REINFORCED SOIL FOUNDATION FOR EXPANSIVE SOILS

FONDATION RENFORCEE EN SOLS EXPANSIES

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SYNOPSIS: Partly saturated expansive soils upon inundation reach a definite equilibrium state depending on the surcharge pressure. Hence, surface footings on expansive soils, upon inundation, are bound to attain limit equilibrium condition, with a factor of safety of unity against bearing capacity failure. To improve the factor of safety of such footings, reinforced soil technique can be adapted. From model plate load tests on unreinforced and reinforced expansive soils it has been shown that the factor of safety against bearing capacity failure can be improved by three fold. Of the three possible methods of reinforcing the expansive, the one with reinforced sand mattress on expansive soil is very efficient.

INTRODUCTION

Design and construction of civil engineering structures resting on and with expansive soils are challenging tasks. The problems are essentially due to changes in the state of soil moisture either by drying or wetting and the associated changes in the volume of the soil. Drying causes an increase in the capillary tension of the soil-water and causes the soil to shrink, while wetting of an already shrunken soil decreases the capillary tension and causes the soil to swell or heave. The effect of shrinkage and swelling is reflected in the movement/ distortion of the engineering structures much more than their responses due to the usual structural loadings.

The swelling behaviour of an expansive soil is generally characterized by the mobilized swelling pressure under constant volume conditions and/ or the increase in volume or heave under constant surcharge conditions, upon inundation. The effect of heave is to drastically reduce the shear strength of the soil consequently endangering the stability of the structure. For a given structural condition the problem of expansive soil can be solved by either controlling the heave with mechanical or chemical means or designing the structure to adequately take care of the effects of heave and shrinkage. There are a number of methods by which the above objectives can be achieved for a small building foundation. For other structures like embankments built with and on expansive soils, highway pavements and very large foundation systems where the involved soil volume is considerable most of the techniques are economically not viable.

In recent years reinforced soil technique has emerged as a viable alternative to improve the load carrying capacity of weak foundation soils. The improvement is realized by frictional interaction between the horizontally placed reinforcements and the soil. Since the expansive soil in its swollen state has very low shear strength and hence very low load carrying capacity, the above technique can be gainfully adopted to improve the stability of structures resting on expansive soils. It is attempted in this investigation to examine the above possibility by conducting model plate load tests on swollen expansive soil with and with out reinforcing the soil.

Since, the performance of a reinforced soil system depends on the mobilization of interfacial friction it may not be advantageous to reinforce the expansive soil directly as it possesses very low shear strength under swollen condition. Hence two alternative methods:

a) providing a reinforced sand mattress on expansive soil and
b) providing a sandwiched reinforcement technique

are examined.

The improvement in the load carrying capacity of reinforced soil system is always compared with load carrying capacity of unreinforced soil system. Hence a detailed theoretical and experimental discussion on the load carrying capacity of an expansive soil, upon inundation is presented.

BASIC CONSIDERATIONS

The swelling nature of soils is attributed to the presence of montmorillonitic mineral in them. It is generally understood that soils with high liquid limit water content and low in-situ void ratio, under low overburden pressure conditions exhibit high swelling characteristics, upon inundation. The final equilibrium state is governed by the overburden pressure.

Now consider a surface loaded footing on a partly saturated expansive soil. Upon inundation the footing is lifted up if the swelling pressure is greater than the footing pressure and settles down otherwise. However in both the cases the soil outside the footing area heaves up. This may be due to both swelling of the soil in that zone and squeezing out of the soil from below the footing. Further the normal stresses in the soil due to applied loading on the footing are different at different points inside the soil mass, i.e., high stresses below the footing and at shallow depths, and low stresses outside the footing and at greater depths. The soil overburden pressure increases linearly with depth. The combined stress distribution is nonuniform. Now upon inundation the swelling at any point depends on the stress at that point which results in a nonuniform cumulative heave at the surface. The shear strength of the soil also varies from point to point. Just outside the footing the soil at the surface will be in its free swell state with negligible shear strength and this shear strength increases with depth. The soil below the footing has greater shear strength at the surface and it decreases with depth and after certain depth increases. This induces a nonhomogeneous condition which cannot be mathematically modeled. As there is a general reduction in shear strength at every point the factory of safety against bearing capacity failure reduces. Since the shear strength at any point depends on the amount of swelling which in turn depends on the normal stress (or surcharge pressure on the footing), it is reasonable to expect that surface loaded footings on expansive soils equilibrate upon inundation to a definite state depending on the surcharge load, with a unique factor of safety against bearing capacity failure. As it may not be possible to theoretically evaluate this unique value it is attempted in the next section to bring out the same experimentally.

Plate Load Tests on Expansive Soils

The possibility of surface loaded footings on expansive soil, upon inundation attaining a unique factor of safety was examined by conducting plate load tests with different initial surcharge pressures. The selected initial surcharge pressures were 7.5, 75, 150 and 220 kPa. The expansive soil used was black cotton soil from Davanagere area in Karnataka. Table 1 indicates the index properties of the soil and the test conditions adopted in the plate load test. From odeometer tests the swelling pressure under test conditions was estimated to be about 200 kPa.

Table 1 Index properties and Test conditions of Black cotton soil

Liquid limit	84%
Plastic limit	32%
Plasticity index	52%
Shrinkage limit	13%
Specific gravity	2.73
Free Swell index	104%
Moisture content	18%
Dry density	12.3 kN/m^3
Swelling pressure	200 kPa

The rigid model footing had a size of 100 x 100 x 100 mm cube. The size of the test tank was 305 x 305 x 400 mm. The sides and bottom of the tank had perforations for easy saturation of the soil. The soil was compacted in the tank in six layers of 50 mm each by applying standard Proctor energy. The footing was placed concentrically with the tank on the top of the compacted soil. The tank was placed in an empty water bath. The whole assembly was transferred on to a self straining loading frame. The required surcharge pressure was applied through a sensitive screw jack system and was monitored through a load cell. Two deformation dial gauges were fixed on diagonally opposite points of the model plate to measure the deformation (Figure 1). The soil was inundated by raising the water level in the bath to the level of the model footing. The constant surcharge was maintained by operating the screw jack and the deformation was monitored at regular intervals. The steady state, at which there was no deformation of the footing, was reached for the first two tests with 7.5 and 75 kPa surcharge pressure within four to six hours. In these tests the maximum heave values were 18 mm and 8 mm respectively. The third test with 150 kPa surcharge pressure indicated an initial heave of about 2 mm in 40 minutes and showed a continuous settlement thereafter. The footing failed due to excess settlement and rotation in about 6 hours. In the last test with 225 kPa surcharge pressure there was a continuous settlement right from the beginning and the footing failed after about 8 hours due to excess settlement and rotation of the footing. In the test with 7.5 and 75 kPa surcharge pressures, addition of a small load on the footing (to increase the pressure by 2 kPa) resulted in rotational failure associated with excess settlement. This confirmed that the footing on an expansive soil, upon inundation, irrespective of the surcharge pressure reaches a definite equilibrium state at which the factor of safety against bearing capacity failure was just unity.

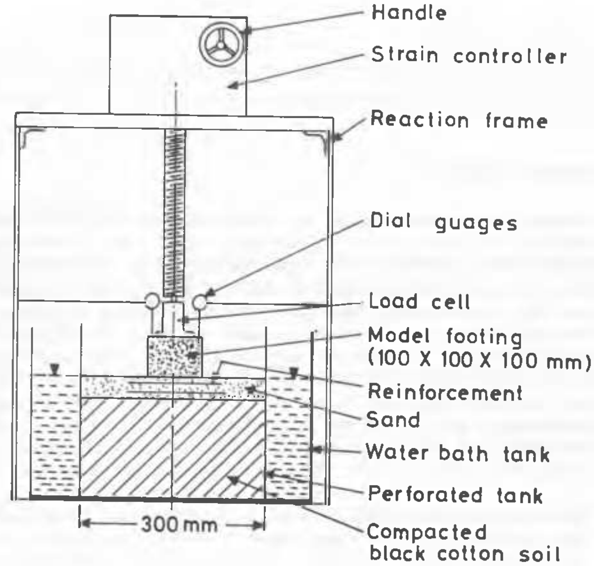

Fig. 1. Experimental setup for plate load test

It is interesting to note that similar plate load test results by Agarwal and Rathee (1989) on three different swelling soils having different swelling potential, resulted in identical bearing capacity under a given surcharge load. Further, the work of Abouleid and Reyad (1985), wherein they have studied the behaviour upon inundation of surface loaded footings on expansive soils with and without sand blankets, has clearly indicated that failure condition is reached under a constant surcharge in all the tests. The above discussions bring out that the surface loaded footings on expansive soil reach the limit equilibrium state upon inundation. There is no means by which their factor of safety can be improved by manipulating load and footing size.

REINFORCED SOIL FOUNDATIONS

The concept of soil reinforcement developed by Henry Vidal (1978) has been extended to improve the bearing capacity of weak soils by introducing horizontal reinforcements below the footings (Binquet and Lee, 1975; Patel, 1982; Sridharan et. al., 1988 and 1989 and others). In the analysis of reinforced soil foundation the load carried by the footing at any given settlement has been considered to have two components in the form:

$$P = P_s + P_r \qquad (1)$$

where P is the total load on the footing on reinforced soil foundation at a given settlement
P_s is the load on the footing on unreinforced soil foundation at the same settlement
P_r is the load carried by the reinforcements.

It has been brought out that due to frictional interaction between soil and reinforcement interfacial shear stresses are mobilized in proportion to the normal stress on the reinforcement. The shear stresses induce confinement for the soil and constrain its lateral flow beneath the foundation, which is reflected in increased load carrying capacity at the same settlement or reduced settlement at the same load. The interfacial shear stress induces tension in the reinforcement. The reinforcement component of load carrying capacity in proportional to this mobilized tension. It is customary to define the improvement in load carrying capacity of a reinforced soil foundation in terms of bearing capacity ratio which is defined as:

$$BCR = (P_r + P_s)/\ P_s \qquad (2)$$

The reinforcement component of load, P_r is over and above the load carrying capacity of the soil, P_s. Due to inundation and swelling of an expansive soil, P_s may reduce substantially. If an appropriate reinforcing technique is adapted it should be possible to improve the load carrying capacity. The bearing capacity ratio itself will reflect the factor of safety against bearing capacity failure.

For a given footing size, it is possible to achieve a bearing capacity ratio upto 3 by a suitable manipulation of number of layers and spacing of reinforcements and type and length of reinforcement. The performance of a reinforced soil structure essentially depends on the mobilization of interfacial friction. It has been brought out by various investigators that grid type of reinforcement will provide higher frictional resistance due to bearing resistance from the grid elements. Sridharan et. al. (1991) have shown that by providing a small thickness by high frictional soil layer around the reinforcement, low frictional soil can be used as a bulk backfill material with about the same level of efficiency as that of high frictional soil as backfill material. This technique has been referred as sandwich technique. Also it has been shown (Sridharan et al 1988) that for soft soils, the load carrying capacity can be substantially improved (BCR more than 3) by providing a reinforced sand mattress of thickness B/2 with two to three layers of grid reinforcement of size 2B, B being the width of the footing. The swollen expansive soil is very much similar to a soft soil as far as bearing capacity is concerned. Hence, it is attempted in this investigation to examine the different forms of soil reinforcing techniques.

Reinforced Soil Technique for Expansive Soils

To examine the possibility of improving the factor of safety against bearing capacity failure of a surface loaded footing on an expansive soil, upon inundation, the following reinforcing techniques are considered.

1. Reinforced expansive soil
2. Reinforced expansive soil by sandwich technique with a 5 mm thick sand cover alround the reinforcement
3. Reinforced sand mattress of thickness B/2, over the expansive soil.

The feasibility of the approach was examined in relation to the model plate load test results. The reinforcements selected in all the tests were 200 mm x 200 mm, mild steel grids with a grid size of 20 mm x 20 mm and diameter of grid element being 2 mm.

Experimental Programme

The experimental programme consisted of plate load tests with a plate size of 100 mm x 100 mm on unreinforced and reinforced expansive soil. The plate load tests were conducted under the following conditions:

1. Compacted black cotton soil
2. Sand bed of 50 mm thickness over compacted black cotton soil
3. Compacted sand
4. Reinforced expansive soil
5. Reinforced expansive soil with sandwich technique
6. Reinforced sand mattress on expansive soil.

The initial surcharge pressure was varied as a parameter. The selected surcharge pressures were 75, 150 and 225 kPa. The tests with 75 kPa surcharge pressure had three layers of grid reinforcement while those with 150 and 225 kPa had two layers of reinforcements. The experimental set up was same as shown in Figure 1 and the procedure adapted was same as discussed earlier. The expansive soil used is the same black cotton soil reported earlier. The reinforcements were placed carefully concentric with the tank at appropriate levels and the footing was placed concentric with the tank. In all the tests, the compacted expansive soil was inundated under a given surcharge pressure. The surcharge pressure was maintained constant. After reaching the steady state condition i.e., the state at which no further deformation was observed, the footing was loaded further incrementally. The deformation of the footing at each load increment under equilibrium condition was monitored. The test was continued till failure. If defined failure was not observed, the tests were terminated at a settlement level of 15% of the footing size i.e., at 15 mm. Figure 2 shows the load settlement curves for all the six test conditions, with an initial surcharge pressure of 75 kPa. Similar results were obtained for surcharge loads of 150 and 225 kPa.

Test Results and Discussions

The experimental results on reinforced expansive soils are discussed at two levels.

1. During inundation under constant surcharge conditions
2. Load test after reaching steady state condition upon inundation

It has been presented earlier that footings on the surface of an expansive soil tended towards limit equilibrium condition upon inundation. It is interesting to note that in all the cases with soil reinforcement steady state was reached in about 8 to 10 hours with reduced heave and settlement as the case may be. There was no indication at all of the footing reaching the limit equilibrium condition. Hence, load tests were carried out to determine the factor of safety with reference to the initial surcharge pressure.

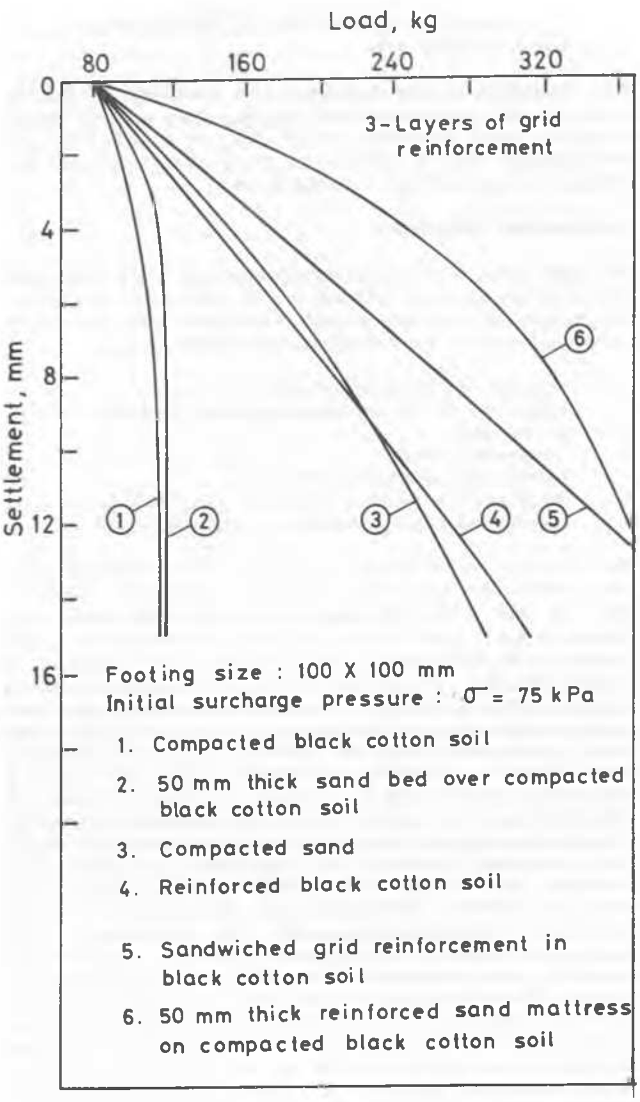

Fig. 2. Load - Settlement behaviour of reinforced expansive soil

It can be seen that the reinforced expansive soil, at comparable settlements carries 2 to 3 times more load. This behaviour is seen in all the tests. The reinforced expansive soil behaviour appears to be similar to that of sand. The sandwich technique carries higher loads than the reinforced expansive soil, while the reinforced sand mattress carries the highest load. It is interesting to note that the mode of failure has also changed from sudden brittle for the unreinforced case to a gradual strain hardening for the reinforced cases. It was also observed that the total heave outside the footing area has substantially reduced for all the reinforced cases. It can be noted that reinforced sandwich technique or the reinforced sand mattress can be effectively used to increase the factor of safety against bearing capacity failure by about two to three times. In this process the system behaves better than the behaviour of the footings on sand.

Concluding Remarks

It has been brought out that surface loaded footings on partly saturated expansive soils, upon inundation tend towards limit equilibrium condition, irrespective of the initial surcharge pressure. There is no conventional means by which this factor of safety against bearing capacity failure can be increased to the desired level. Since, in the reinforced soil technique the load carried by the reinforcement will be over and above that of the soil, this technique can be gainfully adapted. The experimental results of plate load tests on reinforced expansive soil clearly indicate that the factor of safety against bearing capacity failure with respect to the initial surcharge pressure can be increased upto 3, with proper manipulation of reinforcement type, number of layers, size and spacing. Of the three alternative reinforcing conditions presented in this investigation, it has been brought out that reinforced sand mattress of thickness B/2 with 2 - 3 layers of grid reinforcement of size 2B x 2B is sufficient to increase the load carrying capacity by 3 fold. Field tests are required to substantiate the principles presented in this paper.

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