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Effect of Shape of Footing on Coefficient of Elastic Uniform Compression of Polypropylene Fibre Reinforced Fine Sand

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ABSTRACT: Synthetic fibre reinforced granular soils, particularly fine to medium sands have the benefits of improved shear strength and permeability and as a result found wide application as fill and backfill material. However, not much work is reported on coefficient of elastic uniform compression (C_u) of fibre reinforced sand. C_u is used in determination of soil spring stiffness and is an important essential parameter in design of machine foundations and structures subjected to cyclic loads. Hence, in the present study, the effect of addition of polypropylene fibre in fine sand is assessed by conducting small scale cyclic load tests in the laboratory. The study is also intended to evaluate the effect of shape of loading plate on C_u of fibre reinforced sand. Fibres of 6 mm and 12 mm length in proportions of 0.5%, 1.0% and 1.5% by weight are mixed with fine sand in the study. The study yielded the optimum percentage of fibre for stabilization as 1%, with 12 mm fibre more effective than 6 mm fibre. No shape effect on C_u of fibre reinforced fine sand is observed in contrast to unreinforced fine sand for which C_u of circular plate is 0.85 times the C_u of square plate of same size.

KEYWORDS: Fine sand, Coefficient of elastic uniform compression, Polypropylene fibre, Shape of footing.

1. INTRODUCTION

Due to increased construction activity, the conventional fill materials such as sand and moorum are becoming scarce day by day. In order to overcome this situation, alternative fill materials have to be explored. Recent studies suggested the use of fine sand and fly ash as fill materials (Chu et al., 1955; Goecker et al., 1956; Viskochil et al., 1957; Gray and Lin, 1972; Manjesh et al., 2003; Ghosh et al., 2006; Ranjan et al., 1996; Amin Chegenizadeh 2012; Satyanarayana Reddy et al., 2014). Efforts are being made by the researchers to mix fibres into fine sand to overcome the issue of poor drainage leading to liquefaction under dynamic loading and to improve its strength under static loading.

2. REVIEW OF LITERATURE

Varghese et al. (1989) have reported that the addition of natural fibres increases the bearing capacity of cohesionless soils. The available research suggest that the synthetic fibres can be effectively used to improve strength and stiffness of sand (Lindh and Eriksson, 1990; Al-Refeai, 1991; Ranjan et al., 1996; Wasti et al., 1996; Charan, 1996; Rosa Santoni et al., 2001; Amin Chegenizadeh et al., 2012; Satyanarayana Reddy et al., 2014). The synthetic fibres of lengths 6-50 mm have been used and optimum synthetic fibre contents for stabilisation are reported in the range of 1-2% by weight of sand. Studies have been also carried out by researchers (Venkatapparao et al., 2005; Amin and Hamid, 2012; Maity et al., 2011) to evaluate the effect of addition of natural fibres, such as coir, jute, grass of 5-25 mm lengths and the optimum fibre contents for improvement in CBR and shear strength are reported in the range of 1.0-1.5% by weight of sand. However, the use of natural fibres as reinforcement in soils is a major challenge due to their biodegradability in the prevailing hostile environment and hence, synthetic fibres are preferred over natural fibres for use as soil reinforcement.

The studies on dynamic properties of fibre reinforced fine sand are limited and not much emphasis is given to evaluate its behaviour under dynamic loading condition. Coefficient of elastic uniform compression (C_u) is an important parameter for determination of natural frequency of vibration of machine foundations. C_u is determined by conducting cyclic plate load test with square plates (IS 5249-1990) and Barkan's equation (1962) given in Eq. 1 is used for determination of C_{uf} of actual footing size for foundation areas up to 10m^2.

$$C_{uf} = C_u \sqrt{\frac{A}{A_f}} \tag{1}$$

Where, A is area of base area of test plate
A_f is base area of actual footing

For base areas larger than 10 m^2, C_u corresponding to 10 m^2 shall be adopted.

The value of C_u evaluated from square test plates cannot be used for circular footings of machines as C_u depends on shape of footing. Hence, an attempt is made in the present study to reinforce fine sand with polypropylene fibres of varying proportions (0.5%, 1.0% and 1.5%) and length (6 mm and 12 mm) and evaluate coefficients of elastic uniform compression using square and circular plates of same size and weight.

3. MATERIAL PROPERTIES

Fine sand used for the present study is procured from Tenneti Park located in Visakhapatnam beach. Specific gravity of fine sand is determined as per IS 2720 (part 3 - section 2) 1980 and Grain size distribution is established from sieve analysis carried out as per IS 2720 (part 4) 1985. The gradation curve of fine sand is presented in Figure 1 and based on gradation characteristics, it is classified as Poorly Graded Sand (SP) as per Indian Standard Soil Classification System (IS 1498-1970). Compaction characteristics are determined by conducting IS Heavy Compaction test (equivalent to Modified Proctor test) in the laboratory as per IS 2720 (part 8) - 1983. Fine sand is found to have fair drainage based on coefficient of permeability determined from constant head permeability test [IS 2720 (part 17) 1986]. The engineering properties of fine sand determined from the laboratory tests are presented in Table 1.

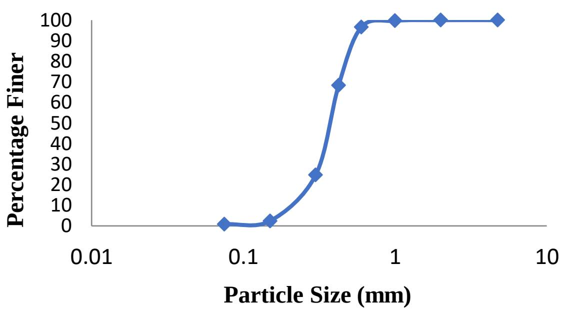

Figure 1 Gradation curve of fine sand

Table 1 Engineering Properties of Fine Sand

Property	Value
Specific Gravity	2.67
Grain Size Distribution	
(a) Gravel (%)	0
(b) Coarse Sand (%)	0
(c) Medium Sand (%)	31
(d) Fine Sand (%)	68
(e) Fines (%)	1
(f) Coefficient of Uniformity	1.8
(g) Coefficient of Curvature	1.2
Plasticity Characteristics	
(a) Liquid limit (%)	NP
(b) Plastic limit (%)	NP
IS Classification Symbol	SP
Compaction Characteristics	
(a) Optimum moisture content	12.0
(b) Maximum dry unit weight (kN/m^3)	17.4
Shear Strength Parameters	
(i) Cohesion(kN/m^2)	0
(ii) Angle of Internal Friction	30^0
Coefficient of Permeability (m/s)	2.26×10^{-5}

Fine sand is reinforced with randomly oriented polypropylene fibres of 6 mm and 12 mm length in varying proportions (0.5%, 1% and 1.5%). Engineering properties of fibre reinforced fine sand determined from laboratory tests are presented in Table 2.

Table 2 Engineering Properties of Fibre Reinforced Fine Sand

Fibre length	Fibre content by weight (%)	Optimum moisture content (%)	Max. dry unit weight (kN/m^3)	Shear Parameters	
				Cohesion (kN/m^2)	Angle of internal friction
6 mm	0.5	13.2	17.3	0	32^0
	1.0	15.4	16.0	0	38^0
	1.5	16.2	15.6	0	36^0
12 mm	0.5	15.6	17.5	0	40^0
	1.0	17.5	16.3	0	41^0
	1.5	18.2	15.8	0	36^0

4. COEFFICIENT OF ELASTIC UNIFORM COMPRESSION OF FIBRE REINFORCED FINE SAND

Fine sand is mixed with polypropylene fibres of 6 mm and 12 mm length in varying proportions (0.5%, 1.0% and 1.5% by weight) and small scale cyclic load tests are conducted on fibre reinforced fine sand specimens to determine C_u as it is laborious to conduct cyclic plate load tests in the field. The tests are conducted on specimens prepared in CBR test mould of 150 mm diameter and 175 mm height (as per IS 2720 (part 16)- 2016) by loading through standard CBR test plunger (circular) and a fabricated square plunger with size and weight same as that of CBR plunger. The load is applied through a manually operated self straining load frame of 50kN capacity as it facilitates maintenance of the applied loads and allows for unloading after each stage of loading. The load frame (Figure 2) is mounted on a bench and comprised of two column frame with adjustable upper cross beam. The specimen is loaded between the cross beam and upward moving loading platform. The load on the test sample applied through the plunger is measured using a calibrated proving ring of 5kN capacity placed between the specimen and cross beam of the frame.

Figure 2 Load Frame used for small scale cyclic load tests

A surcharge weight of 5kg is applied on the sample by placing annular surcharge plate of 150 mm diameter with central hole and slot width of 5.3cm. Further, a seating load of 4 kg is applied through the plunger (to ensure proper contact between specimen surface and plunger surface) and the proving ring and deformation dial gauges are set to zero. Loading is done in stages with increments of 1/5th of anticipated safe bearing capacity (200 kN/m^2) and continued up to 2.5 times the safe bearing capacity. Each stage of loading is maintained till rate of settlement became less than 0.02 mm / minute. Load applied at each stage is released and the plate is allowed to rebound. Dial gauge readings are noted under loading and unloading conditions at each load increment.

Elastic settlement of fibre reinforced fine sand under study is determined as the difference of dial gauge readings of loading and unloading conditions multiplied by least count of dial gauge, at each load increment. Based on the results of cyclic plate load tests, pressure-elastic settlement graphs are plotted as shown in Figures 3 to 6. Coefficient of elastic uniform compression is determined as the slope of pressure-elastic settlement plot. The values of C_u obtained for square and circular plungers for the specimens under study are presented in Table 3. The values of C_u of fine sand reported from earlier study (Satyanarayana Reddy et al., 2017) are also included in Table 3 for comparison.

Table 3 Coefficient of Elastic Uniform Compression of Fibre Reinforced Fine Sand

Length of fibre	Fibre content by weight (%)	Coefficient of Elastic Uniform Compression (C_u) in kN/m^3	
		Square Plunger	Circular Plunger
6 mm	0.0	6.87×10^5	5.89×10^5
	0.5	4.93×10^5	4.89×10^5
	1.0	3.80×10^5	3.74×10^5
	1.5	2.75×10^5	2.68×10^5
12 mm	0.0	6.87×10^5	5.89×10^5
	0.5	4.71×10^5	4.74×10^5
	1.0	3.08×10^5	3.09×10^5
	1.5	2.62×10^5	2.58×10^5

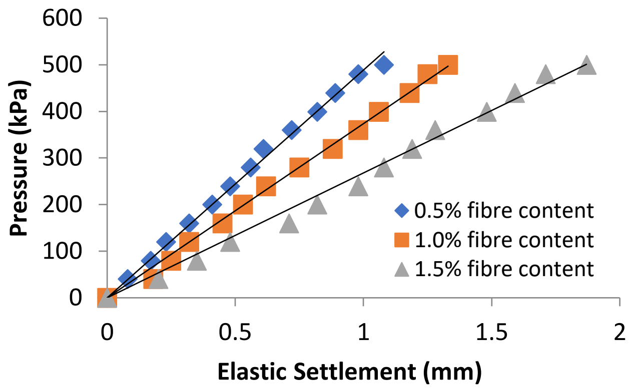

Figure 3 Pressure-elastic settlement plot of 6 mm fibre reinforced fine sand for square plunger

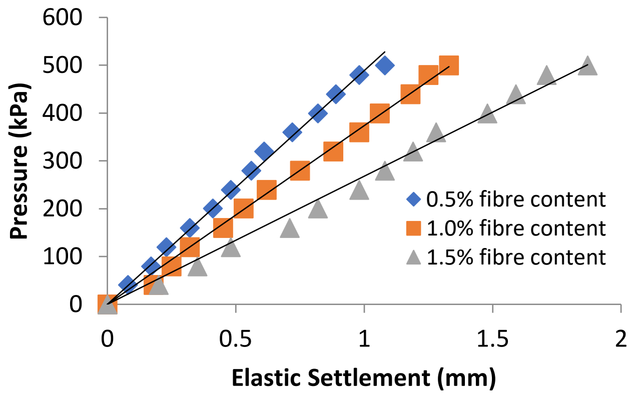

Figure 4 Pressure-elastic settlement plot of 6 mm fibre reinforced fine sand for circular plunger

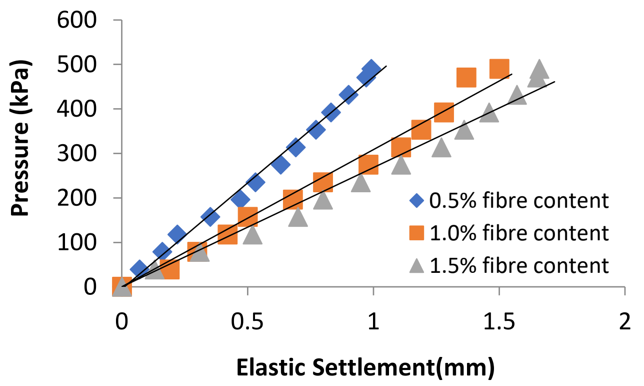

Figure 5 Pressure-elastic settlement plot of 12 mm fibre reinforced fine sand for square plunger

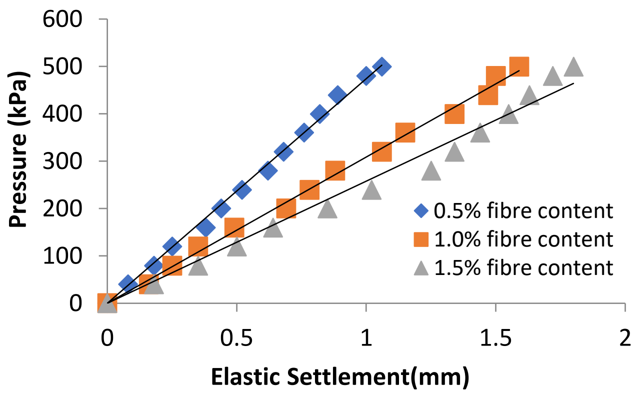

Figure 6 Pressure-elastic settlement plot of 12 mm fibre reinforced fine sand for circular plunger

5. DISCUSSION

Engineering properties of polypropylene fibre reinforced fine sand presented in Table 2 indicated increase in OMC and decrease in corresponding MDD with increase in fibre content. Further, at a given fibre content, OMC value is observed to be lower for 6 mm fibre compared to 12 mm fibre, which is attributed to ease in compaction due to relatively better dispersion of 6 mm fibre. Further, MDD value is observed to be slightly higher for 12 mm fibre compared to 6 mm fibre, which is due to the better restraining of particles by fibres during compaction. Based on improved shear parameters, the optimum fibre content is 1%. 12 mm fibre reinforced sand yielded relatively higher value of angle of Shearing Resistance compared to 6 mm fibre reinforced fine sand.

From the results presented in Table 3, it can be observed that the values of C_u of polypropylene fibre reinforced fine sand are nearly same for square and circular plungers of same size at a given fibre content. Hence, there is no shape effect on C_u in fibre reinforced fine sand where as the shape factor for C_u in case of unreinforced fine sand is 0.85. i.e., C_u of circular footings is 0.85 times C_u of square footings. Further, it can be seen from the results that the values of C_u decreased with increase in fibre content irrespective of shape of plunger and fibre length. This can be attributed to increased elastic compression resulting from fibre replacement in fine sand. At a given fibre content, 6 mm fibre reinforced sand has relatively greater value of C_u compared to 12 mm fibre due its better dispersion / orientation during mixing.

6. CONCLUSIONS

Coefficient of elastic uniform compression (C_u) of fibre reinforced fine sand is independent of shape of footing whereas C_u of fine sand is influenced by shape of footing. C_u of circular footing is 0.85 times the C_u of square footing of same size in fine sand under study. For a given fibre length, the values of C_u of circular and square loaded plates decrease with increase in fibre content. The optimum fibre content for stabilisation of fine sand based on improvement in shear strength parameters is 1 percent (by weight). 12 mm fibre is more effective than 6 mm fibre in increasing the shear strength. At 1% fibre content, the values of C_u of 6 mm and 12 mm fibre reinforced fine sands decreased by about 40% and 58% respectively.

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