EFFECT OF METAL STRIP REINFORCEMENT ON BEARING CAPACITY OF STRIP FOOTING ON SAND

A Project Thesis
By
MD. REZAUL KARIM

A Project Thesis
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of

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May, 2003
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The author also wishes to express his deepest gratitude to the supervisor for his affectionate encouragement discussion and valuable advise at every stages of this study.

The author is grateful to Professor Dr. Md. Abdur Rouf, Head of the Department of Civil Engineering for his continuous support to carry on the project thesis.

Thanks are due to the technicians of the Geotechnical Engineering Division in particular to Mr. Md. Habibur Rahman, for their help with the test and instrumentation.

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The author is grateful to his mother and late father who give up this universe and enter into paradise for their continuous appreciate for study.
This study has been carried out to investigate the effect of metal strip reinforcement on bearing capacity of strip footing resting upon sand deposit. The sand bed consists of horizontally placed metal strip reinforcement in one layer, two layers and three layers. Model tests were conducted to investigate the bearing capacity and settlement of strip footing in two different speed of loadings.

The experimental set-up has been modified and re-modeled. All of the measuring devices were connected to a computer through the data-logger. The out of plane deformation of the loading frame was eliminated by using vertical-ball-bearing system at the mid-level guide-beam.

Tests were carried out in a tank on beds of sand having average densities varying from 14.67 kN/m³ to 15.78 kN/m³. The sand bed thickness was maintained to 3.9 times the least dimension of the footing. Strain controlled vertical loads were applied on the footing placed on the surface of sand bed.

The effect of number of reinforced layer, effect of speed on bearing capacity are studied. The results are established, discussed and compared among different layers of reinforcement and two rates of speeds. From the experimental result for the case of reinforced sand bed, it is observed that the bearing capacity of the footing increases significantly compared to an unreinforced bed. In most of the tests, it is observed that with the increase in number of the layers of reinforcement, bearing capacity has been improved. Due to change in speed of loading the bearing capacity and settlement have been affected. The results also indicate that for slow speed, bearing capacity was of higher value than that of higher speed of loading. On the other hand, settlement due to slow speed of loading is lower than that of higher speed of loading.

In most of the cases, the bearing capacity increases with the increase of metal strip reinforcement. In some cases the results show, opposite trend. For unreinforced bed, failure outcrop arises on the sides which distance of 2B to 3B from the edges of footing. In the case of reinforced bed of sand, failure pattern was not very clear at 20% settlement.
### NOTATION

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Width/Diameter of footing</td>
</tr>
<tr>
<td>b</td>
<td>Half the width of footing</td>
</tr>
<tr>
<td>c</td>
<td>Cohesion of footing</td>
</tr>
<tr>
<td>D, D_f</td>
<td>Depth of footing (overburden surcharge)</td>
</tr>
<tr>
<td>D_r</td>
<td>Relative density of sand</td>
</tr>
<tr>
<td>H_1, H_2, H_3</td>
<td>Depth of metal strip reinforcement</td>
</tr>
<tr>
<td>K_a</td>
<td>Coefficient of active earth pressure</td>
</tr>
<tr>
<td>K_p</td>
<td>Coefficient of passive earth pressure</td>
</tr>
<tr>
<td>N_y, N_c, N_q</td>
<td>Bearing capacity factors</td>
</tr>
<tr>
<td>P_p</td>
<td>Passive pressure</td>
</tr>
<tr>
<td>Q_u</td>
<td>Ultimate bearing capacity</td>
</tr>
<tr>
<td>s</td>
<td>Settlement of sand bed</td>
</tr>
<tr>
<td>β</td>
<td>Angle of load spread</td>
</tr>
<tr>
<td>σ_1</td>
<td>Normal stress</td>
</tr>
<tr>
<td>φ</td>
<td>Angle of internal friction</td>
</tr>
<tr>
<td>φ_t</td>
<td>Triaxial angle of internal friction</td>
</tr>
<tr>
<td>γ</td>
<td>Unit weight</td>
</tr>
</tbody>
</table>
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REFERENCES
The bearing capacity of foundation is an important factor for designing the type of foundation and depth of foundation. The bearing capacity of foundation is an ancient problem. A footing foundation is the supporting base of a structure which transmits the loads to the natural ground. Many earlier scientists postulated their theories on the performance of this type of foundation under external loading. Bearing capacity problems are getting wider day by day with the advent of the researchers to improve the foundation soil conditions by including new material into the soil in various forms. One of the recent inclusion in bearing capacity problem is that of reinforcement.

A reinforced earth slab is essentially a soil foundation containing horizontally bedded thin flat ties with relatively high tensile strength developing strong frictional bond with the soil. Because the reinforcing action requires good frictional bond between the ties and the soil, only free draining granular soils are considered (Binquet and lee, 1975a).

Although the systematic study of reinforced earth did not start until very recently, the practice of building houses and roads on fibre reinforced earth and constructing earth walls with different types of reinforcing intrusions is an age old art. The main advantage of this method of construction is the low cost.

The Bearing capacity of reinforced soil depends on various factors like length of reinforcement, number of reinforcement layers, placement of layers, angle of internal friction of soil and interface friction between soil and reinforcement. In spite of the various semi-empirical approaches available, a simple rational and well accepted solution to determine bearing capacity of reinforced soil is not still available.

In the developing countries there is a growing need for research to be undertaken aimed at channeling local technology to the design and construction of low-cost highway and housing project. This is pertinent with the abundance of cheap locally available materials coupled with the high cost of imported materials of construction. It is expected that the locally available metal strips may provide a good reinforcement to the foundation soil in
particular to long term construction involving heavy loads over inferior foundation soil condition. However its behaviour requires to be examined in an investigation. In that point the present research work is undertaken at the Bangladesh University of Engineering and Technology (BUET).

This study deals with the characteristics of metal strip reinforced sand beds to effect the bearing capacity of strip footing resting on these. The research project is the study of behaviour of a vertically loaded strip footing on an artificially prepared air dry sand layer. The sand bed consists of layers of sands of varying depth with horizontally placed metal strip reinforcement in one layer, two layers, three layers and used at the same number of rods in every layer. Model tests were conducted to investigate the effect of bearing capacity, and settlement of rough based strip footing, in different rate of applied vertical load on the footing.

The bearing capacity testing apparatus was mainly consist of a model tank of dimensions 57cm x 85.5cm x 60cm, a sand spreader, a levelling apparatus, a strip footing and a loading rig having a various capacity, two settlement transducers and a load-cell.

Initially the experiment was conducted according to the previous equipment set-up. During the period of the experiment, when the vertical load applied on the footing, a locking of the loading frame happened. After some times when load increased monotonically, the proving ring displaced from its vertical alignment and deflected. At the same time the two edge loading frame locked by threaded nut which rest on a mid-level guide beam. This unwanted happening increased the load to a fictitious high value. The test perform in several times but at the same result came out of it. The main cause of this draw back was then sorted out and corrected.

A pair of knife-edge loading blades are attach to the bars which transfer the load on the strip footing. After applying the load of the footing, a friction was developed at the place where loading frame runs through the vertical hole of the mid-level guide beam. So the loading frame can not transfer applied load on the strip footing, properly.

As a result the proving ring and loading frame were displaced and deflected. So the load-cell and the two displacement transducers could not take proper reading.
Two vertical ball-bearing assembly were placed at the mid-level guide beam where the loading frame runs through the vertical hole. To solve the previous problem, the following technique was developed.

It is very difficult to take the readings of proving ring for load, strain dial gauge for settlement and rotation with respect of time manually. So to remove this obstacle, a computer-aided experimental set up was developed to investigate the tests properly. The whole method was developed by connecting a data-logger and a computer to transducers. The load cell was used instead of proving ring which was used in between the middle guide beam and vertical shaft of loading rig. The load cell and two deformation transducers were connected with Data Logger.

The present study is aimed to investigate the bearing capacity behaviour of strip footings resting on a granular fill reinforced with metal strips in order to achieve the following objective.

- To investigate the behavior of footing resting on a sand bed reinforced with metal strip in one, two and three layers at different rate of loading.

A series of model tests were carried out in the Geotechnical Engineering Laboratory of Bangladesh University of Engineering and Technology. The tests were performed on a strip footing having a width of 10 cm in a model tank. Uniform sand bed was prepared by using a sand spreader. Two deformation transducers were used to measure settlement. A strain controlled loading rig was used to apply load on the footing. The load was measured by a load-cell. All of the measuring devices were connected to a computer through the Data Logger.

Organization of the Thesis:

The study is presented in six chapters, the first of which is an introduction. Essentially chapter 2 reviews the relevant literature.
Chapter 3 describes the experimental set up and the test programme and procedure of the experiments are described in chapter 4. Chapter 5 discusses the experimental results and provides comparison with these results.

Finally chapter 6 presents the conclusions of the experimental results. Future recommendations are presented in this chapter.
CHAPTER 2
LITERATURE REVIEW

2.1 General

The present investigation is mainly concerned with the effect of metal strip and soil layer thickness on bearing capacity of strip footing resting on finite layer of locally available sand collected from Gozaria near Gomoti Bridge. In this chapter a review of the previous works on bearing capacity is reported and specially discussed about soil improvement and ground strengthening by reinforcement. The particular points of interest are the determination of the bearing capacity of sand including settlement of footing, the development of ultimate bearing capacity due to reinforcing the soil by laboratory model test. In view of the large amount of literature available for homogeneous soil, the review is intended to be brief and selective for this case.

2.2 Bearing capacity of strip footing on semi-infinite soil layer

In the following sections both theoretical and experimental findings of bearing capacity of vertically loaded strip foundations on thick layers (semi-infinite) by different investigations are briefly discussed. Some of the methods available to calculate bearing capacity may be listed as follows. Bearing capacity based on the classical earth pressure theory is given by Pauker (1850) and strip foundation was made by Rankine is 1857, Bell (1915). The modified forms of these theories are also available. Semi-empirical solutions based on theory of plasticity are given by the prominent investigator like, Prandtl (1920), Terzaghi (1943), Meyerhof (1951), Skempton (1951), Balla (1962), Brinch Hansen (1963), Kerisal (1967), and Vesic (1973, 1974). Sokolovski (1960) gave an exact method of calculating bearing capacity. Semi-Graphical methods are presented by Button (1953), Brown and Meyerhof (1969), and Vesic (1970), for two layered stratified deposits.

To estimate the ultimate bearing capacity of soil, the application of standard penetration test, cone penetration test and pressure meter test results were also used.

With the application of load the Rankine (1857), while using earth pressure theory for bearing capacity assumed that, the failure in the soil is initiated by the formation of two
wedge beneath the foundation Fig. 2.1. Bell (1915) modified Rankine’s solution to the bearing capacity of a strip footing on a c-\(\phi\) soil, by assuming a failure mechanism composed of Rankine active and passive region Fig. 2.1. If the foundation depth, \(D\), and the ultimate bearing capacity is \(Q_u\), given by

\[ Q_u = \gamma D \tan^4 \left( \frac{\pi}{4} + \frac{\phi}{2} \right) + \cot(\phi) \left( \tan 4\left( \frac{\pi}{4} + \frac{\phi}{2} \right) - 1 \right) \times c \]  

(2.1)

Where,
- \(\gamma\) = Unit weight of soil.
- \(D\) = Depth of footing.
- \(\phi\) = Angle of internal friction.
- \(C\) = Cohesion.

The theory assumes that, if the stress condition at any point in a soil mass exceeds a certain limit, rupture surfaces are formed in the mass. Thus the stress, developing upon the formation of the rupture surfaces may be considered as the ultimate bearing capacity of the soil.

Prandtl (1920) developed an equation based on his study of penetration of long hard metal puncher into softer materials for computing the ultimate bearing capacity.

Prandtl’s bearing capacity equation is based on the rupture mechanism, shown in Fig. 2.2, which is given by

\[ Q_u = c \cot(\phi) \left( \tan^2 \left( \frac{\pi}{4} + \frac{\phi}{2} \right) \right) \pi \tan(\phi) - 1 \]  

(2.2)

Eq. 2.2, does not take into account the width of the foundation, the weight of the soil and the surcharge effect, An evaluation of Eq. 2.2 reveals that if \(C = 0\) and \(Q_u\) also equal to zero, this would means that for a cohesionless soil the bearing capacity is zero.

Reissner (1924) has taken into account the effect of overburden on bearing capacity and the Prandtl’s equation takes the form:

\[ Q_u = [C \cot(\phi) + \frac{\beta B}{2} \tan(45 + \frac{\phi}{2})] \left[ \tan^2 \left( 45 + \frac{\phi}{2} \right) e^\pi \tan(\phi) - 1 \right] \]  

(2.3)
Fig 2.1 Rankine's Wedges (After Cernica, 1982)

Fig 2.2 Prandtl's Failure Mechanism (After Cernica, 1982)
Terzaghi (1943) first proposed a semi-empirical equation for computing ultimate bearing capacity of strip footing by taking into account cohesion, friction and weight of soil and replacing the overburden pressure with an equivalent surcharge load at the base level of the foundation. His work was an extension of the work of Prandtl. For a shallow depth strip footing resting at a depth not exceeding the width of foundation Terzaghi obtained:

\[ Q_u = cN_c + \frac{1}{2} \gamma BN_v + qN_q \]  \hspace{1cm} (2.4)

Where, \( N_c, N_q, N_v \) = Bearing capacity factor.
\( B \) = Width of foundation.

Buisman (1940) appears to be the first investigator to express the bearing pressure in a form obtained by super-imposing the contributions of cohesion, overburden and density (Lee, White and Ingles, 1983).

Terzaghi (1943) made a rational approach on the basis of the effects of these factors separately determined component of bearing capacity due to cohesion, self-weight and surcharge. The rupture surface is shown in Fig. 2.3.

The bearing capacity factors according to Terzaghi are as follows:

\[ N_q = \left[ \frac{a^2}{2 \cos^2(45 + \phi / 2)} \right] \]  \hspace{1cm} (2.4a)

\[ N_c = \cot\phi \left[ \frac{a^2}{2 \cos^2(45 + \phi / 2)} - 1 \right] \]  \hspace{1cm} (2.4b)

\[ N_v = \frac{1}{2} \tan\phi \left( \frac{K_{py}}{\cos^2\phi} - 1 \right) \]  \hspace{1cm} (2.4c)

where \( a = e^{\left( \frac{3\pi}{4} \frac{\phi}{2} \right) \tan\phi} \)

\( K_{py} \) = co-efficient of passive pressure on mid-zone from two side zones.
(a) Failure Mechanism (After Cornica, 1982)

(b) Bearing Capacity Factors (After Terzaghi, 1962)

Fig 2.3 Terzaghi Bearing Capacity Theory
Fig 2.3(c) Bearing Capacity Factors (After Tomlinson, 1980)
Terzaghi Bearing Capacity Theory
After Terzaghi (1943), many investigators proposed different values for bearing capacity factors considering different failure surface but they all used the general bearing capacity equation proposed by Terzaghi. He assumed the angle that the wedge face forms with the horizontal to be \( \varphi \) rather than the \( (45^\circ + \varphi/2) \) assumed the Prandtl’s theory.

Meyerhof (1951) considers the shear strength of the overburden soil and assumes the boundary of the failure zones as a combination of logarithmic spiral failure surface (CDE) and a free surface (BE) Fig. 2.4 (a). He considered the plastic equilibrium for the zones bounded by the free surface, slip surface and the footing base. The resulting bearing capacity factors are shown in Fig. 2.4(b).

Brinch Hansen (1961) proposed a general formula of bearing capacity for strip footing on \( c-\varphi \) soil which includes the effect of depth and shape of the footing, load and base inclinations and ground slope in a form:

\[
Q_u = \frac{1}{2} \beta_\gamma N_q (s_q d_q i_q b_q g_q) + q N_q (s_d d_q i_q b_q g_q) + c N_c (s_i d_i b_i e_i g_i) \tag{2.5}
\]

Where \( s, d, i, b \) and \( g \)'s are the factors of shape, depth, load inclination, base inclination and ground slope respectively. The bearing capacity factors for Brinch Hansen’s equation are given below:

\[
N_q = \tan^2 \left( \frac{\pi}{4} + \frac{\varphi}{2} \right) e^{\pi \tan \varphi} \tag{2.5a}
\]

\[
N_c = (N_q - 1) \cot \varphi \tag{2.5b}
\]

\[
N_y = 1.8 (N_q - 1) \tan \varphi \tag{2.5c}
\]

Sokolovski (1960, 1965) derived a numerical solution, satisfying the basic equations, using the methods of characteristic to solve the problems involving plastic shear in the soil body.
(a) Failure Mechanism

(b) Bearing Capacity Factors

Fig 2.4 Meyerhof’s Bearing Capacity Theory
Feda (1961), Balla (1962) and other investigators worked extensively and proposed different values of bearing capacity factors. Feda (1961) proposed an empirical relation to calculate the bearing capacity factor for roughness, \( N_r \) as follows:

\[
N_r = 0.01 e^{0.25 \varphi}
\]  

Meyerhof (1963) suggested simple equation for finding the bearing capacity factors for shallow footings on sand and used equation 2.4 (with \( c=0 \)) to predict the ultimate bearing capacity of sand. The bearing capacity factor \( N_q \) similar to that of Reissner (1924) and \( N_r \) and \( N_q \) are given by

\[
N_q = (N_q - 1) \tan (1.4 \varphi) \]  

\[
N_q = e^{x \tan \varphi} \cdot \tan^2 \left( \frac{\pi}{4} + \frac{\varphi}{2} \right) \]  

On the other hand Hansen (1970) revised his expressions for \( N_r \) to be used in Eq. 2.5 as

\[
N_r = 1.4 (N_q - 1) \tan \varphi \]  

For a given friction angle, the recommended values of \( N_r \) are less than those suggested by his earlier (Brinch Hansen, 1961). Abdul Baki and Beik (1970) developed a theoretical solution applicable to cohesionless soils considering the effect of base roughness and shearing strength of overburden. They calculated the bearing capacity factors \( N_r \) and \( N_q \) neglecting the shear strength of overburden and the combined bearing capacity factors \( N_{rq} \) considering the shear strength of overburden. Vesic (1973, 1975) has suggested using Eq. 2.4 of Terzaghi (1943) with the theoretical values of \( N_r \) and \( N_q \) developed by Reissner (1924) and an empirical relation for \( N_r \) given by Caquot and Kerisel (1953) as

\[
N_r = 2 (N_q + 1) \tan \varphi \]
Al Omari (1984) made a useful remark on the variation of Uzunerc’s results pointing out that Uzuner did not take into account the degradation of φ value due to the circulation of sand through the sand spreader.

Quadir (1990) proposed an empirical relation to calculate the bearing capacity factor for Bangladeshi sand, \( N_y \), as follows:

\[
N_y = 40.52 \ e^{(0.054\phi)}
\]  

(2.11)

It is interesting to note that for a given φ, the value of \( N_y \) obtained by using the equations of Meyerhof (1963), Hansen (1970) and Vesic (1973, 1975) are very close.

2.3 Effect of layer thickness and Footing roughness on Bearing capacity

Terzaghi (1943) accounted for the rough base of the footing and mentioned that the tendency of soil located within the zone (1, Fig. 2.3) to spread is counteracted by the friction and adhesion between the soil and the base of the footing. On the other hand the existence of this resistance against lateral spreading, the soil located immediately beneath the base of the footing remains permanently in a state of elastic equilibrium and the soil located within the central zone behaves as if it were a part of the sinking footing.

Livneh (1965) presented a theory for the calculation a bearing capacity of weightless (c-φ) soil layer loaded with a rigid strip footing having a rough or smooth surface. He concluded that the bearing capacity of a soil based on smooth footing surface increase with increasing thickness of soil reaching a constant value at a certain limiting thickness. The presence of friction between the soil and the surface increases the value of bearing capacity and decreases the value of the limiting thickness. Livneh did not present any experimental results to support his theory.

Vyalov (1967) improved a formula for the bearing capacity of weightless weak soil underlying rigid base and subjected to a strip load. He concluded that the bearing capacity decreases to a minimum with increasing layer depth and than it starts increasing.
Kananyan (1970) performed model tests using rigid rough plates of length 0.82 m and widths varying from 0.16 m to 0.30 m on layer of intermediate grain size dry alluvial sand ($\phi_t = 38^\circ$) placed in a metal tank of 2-0 m x 1.2 m x 0.82 m dimensions having a rough rigid base. He implemented tests on two conditions constant footing width of 0.20 m and constant layer thickness of 0.20 m. Kananyan concluded that in both the test conditions bearing capacity increase with decreasing $H/B$ and beyond $H/B = 2.00$ (approx.), the layer thickness has no influence on bearing capacity.

Meherhof has done a lot of pioneering work along the line of shallow and deep footings but his method, despite its effectiveness, is not directly useful to the designer because his curves can not be used for $N_r$ and $N_q$ until the angle $\phi$ is determined, which requires the solution of a transcendental, equation (Abdul Baki and Beik, 1970). One important feature of the study of Abdul Baki and Beik (1970) is that a common slip surface was implied in case of friction and surcharge.

Al-Omari (1984) examined experimentally the behaviour of finite layers of sand overlying a rough or a smooth footing surface under a strip loading condition. The footing has a rough base of width 0.12 m, the relative density of the sand was 88% with $\phi = 37^\circ$.

For a rough interface condition, Al-Omari found that for both surface and shallow ($D/B = 0.5$) foundation the ultimate bearing capacity increased sharply with the decreasing layer thickness below a limiting value of $H/B = 1.5$. For smooth surface footing, he concluded that the ultimate bearing capacity decreased to a minimum when $H/B = 0.5$ and the limiting depth was around $3B$ $(\phi = 37^\circ)$.

Abedin (1986) studied the eccentrically loaded strip footing on a sand layer overlaying a rigid stratum. He used the similar experimental setup as used by Al-Omari. He concluded that for a rough footing base $(\phi_t = 36.5^\circ)$ the limiting thickness is 1.5 B for zero eccentricities.
2.4 Effect of Soil-reinforcement on bearing capacity

The beneficial effect of incorporating tensile reinforcing elements in granular soil fills has been described by several authors. Vidal (1966) mentioned use of a reinforced earth mat to develop the bearing capacity of a soft subsoil foundation in France. Yang (1972) performed some model plate bearing tests on sand reinforced with fibre glass mats in connection with fundamental studies of the mechanism of reinforced earth. Schlosser and Long (1972, 1973) have performed triaxial tests on sand containing horizontal beds of reinforcement.

Nasu and Useawa (1973) have studied the potential benefit to be gained from using a reinforced earth slab for a railroad embankment over loose saturated sand likely to liquefy during an earthquake. A large reinforced earth mat has been constructed over potential limestone, caverns as described by Steiner (1975), Brown (1977) have performed triaxial test on sand containing fabric. However in the past, reinforced earth has been mainly used in connection with earth retaining structures. Various types of reinforcing were used such as aluminum foil, galvanized metal strips, wire mesh, geotextiles and geogrids. Numerous investigators, Bell (1980), Haliburton (1981), Jewell (1982), Ingold (1982), Fowler (1982), Soderman and Rowe (1984) have extended the stabilizing effect of geotextile reinforcement on embankment.

The work of Binquet and Lee (1975b) show that reinforced soil technology is also applicable to bearing capacity problems. Because the reinforcing action under a footing requires good frictional bond between the horizontal lies and the soil, the use of free draining granular soil fills is advantageous.

A large number of model tests provide experimental data by which to compare the hypothesis expressed by the analytical method described here in. These model tests used a 3.0 in (76-mm) wide strip footing on the surface of medium dense sand, reinforced with 0.5 in (13-mm) wide strips of household aluminum foil spaced to give a linear Density of Reinforcement, LDR = 42.5%. The experimental values of BCR found for different layers of reinforcing are shown in Fig. 2.5. For this series of tests, the experimental curve was the same for all values of settlement S/B up to and including complete failure. For comprise on the theoretical bearing capacity data are calculated and are also shown in Fig. 2.5. There is a remarkable agreement between theory and experimental data both for the bearing capacity ratios and for the mode of failure.
2.5. Comparison of Theoretical and Experimental Bearing Capacity Ratios for Model Strip Footings (Binque and Lee, 1975)
Lawton and Fragaszy conducted laboratory tests on dense sand reinforced with household aluminum foil over a wide range of relative densities (Dr = 51% - 90%). When bearing capacity ratio is calculated at a settlement equal to 10% of the footing width, the bearing capacity is independent of the soil density. When calculated at a settlement of 4% of the footing width, the percentage increase in bearing capacity appears to be less for loose sands than for dense sands. Failure of rectangular footing on dense reinforced sand occur at a larger settlement than an identical footing on unreinforced sand at the same density. Effect of soil density on bearing capacity ratio of strip footing.

The test performed by Lawton and Fragaszy, 1984 (settlement = 0.04B)

**TABLE 2.1**

<table>
<thead>
<tr>
<th>Relative density (%)</th>
<th>Bearing Pressure Kpa</th>
<th>BCR</th>
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</thead>
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<tr>
<td></td>
<td>Reinforced</td>
<td>Unreinforced</td>
</tr>
<tr>
<td>51</td>
<td>29.6</td>
<td>25.5</td>
</tr>
<tr>
<td>61</td>
<td>32.4</td>
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</tr>
<tr>
<td>90</td>
<td>117.9</td>
<td>78.6</td>
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</table>

\[
BCR = \frac{\text{Bearing pressure for reinforced at settlement } S}{\text{Bearing pressure for unreinforced at settlement } S}
\]
CHAPTER 03
EXPERIMENTAL SET-UP AND MATERIALS

3.1 General

The existing experimental set up was improved to investigate the bearing capacity of footing resting on a sand bed layer with and without reinforcement. Air-dried sand was used in the present investigation. Horizontal metal strip reinforcement were laid in single, double and triple layers in the sand bed. In the following section the improvement of the current experimental system and the characteristics of the sand bed are described.

The previous experimental set-up had several problems. When load was applied in the footing through the proving ring, the loading frame deflected out of plane and the result was erroneous. The loading frame locked due to friction at the point of mid-level guiding beam, where it run through. In order to solve this problems, the experimental set-up was remodelled. To avoid friction and locking of loading frame two vertical ball-bearing assembly were placed at that point where friction and locking happened. After the placement of ball-bearing assembly, locking of the loading frame did not occur again. As a result the applied load was properly distributed beneath the footing.

3.2 The experimental set-up

The detail composition of the old and new experimental set-up has been discussed in this articles. The old experimental set-up consists mainly of a model tank, a sand spreader, a loading rig, a proving ring, two loading bar and also two magnetic stand gauge. A general view of the old experimental set-up is shown in Fig. 3.1(a).

The new experimental set-up consists mainly of a model tank, a sand spreader, a loading rig, two loading bar, a load-cell, a data-logger, two deformation transducers and a computer. A general view of the old deflected experimental set-up is shown in Fig. 3.1 (b) and also new experimental set-up is shown in Fig. 3.1.(c) and 3.1(d).
FIG. 3.1(a) THE EXISTING EXPERIMENTAL SET-UP
Fig. 3.1(b) Deflected Loading Rig
FIG. 3.1(C) THE NEW EXPERIMENTAL SET-UP
FIG. 3.1(d) THE NEW COMPLETED EXPERIMENTAL SET-UP
3.2.1 The existing experimental set-up

(i) **The tank**

Designed and constructed by Quadir (1990) was used in the investigation to house the foundation system. A view of the tank is shown in Fig. 3.2. The Skeleton of the tank is constructed of 35mm x 35mm x 4.5mm mild steel angles. The members of frame were connected to each other by providing necessary bolting and or welding. The 60cm deep tank has an inside dimension of 57cm x 85.5cm. The longer side are bounded by 10mm thick glass sheets whereas wooden plates of 25mm thick are used on the shorter sides. The glass sheets are supported from outside by rubber pads which are attached to the vertical members of the frame in order to prevent any damage of glass walls during loading. Along the edges of the glass sheets rubber channels are provided to have a firm seat for the sheets. Four steel wheels are fitted to the bottom of the tank which rests on a rail system designed to facilitate shuttling of the tank in between the sand spreader and loading rig. Details of the tank are shown in Fig. 3.3.

(ii) **The sand spreader**

A sand spreader, designed and constructed by Quadir (1990), was used to form a uniform sand bed in the tank. A general view of the spreader is shown in Fig. 3.4. The sand spreader has a movable steel hopper supported on four wheels. The horizontal forward and backward movements of the hopper are controlled by chain gear system. The rotation of the solid steel roller mounted at the base of the hopper causes a constant flow of sand curtain through the gap between the roller and the adjustable plate. The opening of the hopper can be adjusted by raising or lowering the plate by adjustable screws fixed at the outer surface of the spreader. A schematic diagram of the roller hopper part of the sand spreader is shown in Fig. 3.5.

The hopper moves for a distance about 130cm on two horizontal rails which can be raised or lowered, over a distance of 80cm on four vertical threaded columns is used to rotate the steel roller. The threaded columns are protected from damage and or dust by wrapping the threaded portion by cloth cover during sand spreading A 0.7mm sieve is placed on the top of the hopper in order to prevent undesirable particles (bigger than the opening size) from entering the hopper. The sand spreader is mobile and runs on wheels over 37mm x 37mm T-Section rails. For each operation of the spreader the rails are fixed.
FIG. 3.2 THE MODEL TANK
MODEL TANK

PLAN

85.5 cm
80 cm

ELEVATION (LONG SIDE)

37mm x 37mm x 5mm for frame of the tank
3.5mm thick rubber cushion
10mm glass
25mm x 25mm Aluminium angle bolted with main frame
2mm U shaped rubber cushion
18mm thick wooden member
37mm x 37mm x 5mm Angle welded with the frame
9mm thick M.S. plate at the bottom

25cm

FIG. 3.3 DETAILS OF TANK

91 cm
18 cm
5 cm
18 cm

3.5 cm dia. wheel
9mm M.S. plate as a floor Tank
3mm bolt for fixing the rubber
10mm glass
18mm thick wood

60.5 cm
28.5 cm
FIG. 3.4 THE SAND SPREADER
FIG. 3.5 SECTION THROUGH ROLLER HOPPER OF SAND SPREADER.
on the threaded columns by nuts through movable bushes, The bottom ends of the threaded columns are bolted and welded by steel plates which are eventually connected with the wooden floor. The swaying of the sand spreader, due to operational movements, is restricted by a mid level and a top level bracings. The mid level bracings consists of four members (25mm x 25mm angle) which are welded and bolted with the vertical column at a height 76cm from the base. The top bracing consist of four 50mm x 5mm flat bar which are connected with the threaded columns by nuts and bolts.

(iii) The Sand Levelling Apparatus
After the sand spreading in the tank, it was required to level of the sand bed in order to achieve the desired depth of the bed and the perfect horizontal surface. Quadir (1990) designed and constructed the sand levelling apparatus similar to that used by Abedin (1986) was fabricated using threaded flat bars and flat plates of mild steel for the purpose. The L-Shaped M.S plate is bolted to the lower end of the threaded bars which acts as the leveller. The other ends of the threaded bars are connected through the holes of the flat bar using proper nuts. Thus the height of the leveler can be adjusted to a desired depth. The projected ends of the flat bar rest on the tank wall during the leveling operation.

(iv) The Footing
General view and schematic diagrams of the model footing used are shown in Fig. 3.6 to 3.7. A strip footing of dimension 100mm x 508mm were used in the present investigation, The model strip footing is made of a prefabricated mild steel channel. The ends of the channel were covered by welding M. S plates of proper sizes. Two V-shaped grooves are out on the base plate to have proper seats for the knife edged loading blades. Hard rubber strip were cemented to the edges of the footing to avoid any shock between the footing and glass. Two U-Shaped mild steel handles are welded on the top of the footing. Rough base of the footing was achieved by gluing emery cloth (no.3) on the footing base. Two 19mm wide steel bars are welded to the top surface of footing which provide provisions for the two magnetic stand gauge used to measure settlement of the footing during loading.
FIG. 3.6 THE STRIP FOOTING
(a) PLAN

(b) CROSS SECTION

(a) ELEVATION

FIG 3.4
(v) **The Loading Rig**

A strain controlled loading rig was used in this investigation. Details of the rig are shown in Fig. 3.8 to 3.9. The loading mechanism is mainly composed of a loading frame, a variable speed electrical motor, a speed control box, a gear box, a vertical threaded shaft, two loading bars and a proving ring. The bottom members of the frame were drilled along with the wooden floor and bolts were used for fixing the frame with the floor. The loading frame is finally bolted to the wooden floor.

The speed of the motor can be controlled by a switch which is connected with the speed control box by a chain which drives down or raised up the vertical threaded shaft by a two point switch attached to the frame. The vertical threaded shaft is connected with a mid-level beam through a proving ring having a different capacity.

The two edge loading bars rest on a mid-level beam and can be lowered or raised by threaded nut.

A pair of knife-edge loading blades are attached to the bars to transfer the load on to the strip footing. Fig. 3.9.

(vi) **The Tank Maneuver System**

The loading frame and sand spreader are mounted on a wooden frame. The vertical threaded columns of the sand spreader are fixed with the floor. The two 2.82 m long, 37mm x 37mm, T-Section were used as a rails and fixed with the floor over which the tank can move smoothly to its desired position.

3.2.2 The new experimental set-up

The existing experimental setup has been modified to suit the purpose of automated and accurate data recording.

The unchanged components of the new experimental set-up were the tank, the sand spreader, the sand levelling apparatus, the footing, the tank maneuver system. In the improved experimental setup, loading frame is augmented by a newly devised ball-bearing assembly, proving ring is totally replaced by a load-cell and dial gauges are
FIG. 3.8 THE EXISTING LOADING RIG WITH STRIP FOOTING.
Fig. 3.9 Loading rig (Schematic) with strip footing.
replaced by deformation transducers. The arrangement at the new loading rig is shown in Fig. 3.10. The additional items which are included in the new system were described below.

(i) The Load-Cell
A load-cell is used in this system instead of the proving ring. It is an equipment which used to transfer vertical load on the footing. The seating arrangement of the loading cell in the loading rig have been improved which shown in Fig. 3.10 and 3.1 (c). The diameter of the loading cell is 10 cm and height is 5 cm.

It placed at the mid portion of horizontal middle beam which supported by two loading bar. The top portion of the loading cell is vertically supported by the plate which connected the threaded vertical shaft. With the help of a gear box, the vertical shaft moves down when loading is applied and moves up in the case of unloading.

A connector goes out from the side of the load-cell which connects it to the Data-logger. The load-cell connector composed of four wires such as Black, White, Red and Blue. They are connected to four point of the Data logger. The red wire is connected to the star (*), Black to the (R), White to the (-), and Blue to the (+) point of the Data logger respectively.

The capacity of load-cell is 20 Ton. The load-cell is calibrated in S.M. Laboratory several times. The calibration chart given in Fig. 3.11.

(ii) The Deformation Transducer
A deformation transducer is used in this current experiment instead of the magnetic stand dial gauge. It is a modern apparatus which used to measure the settlement of a strip footing with the help of Data-logger through a record analog voltage reading. There are two deformation transducer used in these experiment whose active length are 9.50 cm and 6.50 cm respectively. With magnetic stand the deformation transducers have been seat over the two side of the footing.
Fig. 3.10 (New loading rig.)
Load-Cell Calibration

Actual test data
Fitted linear line

\[ Y(\text{lb}) = 48.32281 + 17.84082 \times \text{Reading} \]

FIG 3.11
A connector goes out from the side of the transducer which connects it to the data-logger. The transducers connectors composed of four wires such as Red, Green, Blue and Neutral. The red wire is connected to the positive (+ve), Green to the negative (-ve), Blue to the (R) and Neutral to the star (*) point of the Data-logger respectively. The deformation transducer are calibrated in S.M. Laboratory and soil laboratory.

The calibration chart are given in Fig. 3.12 and Fig. 3.13.

(iii) The Data Logger
The Data Logger is an electronic equipment which is used to record analog voltage reading from load-cell and deformation transducer and pass it to computer digital data. The Data Logger composed of four connections. Each connections has four points, such as, star (*), positive (+ve), negative (-ve) and also R.

The first and second connection fill up the connectors which come from the two deformation transducers. In these two connections star (*) point is neutral and (+ve) point is connected to red wire, (-ve) point is connected to green wire and (R) point is connected to blue wire.

The third connections is connected to the load-cell connector and fourth circuit was free from any connection.

Beside these, there are another two connections which were connected to the power and to the computer as shown in Fig. 3.14.

During the loading of the footing, the Data Logger recorded all the data relevant to bearing capacity and settlement accurately. The Schematic diagram of the Data Logger is shown in Fig. 3.15.

(iv) The Ball-Bearing
The vertical ball-bearing assembly was used at the mid level guide beam, where the loading frame run through the vertical hole. To avoid friction during loading in the point of guide beam and loading frame the ball-bearing assembly was used.
Calibration of Displacement Transducer-1

Data Logger Reading (milliVolts) vs. Displacements (cm)

- Actual test data points
- Fitted linear line

\[ Y(\text{cm}) = 15.66008 - 0.00101 \times \text{Reading} \]
Calibration of Displacement Transducer-2

\[ Y(\text{cm}) = 9.24726 - 4.76025 \times 10^{-4} \times \text{Reading} \]

FIG 3.13
FIG. 3.14 THE DATA-LOGGER
Fig. 3.15 Datalogger
The vertical ball-bearing assembly composed of thirty balls which seats in vertically in five rows and six columns. The outer casing cover is 6.50mm thick and 78mm high. The inner casing is 5mm thick and size of ball is 12.50mm dia. The arrangement of Ball bearing is shown in Fig. 3.16. The Balls were placed at the surrounding side of the loading bar with casing. So during loading, the loading frame could transfer the load to strip footing through the loading frame smoothly without any locking.

3.3 The sand

The sand used in this investigation was collected from Gazaria near Meghna Gomoti Bridge. The samples were collected from ground surface. The characteristics of sand are Grey colored fine to medium. The properties of sand are described in Chapter-4.

3.4 Metal strip

Various types of metal strips are available in Bangladesh-such as M.S. strip, Galvanized metal, copper, lead etc. M. S. strips are used in this investigation. The strength properties of the metal strip are described in Chapter-4.
Fig. 3.16 The Ball bearing
CHAPTER 4
TEST PROGRAMME AND PROCEDURE

4.1 General

The present research is carried out to investigate the beneficial effects of metal strip in single layer, two layers, three layers within a strip foundation bearing sand deposit. The research is concentrated primarily on bearing capacity and settlement of foundation. Tests were conducted using rough and rigid based strip footing on sand layers without and with different layers of metal strip reinforcement. Tests were performed for vertical load to new equipment set-up which discuss in chapter three in article 3.2.

In order to examine the reproducibility of the results some tests were repeated several times. The physical properties of the sand used were determined using ASTM test procedure. The average densities of the samples were determined in every experiment.

The strength properties of metal strip were determined in S.M. Laboratory using ASTM test procedures. The loading rate of load-cell was also calibrated.

Total twelve number bearing capacity tests were performed but experimental errors four test are discarded. Two of them were on unreinforced sand bed, two of one layer reinforced, two of two layer reinforced and the rests were on the three layer reinforced bed. The total bed depth was 39 cm. Initially a base sand bed was formed into the tank using the sand spreader for preparation of the reinforced sand bed. The reinforcing metal strip has been placed on the single layer, two layers and three layers. Finally a top sand layer has been formed on it. All the test programme the total thickness of the sand layer was kept constant.

The first layer of metal strip was 5 cm, second layer was 10 cm and third layer was 15 cm below the top surface of the sand layer. The length of metal strip reinforcement were 5 feet which placed laterally below the strip footing. Every layer of metal strip reinforcement was six number of rods which centre to centre distance 10.6 cm. The geometry of the problem is shown in Fig. 4.1. The parameter studied are listed in Table 4.1.

4.2 Properties of Sand

The grain size, specific gravity and density properties etc. of the sand used are studied. The results are reported in the following articles.
Fig. 4.1 Geometry of Earth Reinforcement Problem

- Sample collection pel for density
- $B = 10$ cm
- $H = 39.00$ cm
- $H1 = 5$ cm
- $H2 = 5$ cm
- $H3 = 5$ cm
- Length of Rod = 5 ft.
- Every Layer = 6.00 no. Rod
Table 4.1: Bearing Capacity Test Programme (Surface footing)

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Sand Bed</th>
<th>Rate of Load</th>
<th>H/B</th>
<th>H1/B</th>
<th>H2/B</th>
<th>H3/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_un-1</td>
<td>Unreinforced</td>
<td>5.0</td>
<td>3.90</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T_R1-2</td>
<td>One layer reinforced</td>
<td>5.0</td>
<td>3.90</td>
<td>0.50</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T_R2-3</td>
<td>Two layer reinforced</td>
<td>5.0</td>
<td>3.90</td>
<td>0.50</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>T_R3-4</td>
<td>Three layer reinforced</td>
<td>5.0</td>
<td>3.90</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>T_un-5</td>
<td>Unreinforced</td>
<td>25.00</td>
<td>3.90</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T_R1-6</td>
<td>One layer reinforced</td>
<td>25.00</td>
<td>3.90</td>
<td>0.50</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T_R2-7</td>
<td>Two layer reinforced</td>
<td>25.00</td>
<td>3.90</td>
<td>0.50</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>T_R3-8</td>
<td>Three layer reinforced</td>
<td>25.00</td>
<td>3.90</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
</tbody>
</table>

4.2.1 Grain size distribution and specific gravity

Grain size distribution curves of sands used in this research are shown in Fig. 4.2. The experimental result of grain size distribution and specific gravity are given here. The result of Fineness Modulus (F.M.) is 1.17, grain sizes d_{10}, d_{30} and d_{60} are 0.15, 0.19, 0.26, uniformity co-efficient is 1.73, co-efficient of curvature is 0.93 and specific gravity is 2.61.

4.2.2 Average Density

To determine the average density of sands the individual experimental procedures which adopted given below.

There are four cylindrical density pots were placed in the tank sand bed of different height and places. The size of pots are 108 mm diameter and 51 mm height. During filling the tank with sand by sand spreader the pots place in the tank as shown in Fig. 4.1.
Figure No. 4.2 Grain size distribution curve
After complete the bearing capacity test of the footing the tank remove to its position for cleaning and carefully collect the pots with sample. The top surface of the pots were level by using a straight edge and take weight. Now the sand was remove from the density pots and again weight at empty condition. The sample was determine at difference of two weight of the pot. Volume of the sample was recorded and the density calculated (Table 4.2) and can easily find out average density of every test.

Table 4.2: Height of fall and Density

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Height of fall (mm)</th>
<th>Dry. Density KN/m3</th>
<th>Average. Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tun-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>825</td>
<td>14.57</td>
<td></td>
</tr>
<tr>
<td></td>
<td>900</td>
<td>14.79</td>
<td></td>
</tr>
<tr>
<td></td>
<td>940</td>
<td>14.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1010</td>
<td>14.97</td>
<td></td>
</tr>
<tr>
<td>T_R1-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>830</td>
<td>14.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>895</td>
<td>14.82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>945</td>
<td>15.51</td>
<td></td>
</tr>
<tr>
<td>T_R2-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>830</td>
<td>15.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>895</td>
<td>15.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>969</td>
<td>15.62</td>
<td></td>
</tr>
<tr>
<td>T_R3-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>825</td>
<td>14.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>890</td>
<td>14.88</td>
<td></td>
</tr>
<tr>
<td></td>
<td>955</td>
<td>15.52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1008</td>
<td>15.69</td>
<td></td>
</tr>
<tr>
<td>Tun-5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>830</td>
<td>14.27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>895</td>
<td>14.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>960</td>
<td>14.84</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1012</td>
<td>14.97</td>
<td></td>
</tr>
<tr>
<td>T_R1-6</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>828</td>
<td>14.77</td>
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</tr>
<tr>
<td></td>
<td>895</td>
<td>14.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>950</td>
<td>14.27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1010</td>
<td>15.42</td>
<td></td>
</tr>
<tr>
<td>T_R2-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>840</td>
<td>14.67</td>
<td></td>
</tr>
<tr>
<td></td>
<td>910</td>
<td>14.72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>960</td>
<td>15.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1015</td>
<td>15.32</td>
<td></td>
</tr>
<tr>
<td>T_R3-8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>880</td>
<td>14.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>895</td>
<td>14.89</td>
<td></td>
</tr>
<tr>
<td></td>
<td>930</td>
<td>15.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1050</td>
<td>15.30</td>
<td></td>
</tr>
</tbody>
</table>
4.3 Properties of Metal Strip Reinforcement

The strength properties of the metal strip reinforcement were determined in the S.M. Laboratory and the test results are stated below.

4.3.1 Cross-sectional area and Breaking Strength

The cross-sectional area of the metal strip reinforcement is 16 mm$^2$. The breaking strength of the metal strip is 341.18 N/mm$^2$.

4.4 Calibration of Apparatus

The machines and apparatus used in this investigation have been conducted properly calibrations. Calibration procedures are described in the following articles.

4.4.1 Calibration for Motor speed

The variable speed motor used in the loading rig. So it is essential to calibrate, the speed meter. The speed control handle applies variable hydraulic pressure depending on the rotational position of the circular disc of the handle Fig 3.1. In order to calibrate the motor speed, the circular disc was set at a graduated position and motor was set on. The distance moved by the shaft of the loading rig and the time required were recorded. The speed was calculated accordingly.

4.4.2 Calibration of load cell

The load-cell is calibrated in S.M. Laboratory. The calibration chart has previously given in Fig. 3.11.

4.4.3 The deformation transducer

The deformation transducers are calibrated in S.M. and Soil Laboratory. The calibration chart have previously given in Fig. 3.12 and Fig. 3.13.

4.5 Bearing capacity test procedure

The experimental procedures for all the bearing capacity tests were followed. In the following section the test method is described in detail.
4.5.1 Sand bed formation

The respective tank was brought under the sand spreader and the sand spreader was placed in position, which covered the whole tank area. During operation, the swaying of the sand spreader was prevented by the mid level and top-level bracing's bolted with vertical threaded stand of the spreader. Fig. 3.4. The L-section aluminum plates were screwed to the top of the four side walls of the tank to prevent rolling of the sand into the tank from its walls. Polythene curtains were hung from the L-section on all the four sides of the tank to prevent the sand particles from entering the tank frame, wheels and base. The initial height of the hopper (roller) was adjusted by using the nuts of threaded stand of the spreader. The hopper of sand spreader was taken to the end of its run and sand was poured on it. A mild shaking was applied to drop sand into the hopper. When the hopper was approximately 3/4th full, the spreading of sand over the tank were done by using the handle of chain gear arrangements of the sand spreader. After each 50mm of deposition the sand spreading were stopped and the hopper was raised to keep a constant height of fall. The pouring operation, spreading, and raising were continued until the depth of deposition is small higher than the target layer thickness. The sand storied on the side of the L-section was removed, the polythene curtains from the L-section were taken off and the tank side was cleaned. The spreader was cleaned and pulled away from the loading rig leveling the tank.

Two square steel bars were screwed to the top of the tank wall which serve as the rails for the sand leveler. The excess sand beyond the desired layer thickness was pushed to the edge of tank and eventually removed with the help of a flat bottom shovel.

During leveling operation a spirit level was used to check the top level of the layer. The necessary depth was obtained by adjusting the control nuts of the sand leveling apparatus. The thickness of the layer was measured using the depth gauge.

In some of the tests glass wall was lubricated by using rubber membrane and silica-grease. A thin layer of grease was applied on small pieces of rubber membrane. They were than stuck to the glass walls of the tank and were deposited as usual to form the sand bed.
4.5.2 Reinforced Bed Formation

For finding out the effect of metal strip of bearing capacity with a particular sand type, the sand bed was formed up to a desired depth. The metal strip used as a reinforced which laid in single layer, double layers, triple layers in different stage of height. Required depth of sand was sprayed from the spreader over reinforcing layer, the adequate sand beyond the desired layer thickness was removed by using a leveling apparatus.

4.5.3 Placement of footing

For tests with surface footing the model footing was placed after placing the tank in proper position. For placing the footing in proper position and to ensure the central loading condition the footing location over the sand bed was marked on the glass by a glass marker before sand bed formation.

4.5.4 Placing the tank below the loading Rig

The tank was pushed very slowly to move toward the loading rig after the sand bed prepared. The tank was placed in such a position that the center of the tank is just below the loading plates to ensure the vertical central loading condition. Cross bracing's were fitted at the end of the tank to avoid the counter balance the load to the tank. The nuts of the bracing were tightened so that maximum portion of the applied load could be transmitted to the bracing members and the tank wheels were kept free from applied load for their safety. The tank was set in position so that the loading blades fixed at the respective grooves of the footing.

Two magnetic stand dial gauge were placed on the footing for measuring settlement of footing during loading. After remodeled the existing experimental set-up, the two deformation transducers are replaced to remove of dial gauge.

4.5.5 Loading the footing

The loading bars were adjusted in mid level beam with vertical ball bearing which composed of ball in five rows and six columns to avoid friction when applied load in footing. The loading blades must be touch the strip footing at the grooves before loading. To remain friction less of ball bearing, always given grease in it.
The loading motor was switched on and off to set the zero position of proving ring dial and strain dial at the footing. This system had several problems. So the existing experimental set-up was remodelled.

The existing experimental set-up and remodelled experimental set-up previously discuss in articles 3.2.

When applied load on the footing, the load-cell data and the deformation transducer data were automated and accurately to record analog voltage reading through data-logger and pass it to computer on digital data.

This was continued until a decrease or a small rate of increase in its reading. The loading was stopped and the machine was switched on for unloading.

The strain dial attachment, and bracings were removed, Data logger and computer was disconnected and the tank was move to its position for cleaning.
CHAPTER 5
EXPERIMENTAL RESULTS AND DISCUSSION

5.1 Introduction
This chapter presents the major findings of laboratory investigation into the bearing capacity of strip footings on sand bed. The sand bed consists of four dissimilar conditions such as (i) homogeneous deep sand bed (ii) deep homogeneous sand bed reinforced with one layer (iii) two layers and (iv) three layers. The locally available metal strip reinforcement was used in the investigation. The sand bed was prepared by using a sand spreader maintaining a constant height of fall to ensure uniform density throughout the depth. The depth of the sand layer in the present investigation was always maintained at 3.9 times the width, B, of footing and lateral extension of the layers on both sides of the footing were approximately 3.5B. The tests were performed with the help of computer aided data acquisition system through a data-logger. The speed of load was varied in this investigation. The test results show that bearing capacity of reinforced soil is greater than that of unreinforced soil. Table 5.1 during peak load the result have been varied to change the rate of speed as 0.007 cm/sec and 0.015 cm/sec. Table 5.2 settlement at peak load slow speed was lower than higher speed of loading.

5.2 Effect of Speed
The experiment were performed in two different speeds of loadings such as 0.007 cm/sec and 0.015 cm/sec. The observed settlement against applied load on the footing is presented in Fig. 5.1(a) and (b). Four experiments were carried out in high speed. It has been observed from Table 5.1 that bearing capacity from un-reinforced condition with high speed of loading increases than that of the slow speed rate of loading. In other three tests bearing capacity from the slow speed of loading were of higher value than higher speed of applied loadings.

Again it has been observed from Table 5.2 that the settlement of the strip footing is higher in high speed of applied load than lower speed of loading condition.
5.3 Effect of Number of Reinforced Layer

In this investigation, eight experiments have been successfully done. Two un-reinforced, two one layer reinforced, two two layers reinforced and two three layers reinforced bed were used in these investigation.

The Bearing Capacity Ratio (BCR) of the reinforced and un-reinforced layer in the present study are shown in Table 5.3. The BCR ratios of the slow speed were 1.77 for one layer, 1.80 for two layers but 2.53 for three layers. During the experiment of the three layers configuration, the density pots were kept below the footing. For this reason the value might go up due to the density pot. The ratios of the 2nd speed were 1.45 for one layer, 1.58 for two layers and 1.39 for three layers. The last ratio is lower than the 1st two ratios. The minimum BCR ratio of the two speed were 1.39 and maximum ratio were 2.53.

Given from experimental result shown in Table 5.2 most of the settlement of heavy layers reinforced was less than the other light layers reinforced in all rate of speed of loading. But only higher speed of loading one layer reinforced settlement was less than two layers of reinforced. It has been concluded that most of the results of the settlement indicate that within increase of reinforced layers, the settlement decreases.

5.4 Overall Performance of the Experiment

The present investigation was aimed at determination of the effect of metal strip reinforced on bearing capacity of strips were footing on sand. The metal strip were placed at one, two and three layers. Initially the test was performed by the existing experimental set-up. During the experiment, when vertical load applied on the footing the load-bearing frame locked at the mid-level guide beam. So the previous experimental set-up could not perform the test successfully. The procedure and set-up of the experiment were modified. The testing equipment was improved and re-modelled. A lot of time was spent to design and improve the equipment. In order to get the uniform density of the sand bed, a constant height of fall should be maintained. But many times, it was not exactly possible to maintain constant height. Sometimes sand spreader did not function properly. Total twelve number of tests were performed. Due to possible experimental errors, four tests are discarded. The rest eight experiments are discussed here. The overall BCR shows that, metal strip reinforcement increases the bearing capacity of soil even it is done in single layer.
5.5 Practical Utility

In consideration of above observation it appears that the sand bed reinforced with locally available metal strip offers advantages and possibilities for improvement in the road settlement and ultimate bearing capacity of footings on granular soils. Use of that reinforced earth slabs could offer favourable alternatives to conventional design for special foundation problems. As a consequence of this study, it is necessary to look into the long-term effect of this type of reinforcement material on actual bearing capacity improvement design projects.

A most obvious problem arises as the water table in the soil rise above the level of reinforcement thereby weakening the reinforcing strips. Another is the risk of the long term fate of things that are added to the ground and there are potentials for adverse environmental impacts.

It will therefore be necessary to determine what locally available methods can be used to treat the reinforcement to render them water proof and free from adverse environmental impacts.
Table 5.1  Peak Load

<table>
<thead>
<tr>
<th>Reinforced layer</th>
<th>Speed 0.007 cm/sec</th>
<th>Speed 0.015 cm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unreinforced</td>
<td>1500 lbs</td>
<td>1550 lbs</td>
</tr>
<tr>
<td>Reinforced (one layer)</td>
<td>2650 lbs</td>
<td>2250 lbs</td>
</tr>
<tr>
<td>Reinforced (two layers)</td>
<td>2700 lbs</td>
<td>2450 lbs</td>
</tr>
<tr>
<td>Reinforced (three layers)</td>
<td>3800 lbs</td>
<td>2150 lbs</td>
</tr>
</tbody>
</table>

Table 5.2  Settlement at Peak Load

<table>
<thead>
<tr>
<th>Reinforced layer</th>
<th>Speed 0.007 cm/sec</th>
<th>Speed 0.015 cm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unreinforced</td>
<td>2.43 cm</td>
<td>3.15 cm</td>
</tr>
<tr>
<td>Reinforced (one layer)</td>
<td>2.65 cm</td>
<td>2.88 cm</td>
</tr>
<tr>
<td>Reinforced (two layers)</td>
<td>2.20 cm</td>
<td>3.30 cm</td>
</tr>
<tr>
<td>Reinforced (three layers)</td>
<td>1.88 cm</td>
<td>3.13 cm</td>
</tr>
</tbody>
</table>

Table 5.3  Bearing Capacity Ratio (BCR) of Reinforced and Unreinforced Sand Bed

<table>
<thead>
<tr>
<th>Reinforced layer</th>
<th>Speed 0.007 cm/sec</th>
<th>Speed 0.015 cm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced (one layer)</td>
<td>1.77</td>
<td>1.45</td>
</tr>
<tr>
<td>Reinforced (two layers)</td>
<td>1.80</td>
<td>1.58</td>
</tr>
<tr>
<td>Reinforced (three layers)</td>
<td>2.53</td>
<td>1.39</td>
</tr>
</tbody>
</table>
4000 Speed 0.007 cm/sec

- T - Un-reinforced soil
- A - Reinforced (one layer)
- e - Reinforced (two layer)
- R - Reinforced (three layer)

FIG 5.1 (a)
FIG 5.1 (b)

Load (lbs) vs. Settlement (cm)

- Un-Reinforced soil
- Reinforced (one layer)
- Reinforced (two layer)
- Reinforced (three layer)

Speed = 0.015 cm/sec
FIG 5.2 (a)

- Un-reinforced soil
- Reinforced (one layer)
- Reinforced (two layer)
- Reinforced (three layer)
FIG 5.2 (b)
CHAPTER-6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The present investigation was aimed at the development of an experimental set up and to study the behaviour of a centrally loaded strip footing resting on a sand bed reinforced with a one layer, two layers and three layers of metal strip.

The investigation has been conducted using a model footing of 10 cm wide and 51 cm long resting on dense semi-infinite (H/B = 3.9, approximate) sand layer of average density from 14.67 to 15.78 kn/m\(^3\) contained in a model tank of dimensions 57 cm x 60 cm x 85.5 cm. Tests were carried out under plane strain conditions. The footing was subjected to a strain controlled central loading and free to rotate about the loading point. The load, settlement measurements were taken using load-cell, deformation transducer, to record analog voltage reading to computer on digital data through Data-logger.

On the basis of experimental observation the following conclusions can be summarized as follows:

1. The existing loading arrangement was remodeled. The loading frame is augmented by a newly devised ball-bearing assembly, proving ring is totally replaced by an electronic load cell and dial gauges are replaced by a couple electronic deformation transducers.
2. To automate and record accurate readings to computer as digital data, all data are logged by a data-logger.
3. In the present research, using new equipmental set-up, 8 successful laboratory scale bearing capacity model tests were carried out using strip footing resting on a sand bed reinforced with single, double and triple layers of metal strips.
4. The ultimate bearing capacities of the footing on sand bed reinforced with one layer, two layers and three layers of metal strip can be improved by a factor of about 1.39 to 2.53 times the bearing capacity of an unreinforced soil for otherwise identical conditions.
(5) From the experimental data it is observed that the bearing capacity of strip footing was affected by the speed of loading. It is found that slow speed of loading gives higher value of bearing capacity than that of higher speed of loading.

(6) In most cases the settlement at ultimate bearing pressure of unreinforced soil were greater than that of reinforced soil and gives high magnitude in higher speed of loading than lower speed of loading.

6.2 Recommendation for Future Study

In the present study model tests were conducted on footing resting on a sand bed reinforced with one layer, two layers, and three layers of metal strip. This research project can be continued to study the other avenues of bearing capacity of shallow foundations on the following aspects:

(i) To study the bearing capacity behaviour of reinforced earth considering rectangular, square and circular footing.

(ii) To investigate the effects of various reinforced earth such as galvanized metal strip, Aluminum, wire mesh, geotextiles and geogrids.

(iii) To study similar investigation can be done using sands of different properties and location.

(iv) To investigation the inclination, eccentricity and surcharge effect on bearing capacity.

(v) To study the distribution of stresses beneath the footing by installing appropriate measuring instrument like strain gauges.

(vi) To study the effect of ground water table on bearing capacity and reinforced earth.

(vii) To study the economic of bearing capacity improvement of compaction, consolidation, grouting, soil stabilization using admixture, thermal stabilization and reinforced of soil.
REFERENCES


HASAN, MAHNAZ (1993), "Bearing capacity of a sand bed overlying a single layer of jute cloth.


