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Effect of Cohesive Fines on Performance of Compacted Sand Fills

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Introduction

Low-lying areas are often required to be developed as sites for construction of residential and industrial buildings. To avoid flooding of the area and to place the foundation at an appropriate level, formation level of such sites is required to be raised through compacted fills. Further, in situations where topsoil is weak, it may be replaced by stronger compacted fill to improve bearing capacity and limit settlement of foundations. Fills may also be used to level undulating ground.

Literature (Peck et al., 1974) indicates that fills placed by carefully controlled procedure can provide better support for structures than even natural deposits. There are many cases where compacted fills have been used successfully in construction work. Availability of a suitable fill material (i.e., easily transportable, compactable and which can develop adequate strength to support the structural loads) near the construction site is the ideal condition for construction of fills. Well-graded sand and gravels containing small percentage of clayey fines are considered the most suitable fill materials (Peck et al., 1974). Well-graded sand when compacted results in a dense mass compared to a poorly graded sand. The small percentage of fines helps in better compaction. However, it is rare that such materials become available at reasonable cost.

It is a common practice to use river sand and soil from borrow areas as fill material. The river sand, mostly poorly graded sand and available in

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wet condition, is not easily amenable to high degree of compaction due to its bulking (Schroeder, 1975). Literature suggests that small amount of clayey fines can improve the density and hence the performance of fills under loads. (Peck et al., 1974; Shankaraiah et al., 1988; Lade and Yamamuro, 1997; Chein and Oh, 1998; Thevanayagam, 1998 and Pitmen et al., 1994). The available literature is briefly summarized to bring out the scope of the present work:

Maximum Dry Density

It is observed that as the amount of fines is increased the density of the sand increases, reaching a peak value for addition of 25-30% fines (Pitmen et al., 1994). Further addition of fines shows a decreasing trend in the density. Larger increase in density on addition of fines is observed for poorly graded sand as compared to well-graded sand. Chein and Oh (1998) report that the density of mixture of sand and fines improves by 8% on addition of 30% fines. Pitmen et al., (1994) used kaolinite as plastic fines and crushed silica as non-plastic fines. Density is found to improve on addition of both plastic and non-plastic fines up to 20%. However, larger increase in density is observed on addition of plastic fines as compared to that due to the addition of non-plastic fines.

Shear Strength Parameters (c and ϕ)

On addition of plastic fines, cohesion is imparted to the mix of sand and fines. It is also observed that as the amount of fines is increased the 'ϕ' (angle of shearing resistance) value decreases (Pitmen et al., 1994, Thevanayagam, 1998, Chein and Oh, 1998).

Compressibility Characteristics

Shultz and Moussa (1961) report that compressibility of sand increases on addition of both plastic and non-plastic fines. A mix of sand and non-plastic fines is found less compressible than a mix of sand and plastic fines. Shoby and Rabbaa (1984) report that on addition of fine upto 25-30%, the compression of the mix increases significantly as compared to that of the sand alone.

The above cited literature indicates that when clayey fines are added to sand and compacted, the dry density increases, some cohesion is imparted and the ϕ value is reduced. Addition of fines though reported to increase compressibility, the increase appears to be significant only for addition of fines of the order of 30%. This indicates that a better fill material than sand can be produced by adding appropriate amount of fines to sand.

Therefore the aim of this study is to examine the effect of addition of cohesive fines to sand on load-settlement behaviour of the compacted mix and to find the optimum combination of sand and fines which when compacted, gives the best performance under loads.

In view of the above a comprehensive experimental study was carried out. The study involves model plate load-tests on compacted test beds of sand and mixture of sand and fines. The study also involved shear and compressibility tests on compacted samples of different mixtures of sand and cohesive soil.

Experimental Study and Results

Materials Used

The Following materials were used in the experimental study:

(i) Sand: A locally available sand (Solani River sand) containing negligible fines (percentage of particles passing 0.075 mm sieve is 2.5) was selected as host sand.

(ii) Fines: A locally available clayey soil (Dhanori clay) was used as cohesive fines.

The physical properties of the above materials are presented in Table 1.

Compaction Characteristics

Compaction Characteristics i.e. maximum dry density (γ_{dmax}) and optimum moisture content (OMC) for various combinations of sand and cohesive fines (Table 2) were determined by standard Proctor test method (IS-2720 Part-7, 1980) and these results were used in the preparation of so samples for various tests.

The results of compaction tests (Fig.1) indicate that the dry density increases and the optimum moisture content (OMC) decreases with the increase in amount of fines upto about 30% and vice–versa for further addition. The increase in dry density and consequent reduction in void ratio is almost linear for addition of fines up to about 20%. This is because addition of fines fill up the void spaces between larger grains, resulting in a decrease in void ratio and consequent increase in the dry density. As the quantity of fines is increased beyond certain limit (30% in the present case), the additional fines occupy the space which otherwise must have been occupied by the sand grains resulting in the increased void ratio and decreased dry density (Pitmen et al., 1994). Improvement in the maximum

TABLE 1 : Properties of the Test Soils

Properties	Sand	Dhanori Clay
Specific Gravity (G)	2.65	2.68
Particle Size Distribution		
(i) Sand size (%)	97.5	2.0
(ii) Silt size (%)	2.5	68.0
(iii) Clay size (%)	0.0	30.0
Coefficient of Uniformity (C_U)	1.94	–
Coefficient of Curvature (C_C)	1.07	–
Standard Proctor Density		
$\gamma_{d\ max}$ (kN/m^3)	16.2	15.4
O.M.C (%)	14.0	24.0
Void Ratio		
e_{min}	0.529	–
e_{max}	0.833	–
Plasticity Characteristics		
Liquid Limit (%)	NP	49.0
Plastic Limit (%)	NP	25.0
Indian Standard Classification (IS:1498-1970)	SP	CI

NP - Non Plastic

TABLE 2 : Composition of Mixture of Sand and Fines

Mixture No. (1)	Sand (%) (2)	Fines (%) (3)
1	100	0
2	95	5
3	90	10
4	85	15
5	80	20
6	75	25
7	70	30
8	60	40

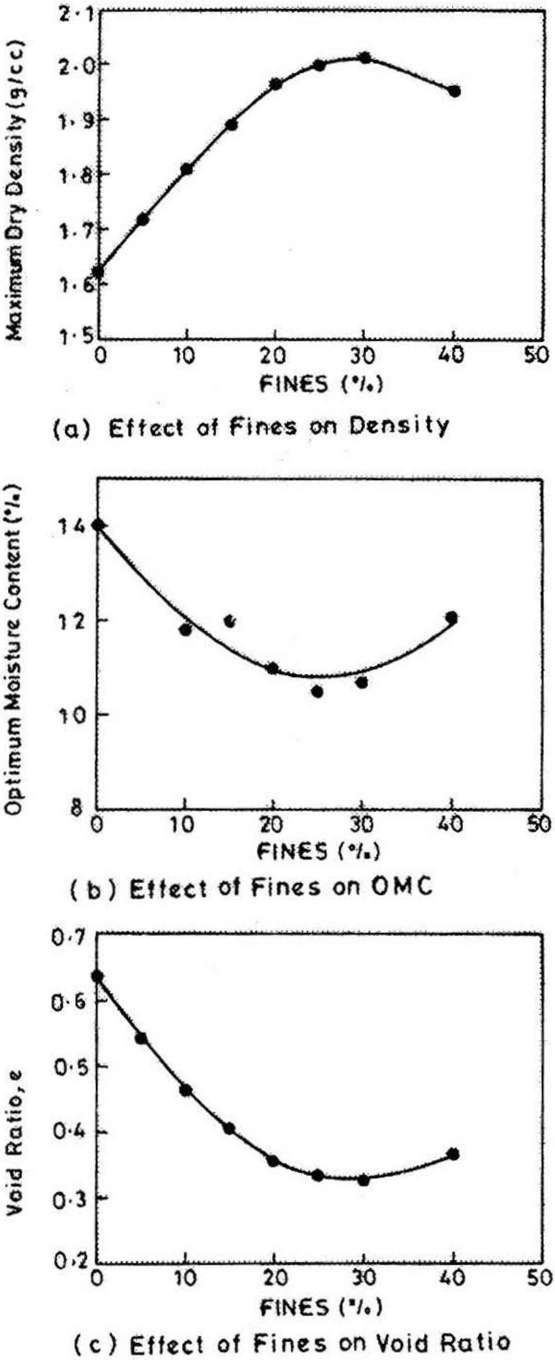

FIGURE 1 : Effect of Fines on Compaction Characteristics

dry density by about 21% is observed for addition of 20% fines. The above observations are on similar lines as reported in the literature (Pitmen et al., 1994; Lade and Yamamuro, 1997 and Chein and Oh, 1998).

Maximum and minimum dry density values (consequently the values of minimum and maximum void ratios) for the host sand were also determined as per IS-2720 (Part 14) 1983 (Subjecting a sample to vibration on a shake table for minimum void ratio and filling sand in loose state in a container through a funnel with a small (25 mm) height of fall for maximum void ratio). The minimum void ratio (e_{min}) was found to be 0.529 and maximum void ratio (e_{max}) was observed equal to 0.833. The sand compacted at OMC achieves a relative density of about 65%, which represents medium dense state. On addition of fines, the void ratio reduces to even less than that corresponding to the densest state of the sand (Fig.1c). This indicates that when sand is compacted with addition of fines the resulting fill can be denser than the possible densest state of the sand bed.

Shear Strength Characteristics

Shear Strength Characteristics (c and ϕ) of compacted mixes of sand and cohesive fines were determined by conducting direct shear test. The test specimen was allowed to consolidate under normal stress and sheared at the rate of 0.625 mm/min. Though the undrained condition cannot be controlled

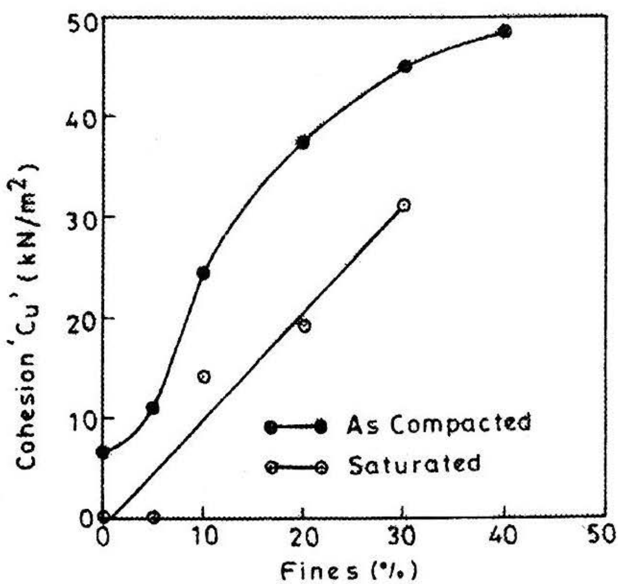

FIGURE 2 : Effect of Fines on Cohesion Intercept, 'c_u'

effectively in a direct shear test, the same is adopted due to its simplicity. The test is designated as consolidated undrained test in view of the fast rate of shearing adopted. The samples for direct shear tests were prepared by Proctor compaction at OMC of the given mix. The specimens for tests were extracted from these samples. The specimens were tested both at compaction and saturation moisture contents.

Results of the study (Fig.2), as expected, indicate that cohesion intercept, c_u, increases as the amount of cohesive fines is increased. However, for fine contents more than 30%, smaller increase in cohesion intercept is observed. As expected, a part of cohesion intercept exhibited under as compacted condition is lost on saturation due to increase in water content. Further, under as compacted condition, a part of the cohesion intercept exhibited may be because of capillarity arising due to contact moisture which is lost on saturation.

There is an increase in the value of ϕ_u by about 2.5 degrees (Fig.3) for addition of 5% and 10% fines under as compacted condition. The small increase in ϕ_u is because of increased density of the mixture of sand and fines. Under saturated condition, ϕ_u increases slightly for a fine content of 5% and decreases thereafter for further addition of fines. This indicates that at higher fine contents, the role of fines becomes predominant and the mix of sand and cohesive fines tends to behave like a cohesive soil.

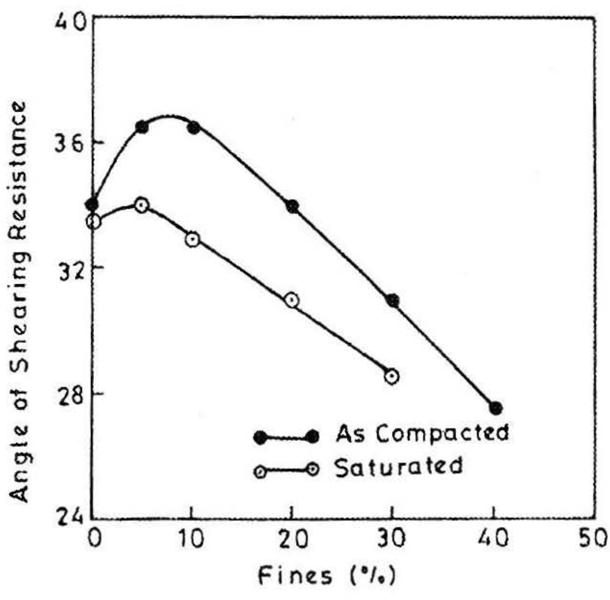

FIGURE 3 : Effect of Fines on Angle of Shearing Resistance

Compressibility Characteristics

One-dimensional consolidation tests (IS-2720, Part-15, 1986) were conducted to determine the compressibility characteristics. The samples for consolidation tests were prepared by Proctor compaction at OMC. Test specimens extracted in a consolidation ring (75 mm diameter and 20 mm high) from these samples were tested both at compaction and saturation moisture contents. For saturation, the samples were kept submerged in consolidation cell for 24 hrs. The load was then applied in specified increments.

The results of the above tests are presented in the form of $e - \log p'$ curves in Fig.4. The results show that the $e - \log p'$ curves are more or less parallel with marginal variation in the values of coefficient of volume compressibility, m_v (computed for pressure range of 25 to 200 kN/m^2) till the fine content is 20%.

Load Tests

The results of index and engineering properties of mixture of sand and fines indicate that a higher density and improved shear strength can be obtained on addition of a limited amount of fines (not more than 20%). To examine how these get reflected in load-settlement behaviour, plate load tests were carried out on the compacted test beds.

Test Set Up

The test beds were prepared in a circular tank. The details of the tank are shown in Fig.5. The tank is provided with arrangements for raising/lowering the water level within the test bed. A 20 cm thick layer of well graded gravel-sand mixture has been provided at the bottom of the tank (Fig.5) to act as a drainage layer to ensure uniform raising and lowering of the water level over the entire plan area of the test bed. Over this drainage bed, the test bed was prepared keeping its thickness about four times the width of the test plate. The load to the test plate (150 mm diameter) was applied through reaction loading, using a hydraulic jack. A calibrated proving ring of 50 kN capacity to measure the load and two dial gauges of 0.01 mm least count for measuring the settlements were used.

The diameter of the tank is about four times the diameter of the test plate as against the recommended minimum of five. However, as the aim of the study is to examine the comparative performance of various mixes of sand and fines, the confinement effect of the tank is likely to be of the same order for all the tests and therefore is not expected to alter inferences drawn from the test results.

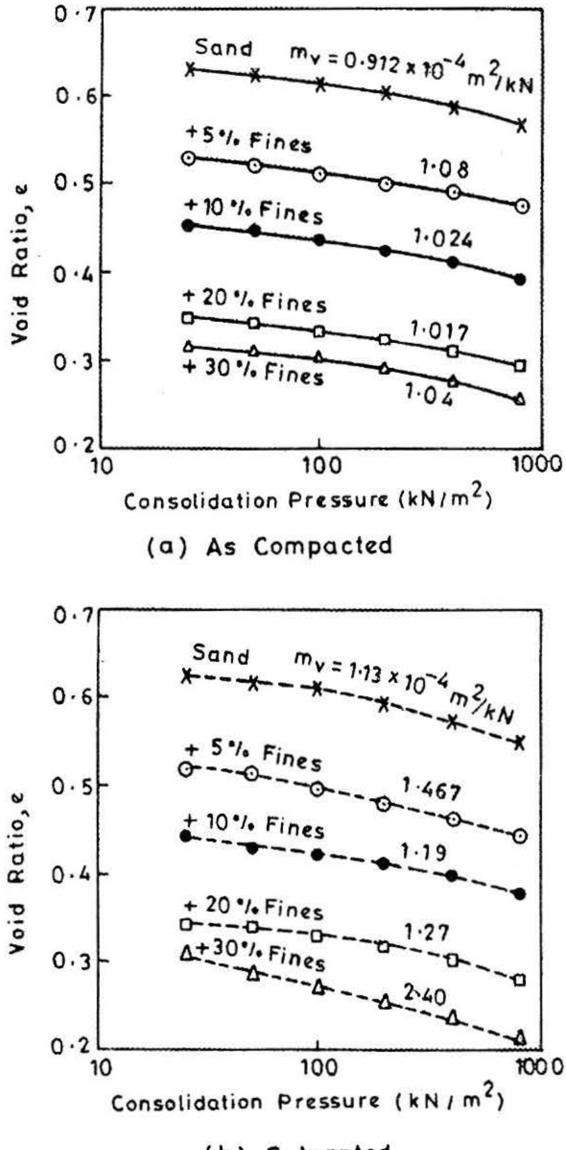

FIGURE 4 : $e - \log p'$ Curves for Sand and Sand+Fines

Preparation of Test Beds

The test beds for a given combination of sand and cohesive soils were prepared by compaction at corresponding optimum moisture content imparting

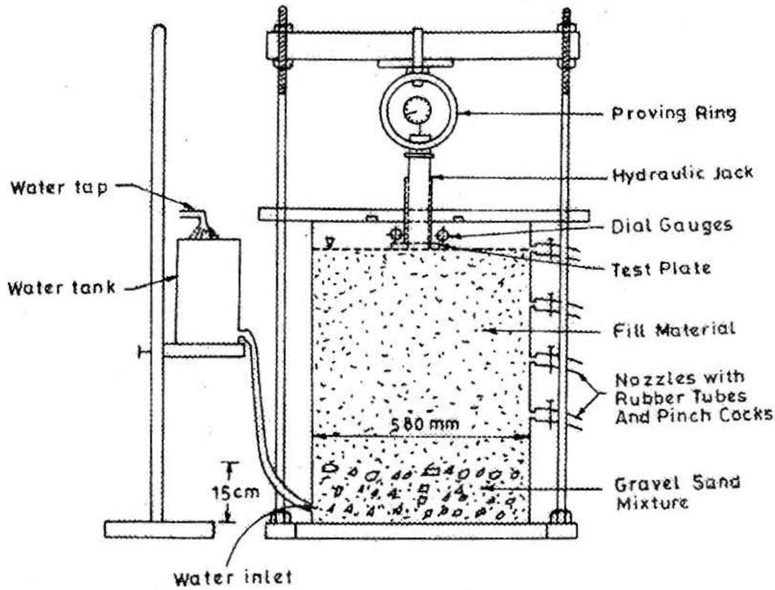

FIGURE 5 : General Arrangement of Test Setup

compactive energy equivalent to Proctor compaction. A hammer, weighing 105 N, with an arrangement of free fall of 50 cm, specially fabricated for the this study, was used for compacting the test beds. The number of blows of hammer to each layer was so chosen as to impart energy per unit volume, equivalent to that provided in standard Proctor test. The sand and cohesive soil, in required proportion were taken by weight for the given combination and were then mixed thoroughly in dry state. Water equivalent to the corresponding optimum moisture content was added to the mix in batches and thoroughly mixed. The mix was then compacted in layers of 8-cm thickness. The density and moisture content were determined by taking samples from test beds. The density achieved is within 2% of the maximum dry density by Proctor compaction for the corresponding mix for all the test beds prepared at OMC.

Test Conditions and Test Procedure

The tests were conducted under following conditions of test beds; (i) As Compacted and (ii) Submerged. Tests under as compacted condition were conducted immediately after the preparation of the test bed. The test plate was placed on leveled surface of prepared test bed. The top surface was leveled with the help of a straight edge and it was checked by a sprit level before placing the plate on it. Plate was then loaded in equal increments of load. Each increment of load was maintained till the rate of settlement becomes less than 0.02 mm/min (IS-1888, 1982). The test was continued till failure, indicated by the increase in rate of settlement of the test plate. For conducting tests under submerged condition, the plate was placed on the compacted test bed and the bed was gradually submerged by raising the water table from bottom of the bed by allowing water to flow from a water tank (Fig.5). It took a few hours for the sand bed and about a week for the bed of sand and 30% fines to get fully submerged. The plate was then loaded in equal increments till the failure occurred. The Water table was maintained at the surface throughout the test by maintaining the water level in water tank same as top of the test bed.

Results and Discussion

The results of the load tests (i.e. load-settlement curves) conducted are shown in Fig.6 and Fig.7. Figure 6 shows the results of tests on beds under as compacted condition. Figure 7 shows the results of tests on submerged beds. For the sake of comparison, standard load-settlement curve for a 30 cm (1 ft.) square plate resting on dry sand suggested by Peck et al. (1974) is also plotted in Fig.6 for very dense (Relative Density > 85%) sand and in Fig.7 for dense sand (Relative Density > 65%). As these plots of Peck et al. (1974) are for a 30 cm plate, the bearing capacity should be higher than for a plate of 15 cm in size. Comparison of the plots may be made keeping this in mind. A critical study of these results shows the following:

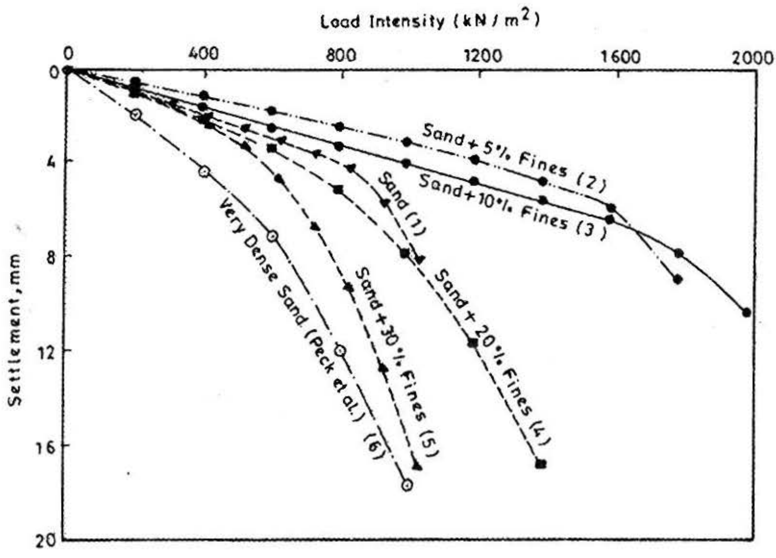

FIGURE 6 : Comparison of Load-Settlement Curves (As Compacted)

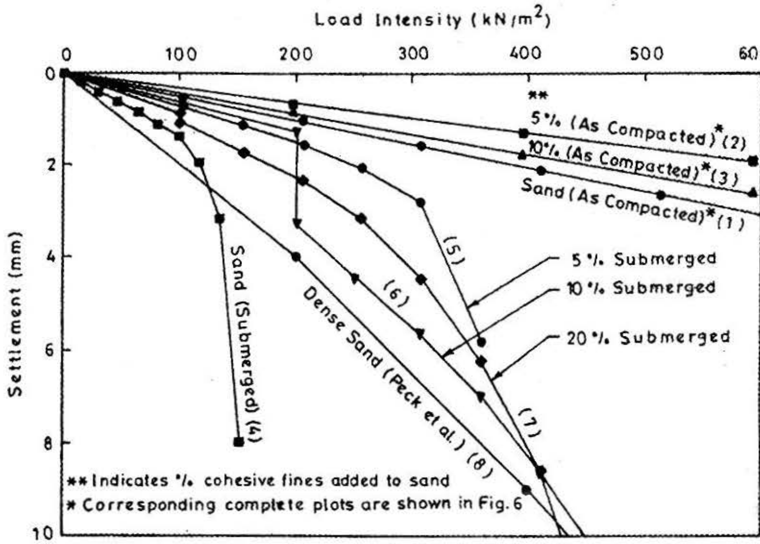

FIGURE 7 : Comparison of Load-Settlement Curves (Submerged)

(i) Plot 1, Fig.6 is the load-settlement curve obtained for a test bed of sand compacted at OMC, having relative density of 65%. Comparing this with the Plot 6, Fig.6, it is seen that the test bed of sand compacted in moist condition exhibits better performance (both in respect of settlement and bearing capacity) than a very dense (Relative Density > 85%) dry sand bed. This is because, the capillarity arising due to contact moisture imparts additional strength to the bed of sand compacted at OMC. Plate load tests carried out on capillary beds have shown such high level of performance (Poudel, 1990 and Ramasamy et al. 1999). Poudel (1990) has reported results of load tests on sand beds of varying thickness of capillary zone (equal to *B*, 2*B*, 3*B*, etc., where *B* is the width of the plate) below the plate. The results show that the bearing capacity of a plate on a capillary bed of thickness 3*B* below the plate is 3 to 4 times the capacity of a plate resting on dry sand bed. However, on submergence, the effect of capillarity is lost and the load carrying capacity of the compacted sand bed gets reduced to a very small value. The Ultimate bearing capacity of test plate on sand gets reduced from about 800 kN/m^2 for compacted bed (Plot 1, Fig.6) to about 120 kN/m^2 for the same bed on submergence (Plot 4, Fig.7). The practical implication of this observation is that one may get mislead if the safe bearing capacity of such compacted beds were to be assessed through the results of load tests.

(ii) Test beds of mixture of sand and fines of 5% and 10% show a much improved performance as compared to the test bed of sand under as compacted (Plots 1 to 3, Fig.6) condition as well as under submerged condition (Plot 5 and 7, Fig.7; Plot 7 shows a sudden increase in settlement as the plate was loaded under as compacted condition upto 200 kN/m^2 and submerged at this load level, and further loading continued under submerged condition). This is because there is an increase in ϕ_u value by about 2.5° (Fig.3) for addition of 5% and 10% fines. Further, in a sand bed, the cohesion component which exists due to capillarity in a partially saturated state (bed compacted at OMC) is completely lost on submergence, whereas in a sand+cohesive fines mixes, the cohesion component is only reduced but not completely lost (Fig.2). In the case of a surface footing on a c-ϕ soil, the major component of the bearing capacity is due to the cohesion component ($c\ N_c$). Therefore, whereas the bearing capacity of the plate on the sand bed is reduced to a very small value on submergence, the bearing capacity in the case of bed of sand+cohesive fine mix is substantial (more than that for a medium dense sand; Plot 8, Fig.7) even on submergence.

(iii) Of the various mixes tested, the bed of mixture of sand and 5% fines exhibits the best performance both under as compacted and submerged conditions. This mix is also found to exhibit the maximum ϕ_u value (Fig.3b). The void ratio for this mix compacted at OMC is 0.541, which is almost equal to the void ratio of the host sand at its densest state (which was 0.529). Thus, it appears, that the optimum fine content is the one which, when added and compacted, results in a void ratio equal to that of the densest state of the host sand.

Conclusions

The Following conclusions are drawn on the basis of the above study:

1. River sand, when borrowed and compacted in wet condition, is not amenable to high degree of compaction and the resulting fill performs poorly when subjected to submergence. However, when a small amount of cohesive fines (< 10%) is added, the fill exhibits higher strength and performs much better under load with respect to bearing capacity and settlement both in as compacted and submerged conditions of fills.

2. On addition of about 5% cohesive fines to sand, the void ratio of the mix attains void ratio of the sand at its densest state and the performance of the test bed of the mix is found to be better than the beds of sand and mix containing fines more than 10%. Therefore, the optimum fines content appears to be the amount which, when added and compacted at OMC results in a void ratio equal to that of the host

sand at its densest state. This however may be considered tentative till it is found valid for a variety of sand types.

3. Sand compacted in moist condition may exhibit very high carrying capacity due to capillarity, when load tested. If a foundation design is made on the basis of the results of such a load test, it may lead to unsafe design, as the carrying capacity is reduced to a very small value when the bed undergoes submergence.

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