# BEHAVIOUR OF A SQUARE FOOTING ON REINFORCED SOIL: AN EXPERIMENTAL STUDY

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**ABSTRACT:** Several investigations are reported in literature pertaining to the numerical and experimental studies on the behaviour of footings subjected to vertical loads on un- reinforced soil and the reinforced. Several works reported in the literature deal with the use of waste materials in various civil engineering works to enhance certain soil characteristics. Hardly any literature is found on reinforced soil technique using rubbergrids as a reinforcing material for foundation on soft clays. In view of this, experimental investigations are reported on the study of load-deformation behavior of a model square footing on reinforced soil in respect of a two-layered system consisting of clay as sub-grade and mine waste as backfill material. The footing was subjected to axial load. Two different types of reinforcing materials such as Kolon Geogrid (KGR-40) and rubber grids derived out of waste tyres were used in the study. The study revealed appreciable increase in ultimate bearing pressure and decrease in settlement with the provision of single layer reinforcement. Further, rubbergrid performed better than the Geogrid in respect of BCR and SRF. The study underscores significance of solid waste materials such as mine wastes and discarded tyres as effective civil engineering construction materials.

**Key Words:** Bearing Pressure, Bearing Capacity Ratio (BCR), Settlement Reduction Factor (SRF), Tyre Wastes.

## 1. INTRODUCTION

Founding of structure on a ground with adequate bearing capacity is one of the basic requirements for the stability of a structure. However, in some situations, structures are required to be built on weak or difficult soils. Under such circumstances, improvement of bearing capacity of such a soil is of great importance for the safety and long term stability of the structures. Inclusion of reinforcing layers within the sub-soil is an effective and economical method amongst many others.

Soil reinforcing technique has emerged as one of the promising fields in civil engineering, especially for a foundation engineer to improve certain characteristics of soils. Many waste materials such as rubber shreds, High Density Polyethylene (HDPE) strips, polypropylene fibers and jute fibers have been used as a fill alongwith soil in embankments and retaining walls to improve certain soil characteristics. Some of the prominent investigations reported in the literature dealing with numerical and experimental studies on the behaviour of footings subjected to vertical loads on un- reinforced soil and the reinforced are briefly reviewed in the subsequent section. Further, a few of the investigations pertaining to the use of waste materials in various civil engineering works is also briefly reviewed.

## 2. BRIEF REVIEW OF LITERATURE

Meyerhof (1957), Zadroga (1994) and Siddiquee *et al.* (2001) and others have reported theoretical studies and model tests to study the behaviour of footings subjected to axial loads on unreinforced soil. The interfacial friction (skin friction) between the soil and construction materials is one of the aspects of the design of reinforced soil system. This aspect was studied by several researchers [Ingold (1982), Kate *et al*. (1988)] through experimental studies by conducting pull out tests and sliding tests on reinforcing materials.

Several experimental and analytical studies have been reported on the behaviour of footing on reinforced soil. Some of the prominent investigations reported on this aspect include those by Binquet & Lee (1975), Dash *et al.* (2001) and Kumar & Saran (2003). There have been several studies conducted to study the effect of waste materials on the performance of subgrade soil. Some of the prominent works include those by Benson *et al.* (1994) Agarwal & Subhashchandra (1997), Garg & O'Shaughnessy (2000) and Praveen Kumar *et al.* (2004).

## 3. SIGNIFICANCE AND SCOPE OF WORK

The above-mentioned review of available literature cites works related to the mobilization of internal friction, reinforced soil bed on soft clay and sand, footings subjected to axial and eccentric loads in respect of reinforced and unreinforced soil bed. Most problems of soft clays under imposed loads can be identified to be associated with low shear strength and high compressibility. The review further highlights scanty work on reinforced soil technique using rubbergrids as reinforcing material in solving engineering problems associated with foundations on soft clays subjected to vertical centric. On the backdrop of the need to understand the behaviour of a rubber reinforced system, an experimental investigation was conducted on the soft soil reinforced with rubbergrid.

The results of experimental investigations are reported on the study of load-deformation behavior of a model square footing under un-reinforced and reinforced conditions in respect of a two-layered system, consisting of clay as sub-grade and mine waste as backfill material, under the application of vertical centric loads. Kolon geogrid KGR-40 and rubbergrids derived out of waste tyres were used as single layer reinforcements of soft sub-grade to control settlements. The width and depth of the reinforcing materials were varied to determine their effects on the settlement and bearing capacity ratios.

## 4. LABORATORY INVESTIGATIONS

Tests were conducted in a tank (1000 mm × 1000 mm × 1000 mm) fabricated out of 8 mm thick M.S. plates. Load was applied through a load cell of 50 kN capacity, attached to a hydraulic jack and it was operated through a hydraulic power pack of 75 kN capacity. A load and displacement indicator unit facilitated reading the applied load and displacement of footing at any instant of time to an accuracy of 10 N. Three linear variable differential transformers (LVDT) were used to record settlements of the footing (Fig.1).

The footings were placed on air-dried (unreinforced and reinforced) mine waste, compacted to a relative density of 78.85% on clay subgrade of wet density 1.768 gm/cc with 88% degree of saturation. Footings were subjected to vertical centric loads. The physical properties of soils are reported in Table 1 and Table 2. The description and properties of the reinforcements are reported in Table 3 and Table 4.

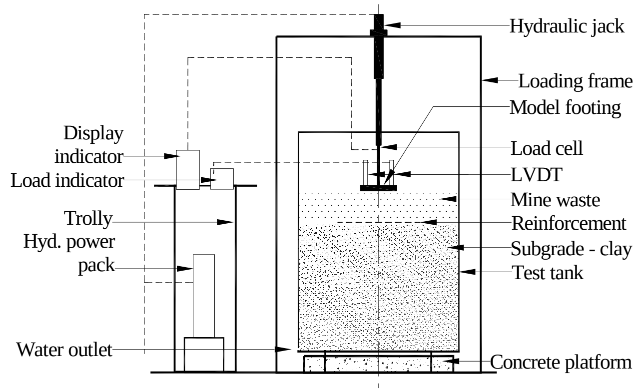


Fig. 1: Details of Test Tank

Table 1: Properties of Processed Mine Waste

| *Physical properties* | | *Geotechnical properties* | |
|---|---|---|---|
| Sp. Gravity | 2.65 | Liquid Limit (%) | 47.0 |
| Max. Density (gm/ cc) | 1.48 | Plastic Limit (%) | 33.33 |
| Min. Density (gm/ cc) | 1.165 | Plasticity Index (%) | 14.67 |
| Rel. density achieved in tank (%) | 78.85 | Angle of int. friction (degrees) | 35.5 |
| E | 0.892 | Density achieved in tank (gm/cc) | 1.4 |
| $e_{max}$ | 1.274 | | |
| $e_{min}$ | 0.790 | | |

Table 2: Properties of Silty Clay Subgrade

| | |
|---|---|
| Bulk density (gm/ cc) | 1.720 |
| Dry density (gm/cc) | 1.33 |
| Specific gravity | 2.619 |
| Liquid limit (%) | 45.75 |
| Plastic limit (%) | 33.09 |
| Plasticity index (%) | 12.66 |
| OMC (%) | 28.9 |
| Undrained cohesion (kPa) | 33.5 |

Table 3: Properties of Geogrid KGR-40

| *Property/ Item* | *Specification* |
|---|---|
| Material | PET |
| Weight (gm/m$^2$) | 280 |
| Aperture size ± 5 % | 20/22 |
| Tensile Strength (kN/m)<br>@ 5 % Strain<br>@ break | <br>14/6<br>40/20 |
| Elongation (%) | <12 |
| Creep (%) | <1 |
| Roll width (m) | 2.0 |
| Roll length (m) | 50 |

Table 4: Properties of Rubber-grid

| *Parameter* | *Specification* |
|---|---|
| Form | Strips |
| Size (mm) | 5 |
| Thickness (mm) | 5 |
| Colour | Blackish white |
| Weight (gm/m) | 50 |
| Tyre type | Nylon reinforced, Bias |
| Corrosion resistant | Yes |
| Light weight | Yes |
| Non biodegradable | Yes |
| Material | SBR |
| Tensile strength at break (kN) | 0.11* |
| Elongation at break (%) | 45 |
| *Applied strain rate 6 mm/ min | |

BCR= $q/q_o$ and SRF = $(S/B)_r/(S/B)_o$

Where

$q_o$ = Average contact pressure of footing for unreinforced soil at failure
$q$ = Average contact pressure for reinforced soil at failure
$(S/B)_r$ = Settlement ratio for reinforced soil and at failure
$(S/B)_o$ = Settlement ratio for unreinforced soil and at failure
$H$ = Thickness of mine waste layer
$B$ = Footing width
$B'$ = Reinforcement width

## 5. RESULTS AND DISCUSSION

Pressure-settlement characteristics were obtained from various tests. The tests were conducted till failure and corresponding load and settlement were recorded. The terms Bearing Capacity Ratio (BCR) and Settlement Reduction Factor (SRF) are used for convenience to interpret the test data. The tests were conducted for three different values of H/B ratios (0.25, 0.375 and 0.5, Fig. 1).

A typical pressure-settlement characteristics for three different values of H/B ratios in respect of unreinforced case is shown in Figure 2.

It is observed that initially the settlement is proportional to increase in bearing pressure for settlement up to about 7% of footing width. However, it increases thereafter at a decreasing rate with increase in pressure. Further, increments in pressure result in continued settlements thereby indicating failure. It is further seen that maximum ultimate bearing pressure is obtained in case of H/B = 0.375. This is considered as the critical H/B ratio. Ultimate bearing pressure corresponding to critical value of H/B ratio is considered in calculating BCR.

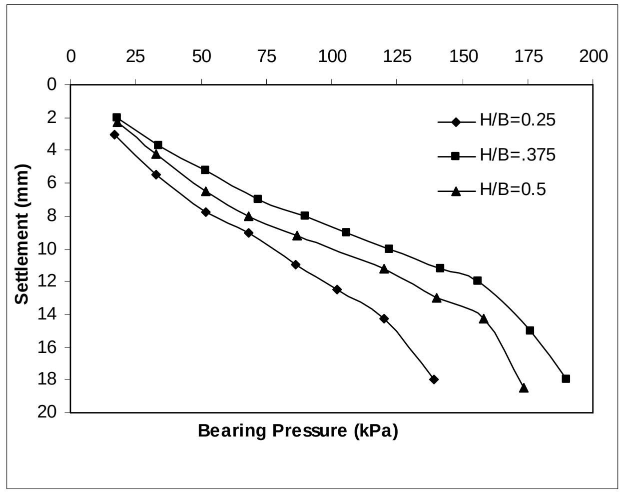


Fig. 2: Pressure-Settlement Curves for Un-Reinforced Case

In respect of tests under reinforced condition, pressure settlement characteristics were obtained to optimize the thickness of backfill material required on clay subgrade and width of reinforcement. Performance of various reinforcements was also evaluated.

### 5.1 Effect of Reinforcement Width

The effect of width of reinforcement was studied for various H/B ratios and the ultimate bearing pressures were calculated for various values of B′/B such as 2, 4 and 6. Typical pressure settlement relationship for H/B = 0.25 and B’/B = 2 is shown in Figure 3. A steady increase is seen in ultimate bearing pressure with increase in the width of reinforcement upto B′/B = 4. With further increase in the width of reinforcement, no noticeable improvement in the ultimate bearing pressure is observed. This indicates that there is an optimum value of B′/B at which maximum ultimate bearing pressure can be reached after which additional area of reinforcement becomes ineffective. This may be due to the fact that below the footing there exists a zone of shearing deformation of soil and only that portion of the reinforcement which lies within this zone will have its tensile strength effectively mobilized. Some part of the reinforcement area beyond this zone serves as anchorage corresponding to a total optimum value B′ and beyond this, a significant portion of the reinforcement functions ineffectively, being neither in the zone of soil extension nor anchorage.

The variation of BCR with H/B for various reinforcements with their widths ranging from 2B to 6B was also studied as shown in Figure 4. BCR is observed to be maximum at B′/B = 4 in respect of all the reinforcements used in the present study. The results further indicate that the combination of B′/B = 4 and H/B = 0.375 yields maximum value of BCR.

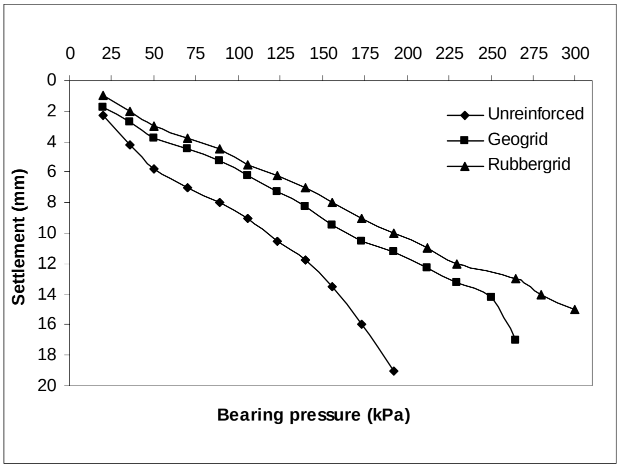


Fig. 3: Pressure-Settlement Curves [H/B =0.25 and B′/B = 2]

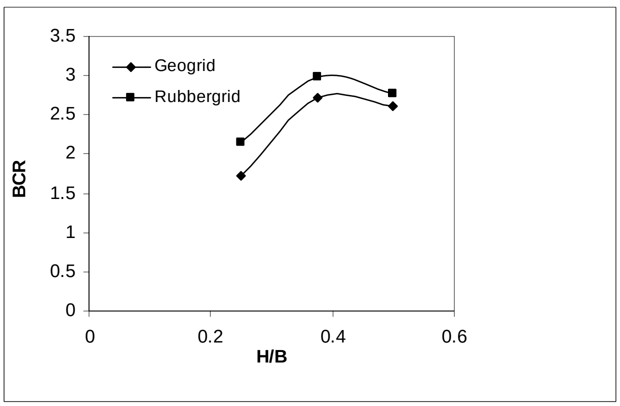


Fig. 4: Variation of BCR with H/B on Reinforced Soil at B′/B = 4 [Critical Case]

### 5.2 Effect on BCR

The effect of reinforcement type (such as geo-grid and rubber-grid) was studied on the performance of reinforced soil beds. The variation of BCR with H/B ratios in respect of the above reinforcements reveal maximum values of BCR to be 2.98 and 2.72, respectively with rubber grid and geogrid at B′/B = 4 and H/B = 0.375. It is further observed that at B′/B = 4 and H/B = 0.375, rubbergrid yields an ultimate bearing pressure of 570 kPa whereas geogrid yields an ultimate bearing pressure of 520 kPa. This is 9.6% higher than that for geogrid.

The above results clearly show that rubbergrid is more effective in terms of improvement in bearing pressure. The superior performance of the rubbergrid may be attributed to better frictional adherence between the longitudinal members of the grid and soil which is influenced by the surface properties and coefficient of friction between them. The nylon belt provided within the tread and sidewalls of the tyre remains protruded even after stripping. This helps in creating the desired roughness in the rubbergrid and in turn develops greater frictional resistance, although its tensile strength is less than that of geogrid. Semi- elastic properties of rubbergrid develop better pseudo- cohesion owing to the temporary deformation of rubbergrid. However, this mechanism is not present in case of other conventional grids.

### 5.3 Effect of Reinforcement on Settlement

The effect of reinforcement was also studied on settlement. It is seen that, at B′/B = 2, SRF decreases with increase in H/B values for all the reinforcements. However, at B′/B = 6, SRF values increase with increase in H/B. It is further seen that at critical values of B′/B and H/B ratios, SRF values are minimum for all the reinforcements. Figure 5 shows the variation of SRF with H/B values at (B′/B)cr. It is further seen from the variation of SRF with H/ B values at (B′/B)cr that SRF of 0.83 is recorded in respect of rubbergrid which is 6.09% less than that for geogrid.

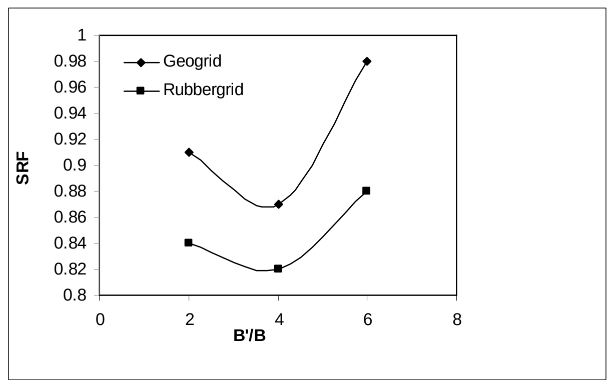


Fig. 5: Variation of SRF with Different Reinforcement Widths at (H/B) = 0.375

## 6. CONCLUDING REMARKS

The experimental investigations reported herein demonstrate the use of mine waste and reinforcing materials towards the improved performance of a soft clay subgrade in respect to bearing capacity and settlements. The better performance of rubber grid could be a cheaper and viable alternative for effective ground improvement.

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