# INFLUENCE OF STONE COLUMNS ON BEARING CAPACITY OF DREDGED SOIL-AN EXPERIMENTAL INVESTIGATION

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## ABSTRACT

Jhelum River (Vyeth in Sanskrit) which originates from Verinag spring in South Kashmir is essentially the lifeline of Kashmir valley, forming the backbone of all its economic activities. However, Jhelum River is also the cause of large and small scale flooding in the region and one of the most disastrous floods occurred in September 2014. In view of this, various flood control measures have been suggested and one among them is flood spill channel which transport excess water from main river body during inundating. But unfortunately, the present capacity of the channel has decreased due to the encroachments and sediment deposition in the river and flood channel over the years. In such a scenario, the threat of flooding is evident and thus various proposals are being formulated, one among them being dredging out sediment deposited in the bed of the flood channel. Dredging of the river bed and flood channels produces dredged soil in large amount posing serious health and environmental problems. Concern over environmental effects of dredging, disposal and the increasing unavailability of suitable disposal sites, has put pressure for characterization of this material. Therefore, the present study investigates the behaviour of dredged soil reinforced with stone columns. The dredged soil samples for the present study were collected from different locations of flood spill channel and characterised through laboratory testing. Test specimens were prepared with dredged soil at 0.95 $_{\gamma dmax}$ and Optimum moisture content and subjected to different tests as per relevant standard procedures. In addition to this, a series of model footing load tests were carried out on stone column reinforced dredged soil bed to understand the load deformation behaviour. The parameters varied in this study were length and diameter of stone column. It was observed that the bearing capacity of the stone column reinforced soil bed increases with increase in the area replacement ratio along with significant reduction in settlement. In addition to this, the optimum length of the stone column was also obtained from the test results. A group based test was also done and compared with single stone column tests with similar area replacement ratio. Hence, due the inclusion of stone columns to the dredged soil, there is improvement in the bearing capacity and reduction in settlement.


## INTRODUCTION

Stone column is an suitable technique for enhancing soil conditions. This method has been used since late 1950s. Through the use of this method, it is possible to limit settlement and enhance the strength of foundation. During an earthquake stone columns also act as a gravel drain column to release pore water pressure and the liquefaction potential of a ground can be decreased. One of the methods extensively used in soft soils is vibro-replacement, which consists of replacing some of the soft soil with crushed rock or gravel to form an array of stone underneath the foundation. The use of conventional stone column in soft soil deposits was found to benefit the foundation. The use of conventional stone columns in soft deposit was found to benefit foundations in many respects.

### *OBJECTIVES OF THE STUDY*

As previously mentioned that Dredging of the river bed and flood channels generates dredged soil in large quantity posing serious health and environmental problems. Concern over environmental effects of dredging, disposal and the increasing unavailability of suitable disposal sites, has put pressure for characterization of this material. This material can be valuable resource for many practical purposes. Depending on the type of environment, excavated material may comprise of gravel, sand , silt or soft clays. Beneficial use of dredged material is an essential and necessary part of dredge material management process. For all above applications , a brief study about geotechnical characterisation of dredged material forms an important consideration. Therefore, an attempt has been made to study some physical and mechanical properties of dredged soil for its application in bulk in several geotechnical applications. In this study, disturbed and undisturbed samples of dredged soil from different locations of flood channel were collected for conduct of various lab.Tests for determination of physical , index and mechanical properties as per relevant standard procedures. Amongst the various engineering properties of soils, Bearing capacity is an important engineering property of soils and is used as a quality control parameter for settlement and stability calculations. The main objective of the present work is to study the bearing capacity of dredged soil reinforced with stone columns.

1. To determine the bearing capacity of mechanically stabilized dredged soil.
2. To determine and compare the bearing capacity of dredged soil reinforced with a single stone column by varying the area replacement ratio.
3. To determine and compare the bearing capacity of dredged soil reinforced with a single stone column by varying the length to diameter ratio.
4. To determine the bearing capacity of dredged soil reinforced with stone column group in triangular pattern .
5. To compare the improvement in bearing capacity of soil reinforced with stone column in group with soil reinforced with single column but approx. of the same area as that of the group.

# MATERIALS AND METHODOLOGY

## Material Used

### *Dredged soil*

In the present investigation, samples of dredged soil have been collected from the flood spill channel. To determine the in-situ parameters of soil, undisturbed samples were collected in core-cutters and UCS test samples at each site at a depth of 0.3m. Besides, adequate quantity of disturbed samples were also collected and transported to the lab.

### *Stone aggregates*

Crushed stone was used as a backfill material. The size was chosen such that the particle size is about (1/6 to *1/7*) of the diameter of stone columns. The minimum particle size is 2mm and maximum particle size is 10mm.

### *Testing Program*

Two series of tests were carried out in this work. The first series of tests intended at assessing the physical, index and engineering properties of dredged soil. Further the compatibility of dredged soil under different compactive energy levels was determined with the help of compaction tests. The shear strength parameters of compacted dredged specimens at 0.95*MDD and optimum moisture content were also determined from Direct shear test and UCS. The second series of tests were carried out to evaluate the reinforcing effects of stone columns in improving the load carrying capacity of compacted dredged soil.

## Shear strength parameters

The Direct shear test is one of the common tests used to study the strength parameter of soil. To get the strength parameter, Direct shear tests on dredged soil specimens compacted at 0.95*MDD and optimum moisture content were performed according to IS: 2720 (Part X)-1991. These specimens were tested in a direct shear testing machine with strain rate of 1.25 mm/minute till failure of the sample.

Fig i.Compacted dredged soil samples failed in shear

### *Unconfined Compression Test*

The Unconfined compressive strength test is one of the common tests used to study the strength characteristics of soil and stabilized soil. To get immediate UCS strength, UCS tests on dredged soil specimens compacted at 0.95*MDD and optimum moisture content, were performed according to IS: 2720 (Part X)-1991. The specimen was prepared in compaction mould and obtained by sample extractor. These specimens were tested in a compression testing machine with strain rate of 1.25 mm/minute till failure of the sample.

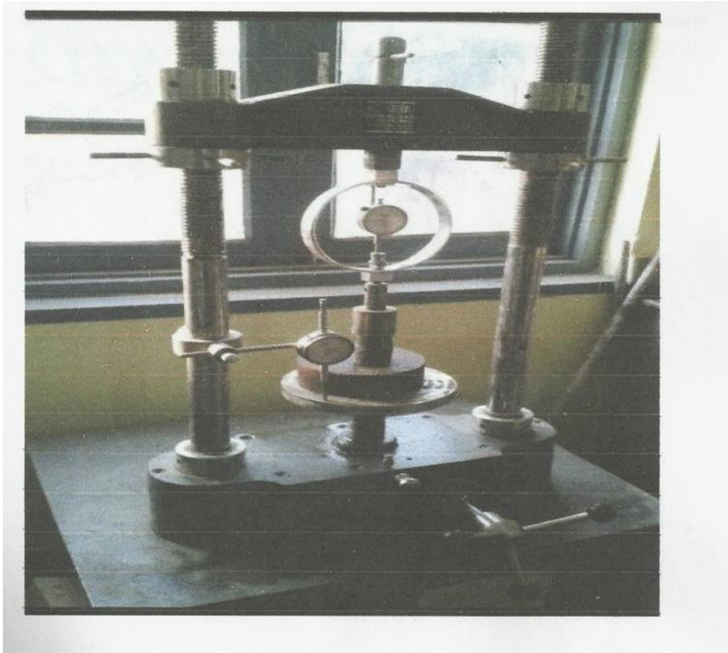

Fig ii. UCS test on compacted soil sample in progress

### *Plate Load Tests*

The tests were conducted to find out the bearing capacity of dredged soil beds, reinforced with stone columns on a stress controlled loading. The test was conducted at area ratio of 4%, 6.25%, 10.25% and 14%. The length to diameter ratios of stone columns was also varied as 2, 4, 6, and 8. A circular footing of 200mm placed centrally on the test bed was tested in a stress controlled loading frame till failure of the sample.

Fig.iii. Experimental setup

# TEST RESULTS AND DISCUSSIONS

## *Shear strength parameters of dredged soil*

Direct shear tests were conducted on dredged soil samples compacted at 0.95%dmax and optimum moisture content. The angle of internal friction varies in a very narrow range between 21 to 26 degrees indicating that dredged soil exhibits loose denseness. The test results are shown in Fig. 1.

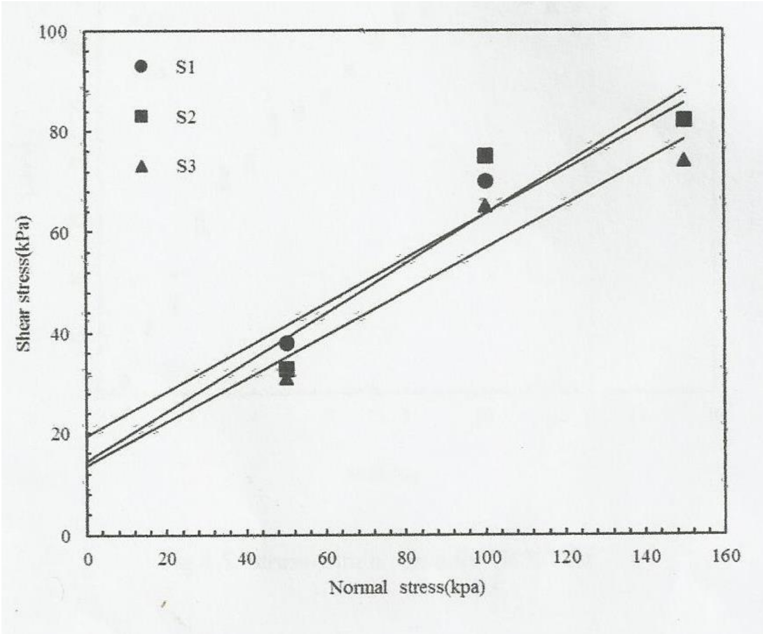


Fig. 1. Mohr column failure envelope for dredged soil.

*Unconfined compression test*

In some cases, as for checking the short-term stability of foundations and slopes where the rate of loading is fast but drainage is very slow, one of the most common methods is the unconfined compression test. Unconfined compression strength test is the simplest and quickest test for determining the shear strength of cohesive soils. The variation of unconfined compression shear strength for dredged soil collected from three locations along flood channel is shown in fig. 2.

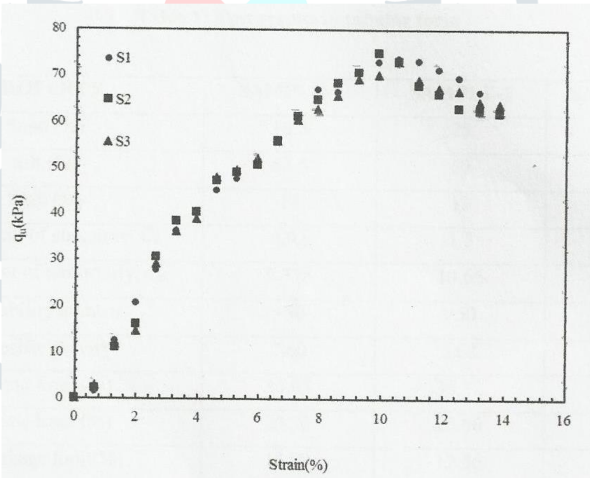


Fig. 2. Stress-strain curve for UCS Test

## *Plate Load Test*

Footing load tests were carried out on unreinforced and reinforced (with stone column) dredged soil compacted at 0.95*MDD and OMC for sample 3 (weakest of three). These tests were carried out to study the load settlement behaviour of reinforced soil with different area replacement ratio and length to diameter ratio.

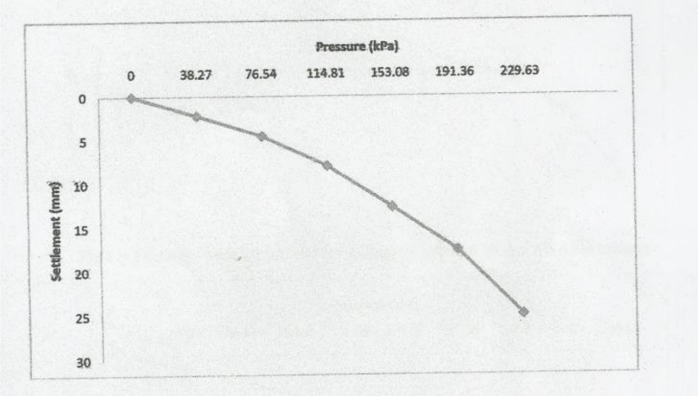


Fig.3. Model test plate results on unreinforced soil

## *Results of stone column reinforced soil with different area ratios*

Model tests were conducted on dredged soil reinforced with stone column with different area replacement ratios. Results of those tests are shown in the graphs and are summarized in Table 2.

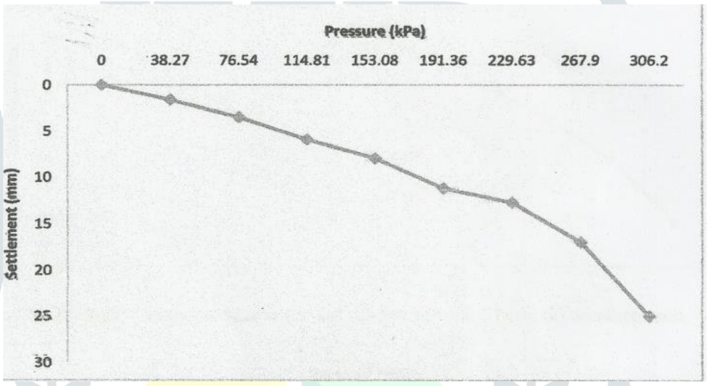


Fig.4. Pressure- settlement curve for soil reinforced with 40mm dia stone column

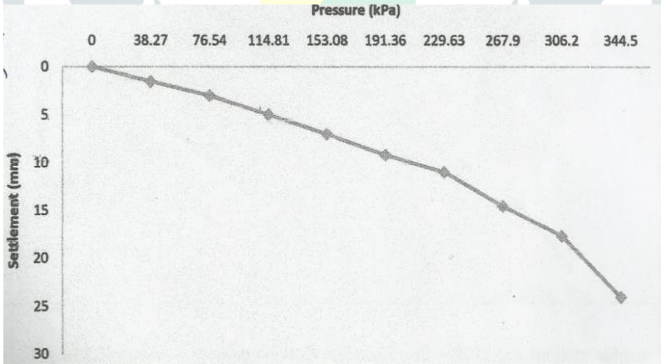


Fig.5. Pressure- settlement curve for soil reinforced with 50mm dia stone column

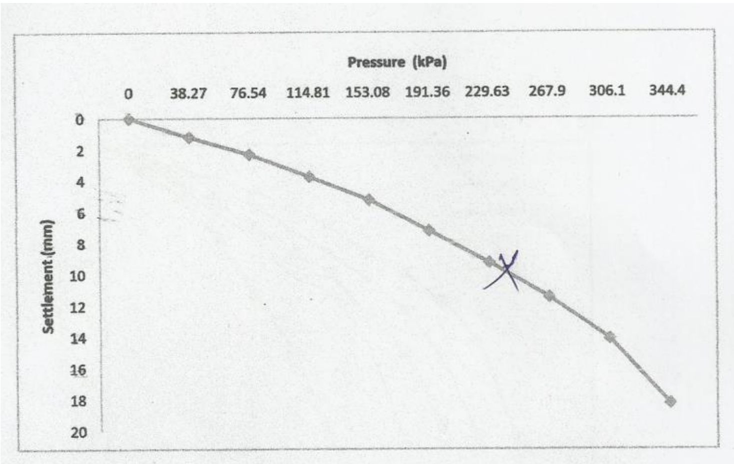


Fig.6. Pressure- settlement curve for soil reinforced with 65 mm dia stone column

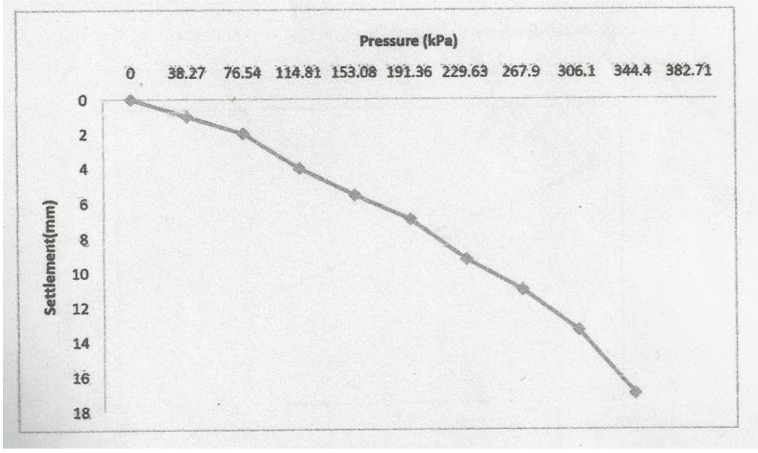


Fig.7. Pressure- settlement curve for soil reinforced with 75mm dia stone column

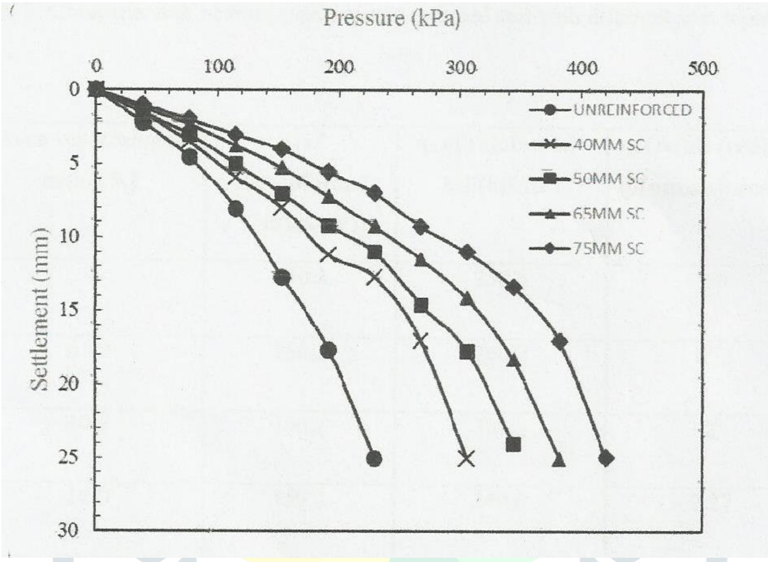


Fig.8. Comparison of pressure- settlement curves for different area ratio

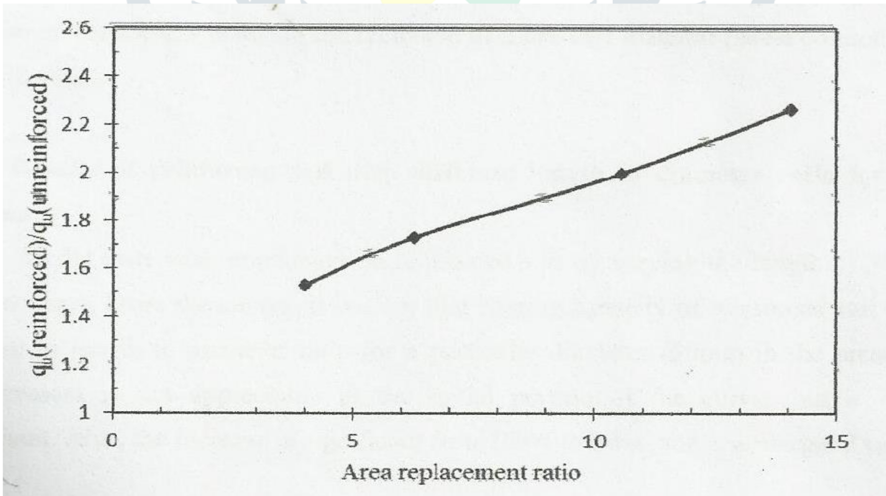


Fig. 9. Bearing capacity improvement ratio vs area replacement ratio

| Area replacement ratio(%) | $Q_u$ of unreinforced soil(KN/m$^2$) | $Q_u$ of reinforced soil(KN/m$^2$) | $Q_u$(reinforced)/$Q_u$(umreinforced) |
|---|---|---|---|
| 4.1 | 150.2 | 230.5 | 1.42 |
| 6.12 | 150.2 | 256.4 | 1.68 |
| 9.34 | 150.2 | 301.4 | 1.9 |
| 13.2 | 150.2 | 340.6 | 2.15 |

Table 2: Comparison of bearing capacity of reinforced soil with different area replacement ratio

From the above curves and table, it is clear that bearing capacity of reinforced soil increases with increase in area replacement ratio. In addition to the increase in bearing capacity, the stiffness of soil also increases, this is due to the inclusion of more stiff material (stone column ) in a less stiff material (soil).

## *Results of reinforced soil with different length to diameter ratio for 50mm stone column*

Model tests were conducted on reinforced soil by varying the length of 50mm diameter stone column. From the curves, it is clear that bearing capacity of reinforced soil increases with increase in length to diameter ratio for a particular diameter (50mm in the present case). The improvement is not appreciable in the initial portion of the curves but it increases with settlement. Also, the increase in significant from l/d=4 to l/d=6 and it is marginal beyond 6.

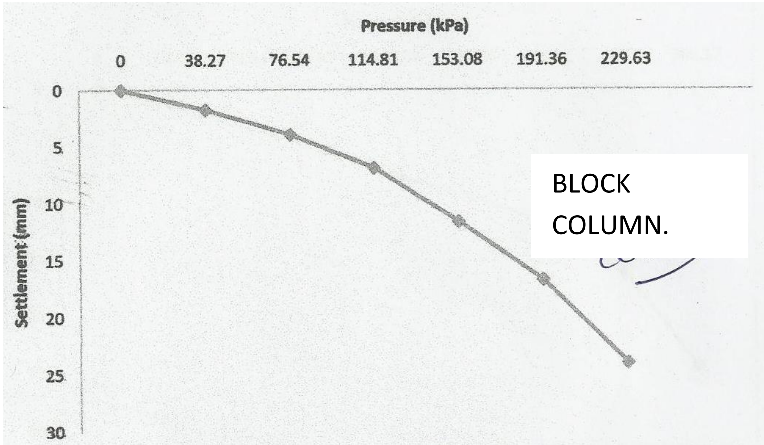


Fig. 10: Pressure-settlement curve for floating stone column of L/D=2

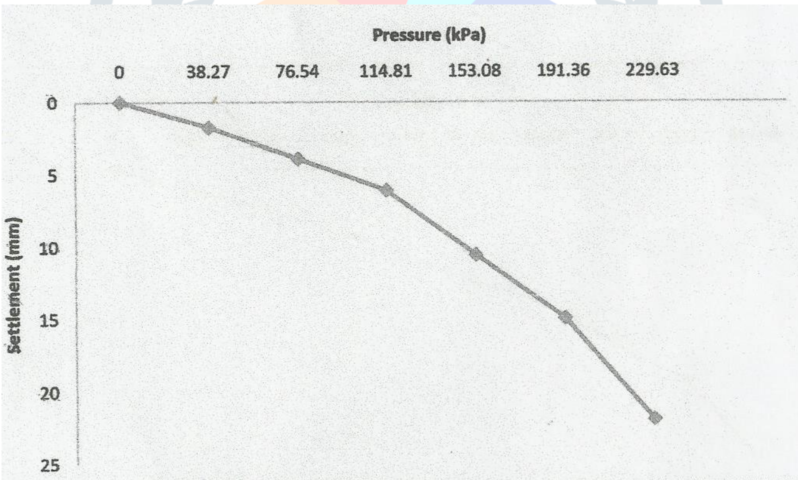


Fig. 11.: Pressure- settlement curve for floating stone column of L/D =4

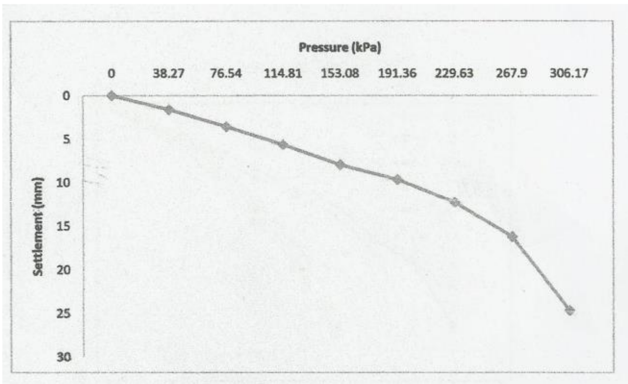


Fig. 12.: Pressure- settlement curve for floating stone column of L/D=6

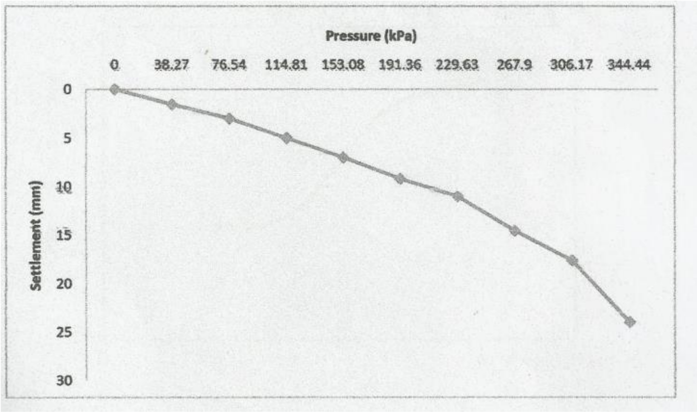


Fig. 13.: Pressure- settlement curve for floating stone column of L/D =8

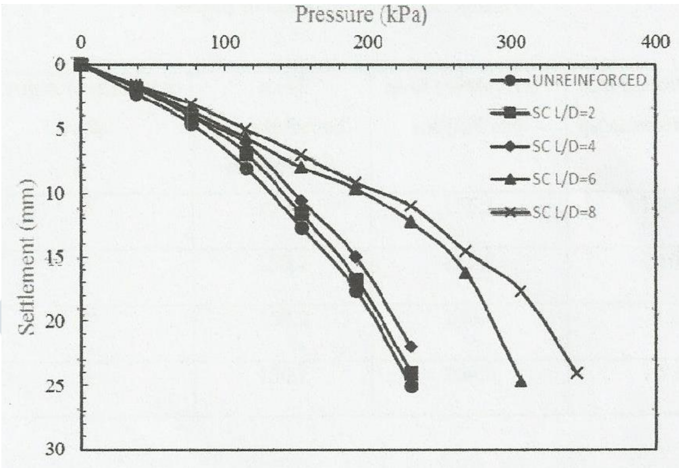


Fig. 14: Comparison of pressure- settlement curves for different L/D ratio

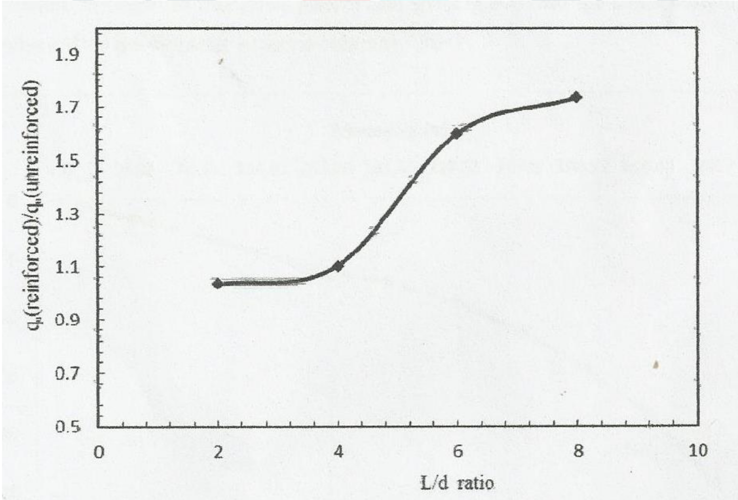


Fig 15.: Bearing capacity improvement ratio vs L/D ratio

| Length to diameter ratio | $Q_u$ of unreinforced soil ($KN/m^2$) | $Q_u$ of reinforced soil ($KN/m^2$) | $Q_u$(reinforced)/$Q_u$(unreinforced) |
|---|---|---|---|
| 2 | 150.2 | 155.5 | 1.035 |
| 4 | 150.2 | 165.3 | 1.101 |
| 6 | 150.2 | 240.4 | 1.6 |
| 8 | 150.2 | 260.6 | 1.735 |

Table 3: Comparison of bearing capacity of stone column reinforced soil with different length to diameter ratio for 50mm SC

## *Result of soil reinforced with stone columns of 50mm diameter in triangular pattern*

Model tests were conducted on soil reinforced with stone columns in group. The stone columns were arranged in triangular pattern and spacing between the stone column is restricted to 2d (where ‘d’ is the diameter of stone column).

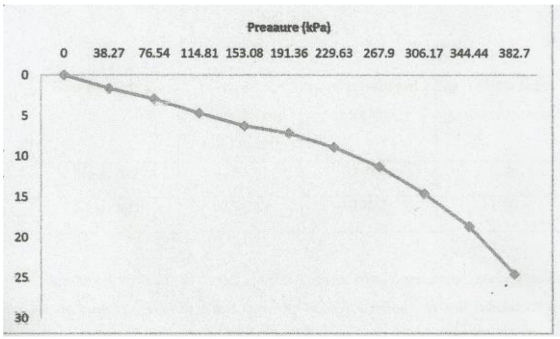


Fig. 16: Pressure- Settlement curve for stone column in group

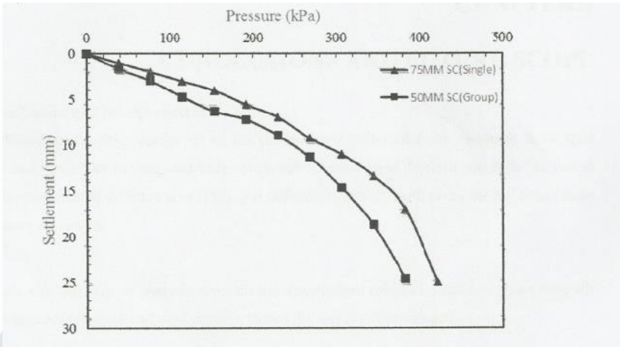


Fig 17: Comparison of pressure-settlement curves for single and SC in group.

| Diameter(mm) | $Q_u$ of unreinforced soil($KN/m^2$) | $Q_u$ of reinforced soil($KN/m^2$) | $Q_u$ (reinforced)/$Q_u$(unreinforced) |
|---|---|---|---|
| 75(single) | 150.2 | 340.8 | 2.26 |
| 50(group) | 150.2 | 290.2 | 1.93 |

Table 4: Comparison of bearing capacity of reinforced soil with single SC and SC in group

From the curves and table, it is clear that the bearing capacity of dredged soil reinforced with stone column in group is lower than the bearing capacity of soil reinforced with single 75mm stone column , even though the latter has more area ratio. This can be due to the less confinement at the periphery in case of stone columns in group.

# CONCLUSIONS AND FUTURE SCOPE

1. Pressure-settlement studies show that there is improvement in stiffness as well as in bearing capacity of composite soil with increase in area replacement ratio. This increase is due to the fact that dredged soil(less stiff) is replaced by stiffer stone column. It also shows that the improvement increases with increase in area replacement ratio, as more and more area occupied by soil is replaced in case of larger area ratios.
2. Pressure-settlement studies also reveal that there is improvement in bearing capacity with increase in 1/d ratio. However the increase is significant from 1/d=4 to 1/d=6 and it is marginal from 1/d=6 to 1/d=8. This study has been done on stone column of 50mm diameter. The significant increase in bearing capacity from 1/d=4 to 1d=6 can be attributed to the change in failure mechanism from punching (in case of smaller length columns) to bulging failure. In addition to this, there is small increase from 1/d=6 to 1/d=8 as lesser load is transmitted to deeper layers in case of bulging failure. However there is significant reduction in settlement in case of columns of larger length.
3. Pressure-settlement studies also reveal that the bearing capacity of stone columns in group (3 in no. and 50mm dia. each) arranged in triangular pattern is less compared to the bearing capacity of single stone column (75mm in dia.) although stone columns in group have greater area replacement ratio. This may be due to the fact that in case of group the stone columns are installed near to the periphery of the footing, as a result of which there is less confinement to the stone column which ultimately results in reduction of load carrying capacity.

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