load carrying capacity is observed from 10% to 20% fine mixed soil.

Fig. 10 shows the percentage of improvement of the load carrying capacity of the soil due to application of geotextile reinforcement for different amount of fines mixed with sand. It is observed that percentage improvement of ultimate load carrying capacity of reinforced soil is more in case of sand mixed with 5% of fines as compared to the pure sand at 65% relative density. This is due to the fact that for dry sand (0% fines), only interface friction is present between the soil and geotextile. However, for 5% fine mixed soil higher value of interface friction and some adhesion are observed. Thus, the effectiveness of the reinforcement is more in the presence of 5% fines and

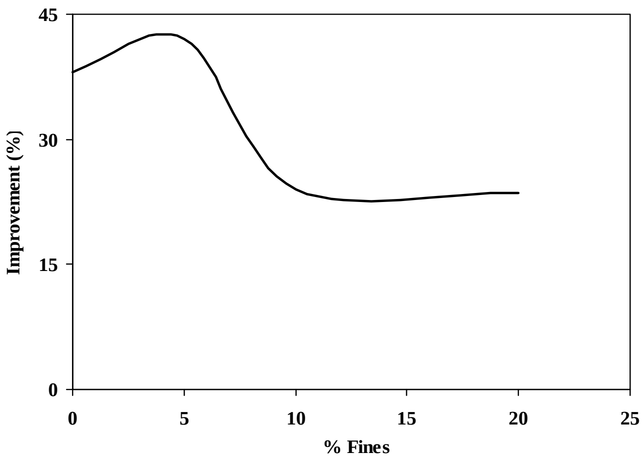

Fig. 10 Variation of improvement with fines

more load carrying capacity improvement is observed due to the application of reinforcement. However, the improvement of load carrying capacity due to the application of reinforcement is more in case of pure sand as compared to the 10% and 20% fine mixed soil. This is due to the fact that higher density is observed in case of 10% and 20% fine mixed soil as compared to the pure sand. The effectiveness of the reinforcement decreases in case of dense soil as compare to the loose soil as in case of loose soil, more deformation is occurred and the effectiveness of the reinforcement also increases which causes more improvement. However, in case of 5% fine mixed soil, the density is also more as compared to the pure sand, but in case of 5% fine mixed soil more improvement is observed due to higher friction and adhesion properties between the reinforcement and sand. The density of 5% fine fixed soil is also less than the density of the 10% and 20% fine mixed soil. Thus, the effectiveness of the reinforcement is not only related to the density of the soil, but also related to the interface properties between the soil and reinforcement and vice versa.

From Figs. 3 and 4 it is observed that as the fine amount increases cohesion value increases (up to 30% fine) and friction angle of the unreinforced soil decreases. Thus, ultimate load carrying capacity increases with a decreasing rate as percentage of fine increases (as shown in Fig. 10) and after certain percentage of fine the ultimate baring capacity of the mixed soil will decrease with in increase of fines. Using the strength parameters obtained from direct shear tests, the ultimate load carrying capacity of the unreinforced mixed soil can be determined (by using available ultimate load carrying capacity expressions). In such determination, the ultimate load carrying capacity of the mixed soil increases up to 20% fines and beyond that it decreases with the addition of more fines. However, in the present study not much variation of ultimate load carrying capacity of the soil is observed with 10% and 20% fines as in case of 20% fine mixed soil 86% maximum bulk unit weight of the soil is achieved in the model tank, whereas in case of 10% fine mixed soil around 90% maximum bulk unit weight of the soil is achieved in the model tank. Thus, not much change in the density is observed for both the cases. The density of the sand also increases up to addition of around 20% fines and after that it decreases with the addition of more fines. However, for reinforced sand having around 5% fines reinforcement can effectively improves the load carrying capacity of the mixed soil. The effectiveness of the reinforcement decreases due to addition of more fines. In the model tank, the pure sand is tested at 65% relative density. However, in case of soil with higher relative density, lower amount of the improvement in load carrying capacity can be observed due to the application of reinforcement and vice versa. The permeability of the sand will decrease with the addition of fines. Thus, if consolidation of the soil is a significant issue then percentage of fine has to be chosen according to the requirement. However, in the present paper the effect of fines on the consolidation behavior of mixed soil is not studied. In the present paper, only one type of sand, fine and reinforcement are used. More studies are required on different types of sands, fines and reinforcements to investigate the effect of fines on the behavior of reinforced sand. However, the information presented in the paper will help to choose the proper soil for geosynthetic-reinforced earth to get maximum effectiveness of the reinforcement.

4. Conclusions

From the experimental results it is observed that as the fine percentage increases up to a certain value, the maximum dry unit weight value of the soil also increases and after that it decreases due to addition of fines. The cohesion value of the soil and adhesion value in between soil and geotextile also increase due to the addition of fines (up to 30%). However, reduction in the cohesion and adhesion value is observed with the presence of excessive fines as water content has a significant effect on the cohesion value of the soil if excessive amount of fines are present in the sand. Friction angle and interface friction value decrease as the percentages of fines increases. The increment or reduction of interface adhesion and friction angle between reinforcement and soil is not much significant with the change in fine content as compared to the cohesion and friction angle value of the unreinforced soil. It is further observed that sand having around 5% of fine is suitable or permissible for significant improvement in load carrying capacity due to the application of reinforcement. The effectiveness of the reinforcement in load carrying capacity improvement decreases due to application of excessive amount of fines.

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