Effect of Footing Shape and Load Eccentricity on Bearing Capacity of Silty Sand Reinforced with Silty Sand

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Abstract: Present research paper is an attempt to study the effect of geometrical shape of footing on load-settlement characteristics of silty sand (SM) with and without reinforcement. The standard geometrical footing shape used in present study are square, circular and rectangular keeping similar planar area. Coir geotextile, a natural geotextile manufactured out of coir fibers, has been recognized as a feasible alternative to geosynthetics for reinforcement applications, due to its longevity and excellent engineering properties. It is best suited for low-cost applications in developing countries due to its availability at low prices compared to its synthetic counterparts. For reinforced conditions, coir mats are used. This research is to understand interaction mechanism between footing surface and natural reinforcement and interaction between natural reinforcement and silty sand. A total of 18 tests are performed. A coir mat of the diameter of 4B and were placed in 3 layers at a depth u/B=0.3 and h/B=0.4. Eccentrical loading is along longitudinal axis at e = 1 cm and e = 2 cm. The results indicated that in unreinforced condition, the ultimate bearing capacity is almost equal for both of the square and circular footings and higher for rectangular footing for axial loading; but with reinforcing the ultimate bearing capacity of circular footing increased compared to square footing and the bearing capacity of rectangular footing is higher than circular for central loading. For eccentric loading, rectangular footing shows better results compared to square and circular footing. In comparison to circular shape, square shape has higher bearing capacity.

***Index Terms* - bearing capacity, silty sand (SM), geotextile, natural fibers, coir mat,**

I. INTRODUCTION

Rapid growth in infrastructural activities and reduction in availability of good construction sites have led to increase in several methods of ground improvement techniques, in which the technique of reinforcing the soil is one of the most preferable methods. The performance of granular soils which are strong in compression and shear, but weak in tension can be substantially improved by the introduction of reinforcing material in the direction of tensile strain. Several researchers have studied advantageous effects of geosynthetic reinforcements in improving the performance of soil. Geosynthetic materials like geotextiles, geogrids etc. generally provide better performance but are costly and non-eco-friendly. Among the range of geosynthetics available in the market, geotextiles are the most favored type of geosynthetic materials for reinforcing the foundation beds. Literature survey shows that the use of coir geotextile in reinforcing sand foundations is underexplored.

Over the last two decades, the beneficial effects of using reinforcement to increase the bearing capacity of sand have been clearly demonstrated by several researched. The increase in bearing capacity in reinforced soil can be understood by two fundamental reinforcement mechanisms viz, confinement effect, membrane effect. First, frictional interaction is induced in interface of soil and reinforcement, due to the relative displacement between them. The vertical deformation of the soil decreases when the interlocking developed between the soil and geotextile. The bearing capacity increases by inducing reinforcement in soil because of improvement in lateral confinement, there by increases the compressive strength of the soil. This mechanism is named lateral restraint method or confinement effect.

The main aim of this study is to compare the load carrying capacity and settlement characteristics of the reinforced soil under various shapes of footing having similar surface area. This paper reports a set of laboratory experimental results of woven coir geotextile reinforced footings. The results reveal the potential of coir geotextiles as an efficient low-cost reinforcement material for shallow foundations. The optimum layout for the placement of geotextile and optimum number of reinforcement layers were found based on literature survey. The soil i.e., silty sand (SM) is reinforced with 3 layers of coir mats. To achieve the objective, 18 number of model footing tests were conducted in the laboratory with a wide range of parameters such as the effect of shape of footing and eccentrical loading. Theoretical estimation of bearing capacity of coir mat reinforced sand was determined to validate the experimental results.

In the present investigation, naturally available coir mats were used as reinforcement in silty sand. Natural geotextiles are manufactured in India from jute and coir fibers, among which coir fiber is the strongest and most durable due to its high lignin content. Coir is a locally available, sustainable organic material having high tearing strength, initial stiffness, and good hydraulic properties. Woven coir geotextiles are manufactured today with wide ranges of physical properties. The use of coir as a reinforcement material has been studied by various investigators. As the synthetic materials may cause environmental problem, also on the other hand, coir is abundantly available in India and it will work out economically.

It is used as a reinforcement material for slope protection, in erosion-controlling blankets and for subgrade stabilization. Studies of various researchers have shown that the durability of coir is adequate for long-term reinforcement applications. Generally, the lifetime of coir geotextiles is around 10-12 years, but it can be enhanced by various treatment methods (i.e., cement coating, bitumen coating, biological treatment, etc.).

Coir geotextile develops good interface friction with granular soil which can induce tensile stress in the reinforcement when reinforced with in the soil. The model test was conducted three layers of coir geotextile reinforced sand with ratio of depth of level of sand to the first layer of reinforcement to the width of foundation, u/B = 0.3 and h/B = 0.4, where h is the distance between two consecutive layers of reinforcement.

The bearing capacity ratio and settlement reduction factor of each ratio were calculated and analyzed. Most importantly, the experimental ultimate bearing capacity of unreinforced silty sand was valuated with the obtained theoretical ultimate bearing capacity of respective set and concluded.

II. MATERIALS

2.1Silty Sand

The soil was procured from Chandranagar cross road, Ahmedabad, Gujarat below 5-6 ft from the natural ground level. The silty sand was sieved through 1.00 mm IS sieve in order to have uniform sized particles to avoid segregation during preparation of the silty sand bed.

2.2Coir Geotextile

Coir fiber was procured from Karnataka Coir Board, Bengaluru, Karnataka.

Table 2.1 Coir Geotextile properties

Properties	Value
Mass/unit area (g/m^2)	87
Thickness (mm)	6.82
Ultimate Load (kN/m)	16
Elongation (%)	31
Aperture size (mm × mm)	6 × 6

III. METHODOLOGY

3.1Loading and Testing Tank

According to IS: 1888 (1982), the tank dimension should be five times the foundation width to depreciate scaling issues. Taking this into account, tests were conducted on a circular tank of internal diameter 600 mm and external diameter of 620 mm with height of 650 mm. The loading system consists of a mechanical jack of 8 ton capacity positioned above the footing.

Fig 1 Laboratory Test Set-up

3.2Footing Plates

The footings used for the study were aluminum plates with 100 mm diameter for circular footing, 100mm × 80 mm for rectangular footing and 90mm × 90 mm for square footing of thickness of 10 mm.

3.3Laboratory Testing Procedure

The sand was compacted by using vibrator, in layers of 12 cm to achieve a relative density of 45%. Sand beds were prepared by pouring the sand using raining technique to achieve a compacted density of 15.4 kN/m^3 for all the tests. Coir mats were placed in 3 layers at u/B = 0.3 and h/B = 0.4 in circular shape of diameter 4B.

After filling the sand to the top, a footing was placed centrally such that load distribution was homogeneous throughout. The base of the footing was coated with epoxy glue and a film of sand was applied over it to reduce the smoothness, A mechanical jack was carefully positioned above the footing and was given loading with small increments. The displacements were measured using the dial gauges positioned at either end of the footing. The average of the two dial readings was taken as final displacement. As per IS: 1888 (1982) the load increment was maintained until the rate of settlement reduced to a value 0.02 mm/min. Loading was continued until the settlement reached a value of about 25% of footing width. The experimental program consists of carrying out eighteen load bearing tests on various shapes of footing for eccentricity at e = 0 cm, e = 1 cm and e = 2 cm along the longitudinal axis of footing. This study investigates the effects of BCR and settlement ratio.

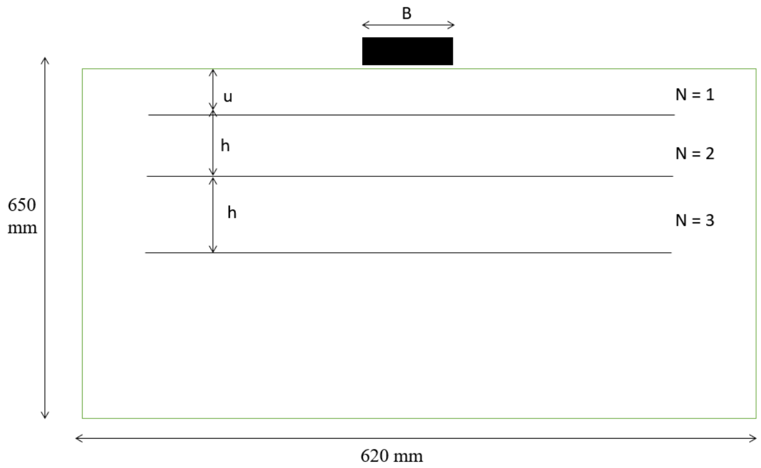

Fig 2 Schematic diagram of laboratory test set up

IV. RESULTS AND DISCUSSION

4.1Material Property

The index and engineering properties of silty sand used for the study are shown below:

Table 4.1 Silty Sand Properties

Test	Value
Specific Gravity	2.62
Coefficient of uniformity (C_u)	4.02
Coefficient of Curvature (C_c)	1.24
Maximum dry density (kN/m^3)	19.14
Minimum dry density (kN/m^3)	13.25
Direct Box Shear	C= 0 Φ= 32º
Relative Density (%)	45%
Compacted Density (kN/m^3)	15.4

4.2Laboratory Test Results

Load settlement curves from eighteen tests carried out on centrally and eccentrically loaded square, circular and rectangular footings in both reinforced and unreinforced conditions. The ultimate bearing capacity of foundation on soil under axial and eccentric loadings was obtained from the load settlement curves. In curves with double tangent method, the ultimate bearing capacity and settlement at failure load are taken at the peak point. In the present research, a dimensionless parameter called bearing capacity ratio (BCR), is used to measure the effect of increasing the bearing capacity in reinforced soil to that in unreinforced soil condition. To analyze the footing settlement, the settlement ratio (SR) is proposed and defined as the ratio of footing settlement in reinforced soil to that in unreinforced soil condition.

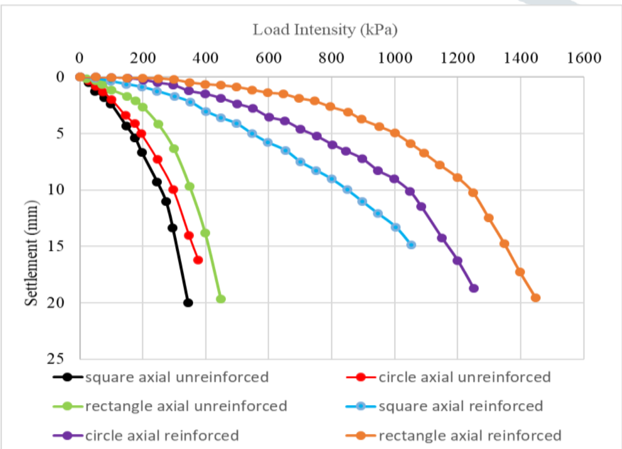

Fig 3 Comparison of various shapes under axial loading in unreinforced and reinforced condition

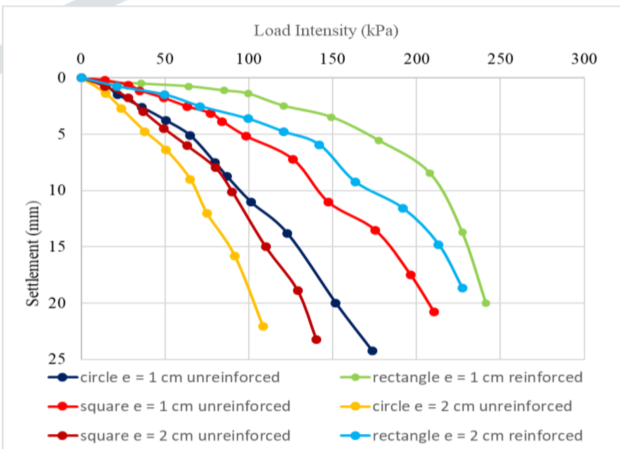

Fig 4 Comparison of various shapes under eccentric loading at e = 1 cm and e = 2 cm in unreinforced condition

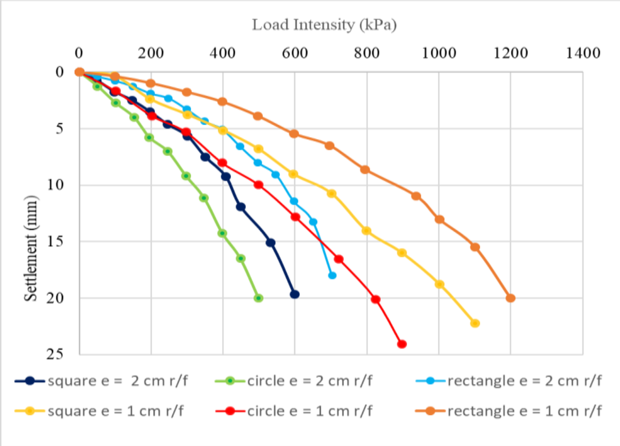

Fig 5 Comparison of various shapes under eccentric loading at e = 1 cm and e = 2 cm in reinforced condition

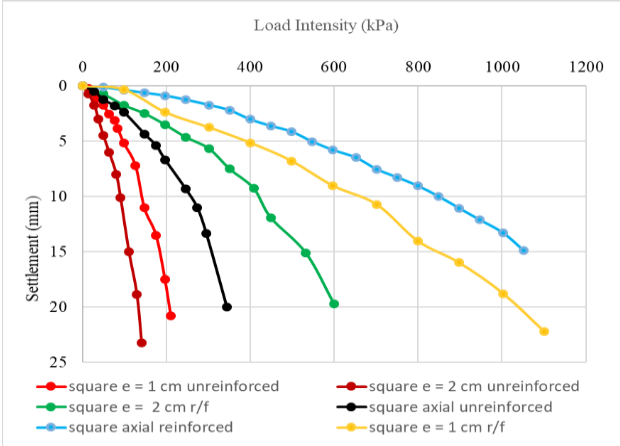

Fig 6 Comparison of various loading for square footing

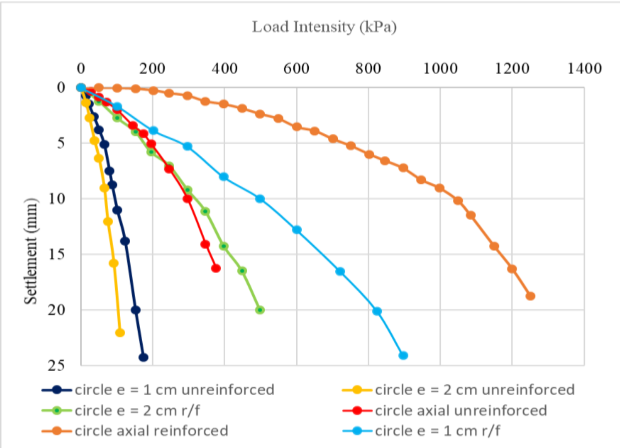

Fig 7 Comparison of various loading for circular footing

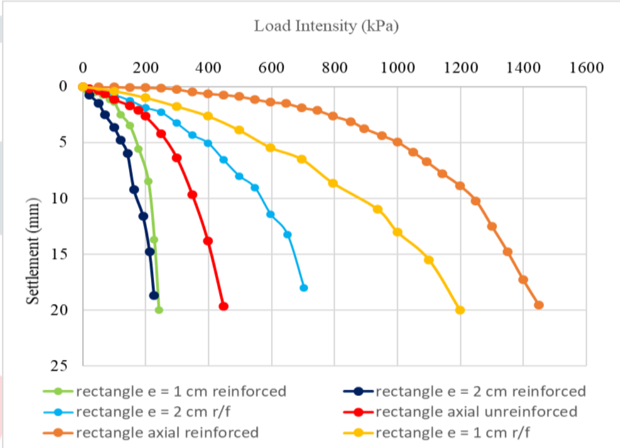

Fig 8 Comparison of various loading for rectangle footing

Table 4.2 Bearing capacity for axial loading

Shape of Footing	**Bearing Capacity (kN/m^3)**	
	Unreinforced	**Reinforced**
Circle	247	922
Square	239	760
Rectangle	313	1078

Table 4.3 Bearing Capacity for eccentric loading

Shape of Footing	**Bearing Capacity (kN/m^3)**			
	e = 1 cm		**e = 2 cm**	
	Unreinforced	**Reinforced**	**Unreinforced**	**Reimforced**
Circle	86	520	69	348
Square	130	650	95	420
Rectangle	181	879	142	582

In case of axial loading for unreinforced condition, it can be observed from above plot; bearing capacity improvements of rectangle and circular shaped footing have been found to be 1.31 and 1.033 times than square footing with similar surface area. For similar surface area, the settlement ratio of circular and rectangular footing is increased by 1.33 and 1.5 times than square footing. While that for reinforced condition, it can be observed that bearing capacity improvements of rectangle and circular footing have been found to be 1.42 and 1.21 times than square footing with similar surface area. For similar surface area, the settlement ratio of circular and rectangular footing is increased by 1.07 and 1.36 times than square footing. In case of eccentric loading, bearing capacity improvements of rectangle and square footing have been found to be 2.1 and 1.51 times respectively than circular footing with similar surface area. For similar surface area, the settlement ratio of square and rectangular footing is increased by 1.43 and 2.85 times than circular footing.

Table 4.4 Comparison of different methods in ultimate load calculations

Shape of footing	IS method	Terzaghi's Method	Vesic's Method
Circle	14	12.63	14
Square	12.56	15.16	12.68
Rectangle	14.24	14.15	12.65

V. Conclusions

As from above graphs, it is observed that in unreinforced condition under axial loading, the bearing capacity of square and circular footing is almost similar; while that in rectangular footing it is higher.

But as the soil is reinforced, the bearing capacity of circular footing is higher compared to square shaped footing. While that for rectangular shaped footing the bearing capacity is considerably higher compared to square and circular shaped footing.

While in case of eccentric loading the bearing capacity of circular footing is comparatively lower than square and rectangular footing. But as soil is reinforced, the bearing capacity is increased by 3 to 4 times compared to unreinforced soil.

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