IMPROVEMENT OF WEAK DEPOSITS USING CUPOLA FURNACE SLAG AND REINFORCEMENT IN GRANULAR COLUMN.

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Abstract. Rapid utilization of conventional materials in the infrastructural projects poses a serious threat to the environment, moreover cost has increased many fold in the last few years. An appropriate answer to this problem is the use of waste material such as furnace slag aggregates for the improvement of weak soil deposits. In this study an effort has been made to study the efficacy of use of furnace slag aggregates along with reinforcement in granular column. In case of very soft soils ($Cu< 15kN/m^2$), granular column generally face excessive settlement along with bulging due to insufficient lateral confinement offered by the surrounding weak soil. To avoid such condition reinforcement is provided either in form of vertical encasing or in the form of horizontal circular discs. The present study involves around the comparison of type of reinforcement form i.e. vertical or horizontal on the effectiveness of granular column. It has been recorded that load carrying capacity of weak soil is considerably increased up to 3-4 times with the use of reinforcement. The effect of horizontal circular discs has been observed increasing with increase in diameter of granular column. However study highlights that vertical encasing is still best option available for reinforcement in granular column.

Keywords: Furnace slag, Granular column, Reinforcement.

1. INTRODUCTION

Water logged areas and areas where water table is high, often has low bearing capacity. Soils in such areas are often very compressible due to high moisture content in the soil. One option available to improve such soils is by introduction of granular columns. Granular columns/ stone columns are basically vertical cylindrical members consisting of granular material normally installed in weak soil deposits. Due to their high modulus of elasticity than soil as well as good drainage capability not only mitigates the chances of uneven settlement but also reduces the chances of liquefaction in the sub soil layers. In case of very soft soils i.e. $Cu<15\ kN/m^2$, unreinforced granular column may not be much effective to improve the load carrying capacity. In such circumstances granular columns reinforced with suitable geosynthetics may be more useful. So in this research both vertical encasement type and horizontal reinforcement in the form of discs have been tried to improve bearing capacity of the weak soils.

2. LITERATURE REVIEW

Many authors have investigated the granular columns improved with vertical encasement with different geosynthetic material like geotextiles, geogrids etc. Ali.K et. al. [1], Mahmoud Ghazavi and Javad Nazari Afshar [2] have concluded that with increase in stiffness of reinforcement, the effectiveness of encasement increases. Murugesan and Rajagopal [3] concluded that benefit of encasement decreases with increase in column diameter due to less generation of hoop stress and performance of smaller encased diameter granular columns are much better than larger diameter encased column. Tandel Y.K. et. al. [4], G.Madhavi Latha and Vidya S. Murthy [5] conducted experimental approach on geosynthetic reinforced sand columns. They also reported the similar findings that with increase in stiffness of reinforcement, capabilities of granular column increases.

Mahumad Ghazavi and Javad Nazari Afshar [6], Prasad S.S.G. and Satyanarayana P.V.V. [7] conducted experimental study on large size tests for horizontally reinforced stone columns embedded in weak soils. They have observed that with increase in the column diameter, the effectiveness of the horizontal reinforcement increases. Also they have highlighted that bearing capacity of horizontally reinforced stone columns can be 30% more than vertically encased stone columns. The best vertical spacing for horizontal reinforcement is 0.25D, where D is the diameter of stone column.

Ali K. et. al. [8] conducted laboratory model tests on unreinforced floating and end bearing columns. They have observed that with increase in the diameter of column with same area ratio and L/D ratio, bearing capacity of composite ground decreases. Ambily A.P. and Shailesh R.G. [9] concluded in their work that bearing capacity of stone column not only depends upon loading conditions but also on angle of internal friction of stones used in stone columns. Ayadat T. et. al. [10] reported in their work that ductile material in form of plates are best reinforcing agent for sand columns.

Use of slag aggregates as granular fill in stone columns has been becoming recent trend. Vaitheswari K. and Sathyapriya S. [11] use steel slag as granular fill in granular columns. They have concluded that bearing capacity improvement factor has been increased from 1.7 to 4.5 with increase in L/D ratio of granular column from 3 to 10. Prasad S.S.G. and Satyanarayana P.V.V. [12] used silica manganese slag aggregate in vertical encased granular column. They have shown in their work that with use of silica manganese slag as granular fill in granular column can have 9% more bearing capacity than granular columns with natural aggregates as fill. Indian mineral book [13] notifies a huge amount of slag production rate in India. About 12 million ton of slag is generated in India annually. Dumping problem of such a huge quantity of slag creates lot of problem. Indian mineral book also notified the recent trend of use of slag aggregates in various engineering works.

Mandeep et. al [14] used slag aggregates as partial replacement of natural aggregates in concrete work . They reported that with replacement of 30 % of natural aggregates with cupola slag aggregates, compressive strength increases up to 25.57% and split tensile strength up to 18.26%. Gourav et. al. [15] tried cupola slag as replacement to natural aggregates in granular column and found 16% increase in bearing capacity of cupola slag granular column then natural aggregate granular column.

The present study involves around the use of cupola slag aggregates as granular fill in reinforced granular column embedded in weak soil.

3. EXPERIMENTAL PROGRAMME

The laboratory model tests were carried out on end bearing granular columns. Four series of testing was planned. First series involves to find bearing capacity of virgin weak soil. Second series involves tests on unreinforced granular columns. Third series tests were conducted on vertically encased granular column and fourth series of tests were conducted on horizontally reinforced granular column. Each model test was done on column with constant L/D ratio of 4.5 and replacement ratios of 25% i.e. two different diameter model footings were used. Model footing was 15 mm in thickness and diameter double of granular column i.e. for 24 mm granular column, model footing used was 48 mm diameter and for 30 mm granular column, model footing used was of 60 mm diameter. All granular columns were constructed using non-displacement method.

Model cylindrical testing tank was used with its clear dimensions of 350mm in diameter and 450 mm in depth. Hard stratum in the form of compacted sand layer is used in current study (Javad et. al. [20], Mehrannia N. et al. [21]). Depth of hard stratum was adjusted corresponding to the length of the column installed.

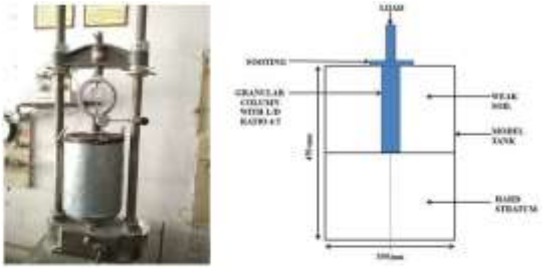

Fig. 1. Model test arrangement

3.1 MATERIALS.

Clayey soil used in current study was collected from Vill Pamal, Distt. Ludhiana, Punjab. The properties of clayey soil are listed as follows:-

Table 1 Properties of soil

Specific gravity	2.53
Liquid limit	42 %
Plastic limit	25 %
Plasticity index	17 %
Soil Classification	CI
Optimum moisture content	14 %
Max dry density	18.53 kN/m^3
Bulk density at 25 % moisture content	19 kN/m^3
Coeff. of permeability	1.547 × 10^{-4} mm/sec

Cupola slag was collected from local foundry, the size of aggregates used in current study was D/6 suggested by Javad et.al. [20], as the oversize aggregates may cause inadequate compaction which may leads to cavity formation in granular column.

Table 2. Properties of slag aggregates

Specific gravity	2.76
Maximum unit weight	16 kN/m^3
Minimum unit weight	15 kN/m^3
Angle of internal friction	49°
Cu	1.58
Cc	0.9958
IS classification	Well graded

Mandeep et al. [14] reported chemical composition of cupola slag. The chemical composition of slag is listed below. Same slag was used in this study.

Table 3. Chemical composition of slag aggregates

Silica oxide	47.99 %
Calcium oxide	24.33 %
Aluminum oxide	16.58 %
Magnesium oxide	7.79 %
Ferrous oxide	1.56 %
Manganese oxide	1.19 %

Reinforcing material used in current study was PVC net with aperture size 1.5 mm × 1.5 mm with E value of 366 kN/m^2.

3.2 PREPARATION OF CLAY BED AND GRANULAR COLUMNS

Air dried pulverized soil was used in current study. After pulverizing the soil, it was passed through IS 4.75mm sieve to remove any lump and foreign material. A series of unconfined compressive strength were done on soil to determine relation between undrained shear strength and water content. From this exercise optimum moisture content was determined corresponding to undrained shear strength less than 15 kN/m^2 i.e. weak deposit.

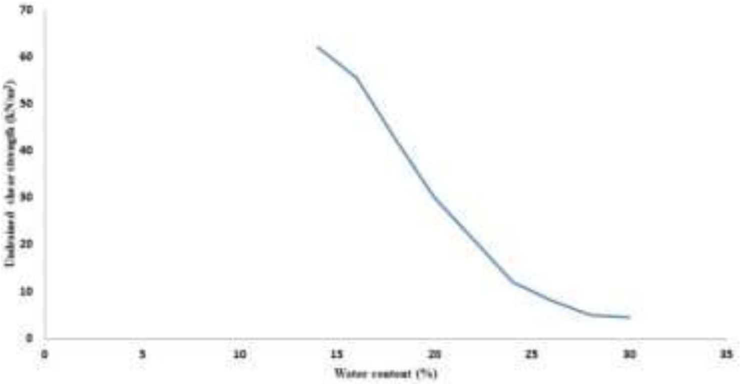

Fig. 2. Variation of undrained shear strength versus water content

From the above curve water content corresponding to undrained shear strength 12 kN/m^2 was chosen and found to be 25%. Compaction level was monitored using core cutter technique and the results were found to be well within the range with an error of $\pm$1%. Each model clayey soil bed was prepared at bulk density corresponding to 25% moisture content.

After compacting soil in the tank, construction of unreinforced granular column was done using conventional non-displacement technique using a PVC pipe with outer side well smeared with oil. Similarly other types of columns were constructed by controlling the compaction of granular aggregates in terms of weight of aggregates corresponding to volume of the column. Placement of reinforcement was also meticulously monitored.

After construction of granular column, the tank was first covered with moist cloth followed by plastic sheet and then it was left for 24 hours for moisture equalization.

4 RESULTS AND DISCUSSIONS

As planned, four series of tests were conducted. In the first series, testing was done on virgin clayey bed, second series was done on composite clayey bed with unreinforced granular column, in third series testing was done on composite clayey bed with vertically encased granular column and in fourth series horizontally reinforced granular column was tested.

Each granular column constructed was end bearing with L/D ratio of 4.5 and replacement ratio of 25%. Diameter of granular column in current study was 24 mm and 30 mm.

4.1 Load settlement behavior of 24 mm granular column.

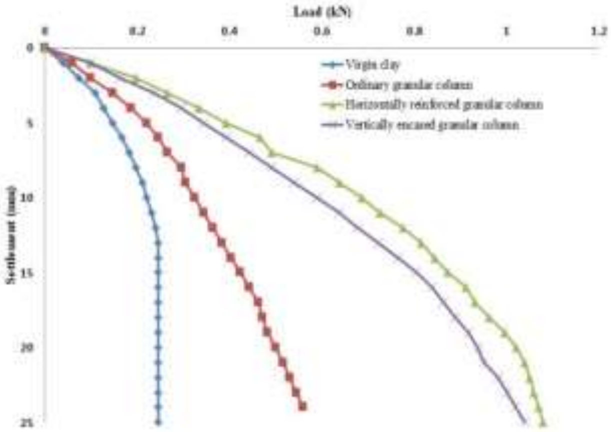

Fig. 3. Load settlement behavior of 24 mm granular column

From Fig. 3, it has been observed that failure pattern changes from punching failure for first series to local shear for second series and then general shear failure for third and forth series.

Similarly there is a huge increase in the ultimate bearing capacity for different cases. It increases from 135.53 kN/m^2 to 325.16 kN/m^2 from series one to series two and further enhances to 574.44 kN/m^2 and 596.12 kN/m^2 for series three and four respectively.

4.2 Load settlement behavior of 30 mm granular column

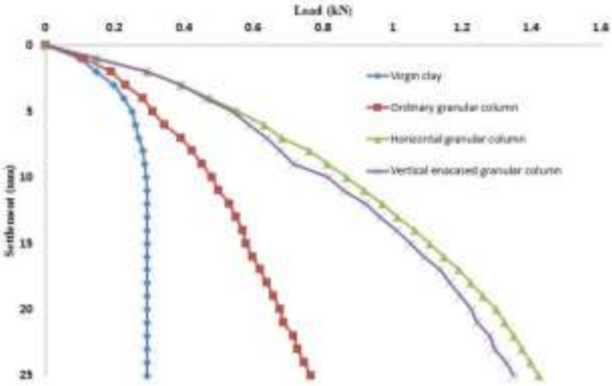

Fig. 4. Load settlement for 30mm granular column

In this case similar trends were observed as in the case of 24 mm diameter column but relative increase corresponding to smaller size diameter column is on the lower side. The ultimate bearing capacity was recorded to be 135.53 kN/m^2, 270.53 kN/m^2, 477.50 kN/m^2 and 502.29 kN/m^2 for virgin clay, ordinary granular column, vertically reinforced and horizontally reinforced granular column respectively. The benefit of encasement decreases with increase in column diameter this may be due to less generation of hoop stress as compare to smaller encased diameter granular columns. On the other hand rise in bearing capacity due to horizontal reinforced granular column with increase in diameter of granular column may be due to increase in mobilization of frictional stresses between granular fill and reinforcement form which leads to less lateral movement of granular fill which leads to prevention of bulging.

4.3 EFFECT ON LOAD RATIO

Efficiency of granular columns for different cases i.e. unreinforced, horizontally reinforced, vertically encased, can be compared with help of another non dimensional parameter known as load ratio. Load ratio can be defined as the ratio of load carried by composite soil with granular column to the load carried by soil bed without any granular column. Fig.6 shows the load ratio variation with settlement.

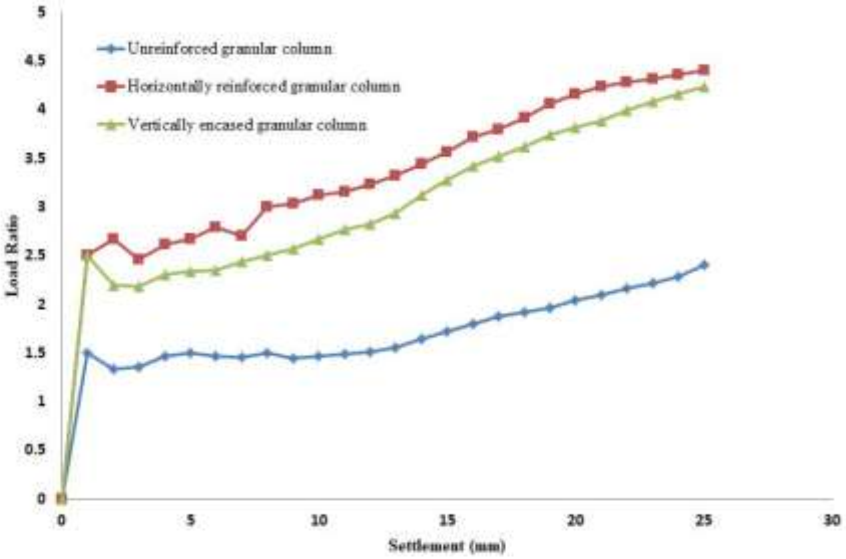

Fig. 5. Load ratio variation for 24 mm granular column

It has been observed from Fig 5 that load ratio keeps on increasing in all the cases for 24 mm granular column. It is in the range of 1.5 - 2.39 for unreinforced granular column, 2.5 - 4.39 for horizontally reinforced granular column, 2.5 – 4.23 for vertically encased granular column for range of settlement of 0 - 25mm.

Similar trends were observed from Fig.6 for 30 mm granular column. It has been seen from Fig. 6 that load ratio tends to remain increasing in all cases of 30 mm granular column. In this case load ratio varies in range of 1.12 – 2.6 for unreinforced granular column, 1.5 – 4.83 for horizontally reinforced granular column and 1.5 – 4.58 for vertically encased granular column for range of 0 – 25 mm settlement. It has also been recorded that load ratio increases with increase in diameter at 25mm settlement, from 2.39 to 2.6 in unreinforced granular column, 4.69 to 4.83 in case of horizontally reinforced granular column and 4.23 to 4.58 in case of vertically encased granular column.

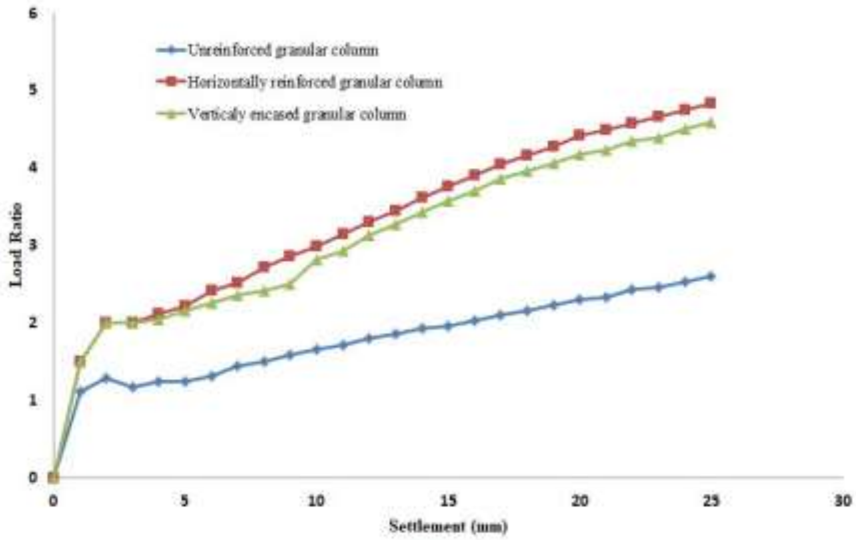

Fig. 6. Load ratio of 30 mm granular column

4.4 POST TEST ANALYSIS

After completion of model testing, the granular material was carefully excavated from column and thin paste of plaster of paris was poured in emptied holes. After filling deformed hole with paste of plaster of paris, it was left for 24 hours to take up the deformed shape of granular column. The dried pop specimen was taken out cautiously and was examined for bulging zone of granular column.

For 24 mm granular column

Deformed plaster of paris specimen of 24 mm granular column was shown in Fig. 7. It was observed that over all increase in diameter has been observed and maximum bulging was measured with vernier calipers. Max bulging in granular column can be viewed in Fig. 8.

Unreinforced granular column

Vertically encased granular column

Horizontally reinforced granular column

Fig. 7. Plaster of paris specimen of 24 mm granular column.

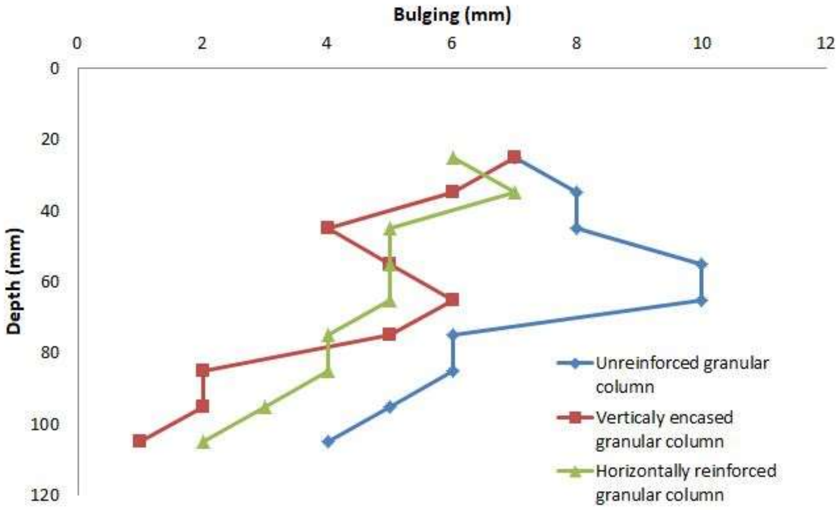

Fig. 8. Bulging analysis of 24 mm granular column

It has been observed from Fig. 8 that max bulging zone lies up to 3.5D in case of unreinforced granular column where as in case of vertically encased and horizontally reinforced granular column bulging zone squeezes to 2.7D. Decrease in this bulging zone may be due to additional confinement provided to granular material. Bulging also decreases with increases in depth of granular column which may be due to larger stress absorption by upper layers of granular material of column. Similar trends were observed for 30mm granular columns.

5 CONCLUSIONS

Four series of model testing were done. First series involves testing of virgin clayey soil bed with different diameter footing. Second involves testing on unreinforced granular column, third involves testing on vertically encased granular column, fourth series involves horizontally reinforced granular columns. Based upon experimental testing series following conclusions can be made out:-

1. The bearing capacity of clay bed treated with unreinforced granular column has been increased up to 2.39 times with 24 mm granular column and 2.6 times with 30 mm granular column, bulging zone lies up to 4D, where D is diameter of granular column.
2. The bearing capacity of composite soil bed with vertically encased granular column increased up to 4.23 times by using 24 mm granular column and 4.58 times by using 30 mm granular column, bulging zone lies between 2.7 – 3D.
3. The effect is more pronounced with horizontally reinforced granular column and ultimate bearing capacity increased by 4.39 times in case of 24 mm granular column and 4.82 times for 30 mm granular column as compared to virgin clayey bed, max bulging zone lies between 2.6 – 2.7 D.
4. Horizontally reinforced granular column were found to be more effective as compared to other cases.
5. However efficacy of horizontally reinforcement in granular column is more than vertical encasement form of reinforcement. But complex installation of horizontal reinforcement makes vertical encasement much user friendly option.

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