REINFORCED STONE COLUMN: REMEDIAL OF ORDINARY STONE COLUMN

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ABSTRACT

Ordinary stone column is one of the ground improvement techniques for deep soil strata in view of their proven performance, short time schedule, durability, constructability and low costs. The technique may not be suitable for soft soil having undrained shear strength less than or equal 15 kPa due to excessive bulging, and also the soft clay squeezed into the voids of the aggregate. In these situations, the strength and stiffness of the stone column can be enhanced by encasing the individual stone column with a suitable geosynthetic. This contribution, reports on small scale model tests for short time loading condition on column foundation, with special analysis of the bearing and deformation behaviour of geotextile-coated sand column under static loading. Numerical analysis for long time loading condition (Embankment loading) is also analysed.

KEYWORDS: *Ground improvement, ordinary stone column, reinforced stone column.*

I. INTRODUCTION

Various deep soil stabilization methods commonly employed in the field are; stone columns [5];[6], vacuum pre-consolidation [7], soil cement columns [18], and lime treatment [17].
Among all these methods, the stone column technique is preferred because it gives the advantage of reduced settlements and accelerated consolidation settlements due to reduction in flow path lengths. Another major advantage with this technique is the simplicity of its construction method [13]. The stone column derives its axial capacity from the passive earth pressure developed due to the bulging effect of the column and increased resistance to lateral deformation under superimposed surcharge load.
When the stone columns are installed in very soft clays, they may not derive significant load capacity owing to low lateral confinement. McKenna et al. [12] reported cases where the stone column was not restrained by the surrounding soft clay, which led to excessive bulging, and also the soft clay squeezed into the voids of the aggregate. The squeezing of clay into the stone aggregate ultimately reduces the bearing capacity of stone column. Also the lower undrained cohesion value demand more stone column material.
It is very important to have appropriate prediction of undrained shear strength as it is having more influence on the design of stone column. Figure 1 & 2 depicts the effect of undrained shear strength of soft soil and angle of internal friction of stone column material on load carrying capacity of stone column calculate by the guideline of IS 15284 [8]. Figure 1 depicts the influence of undrained shear strength on load carrying capacity of stone column. For a given settlement = 200 mm, if the undrained shear strength decrease from 40 kN/m^2 to 15 kN/m^2, there will be a 63 % reduction in load carrying capacity occur. Influence of angle of internal friction of stone column on load carrying capacity can be seen form Figure 2. Normally the value of angle of internal friction of stone column range from 35° to 50° practically. For a settlement = 200 mm, if angle of internal friction of stone column increases from 35° to 45°, then increase in load carrying capacity will be about 50 %.

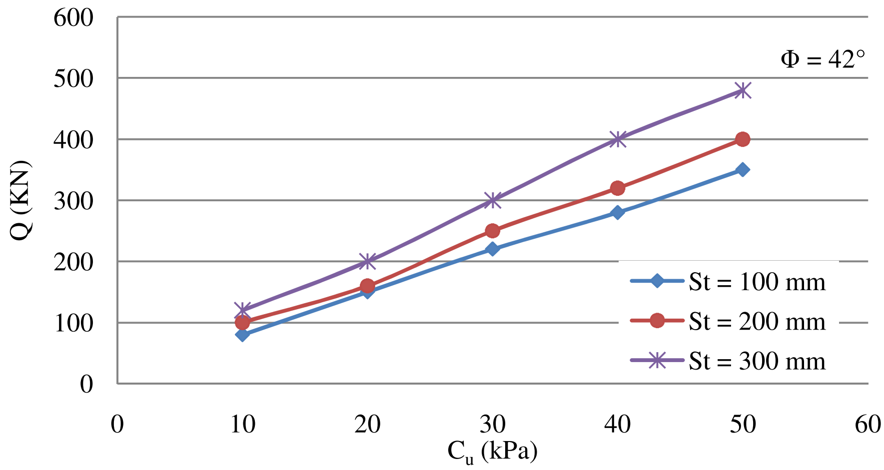

Figure 1. Undrained shear strength v/s load carrying capacity of ordinary stone column

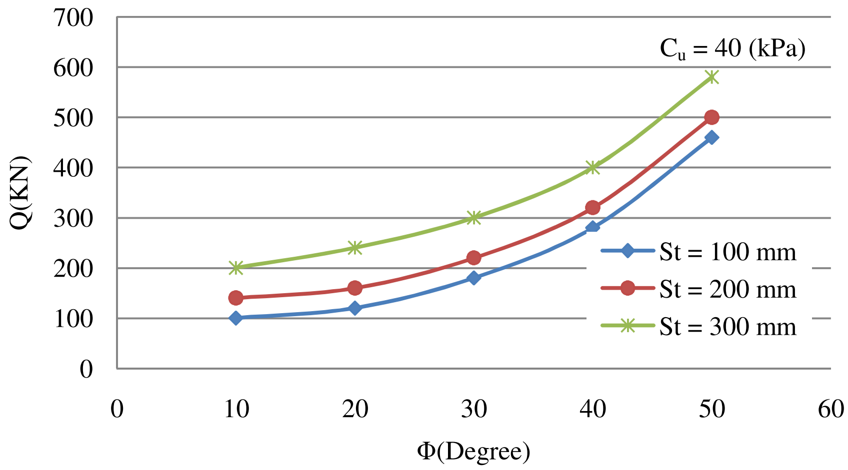

Figure 2. Angle of internal friction of stone column v/s load capacity of stone column

All traditional design of the stone column considers the undrained shear strength value $C_u \geq 15$ kN/m^2(Figure 3-5). So, the soil having undrained shear strength value less than 15 kN/m^2, demand the new development technique. This problem can be solved by confining the compacted sand or gravel column in a high-modulus geosynthetic encasement [1]. Typical geosynthetic wrapping is shown in the Figure 6.

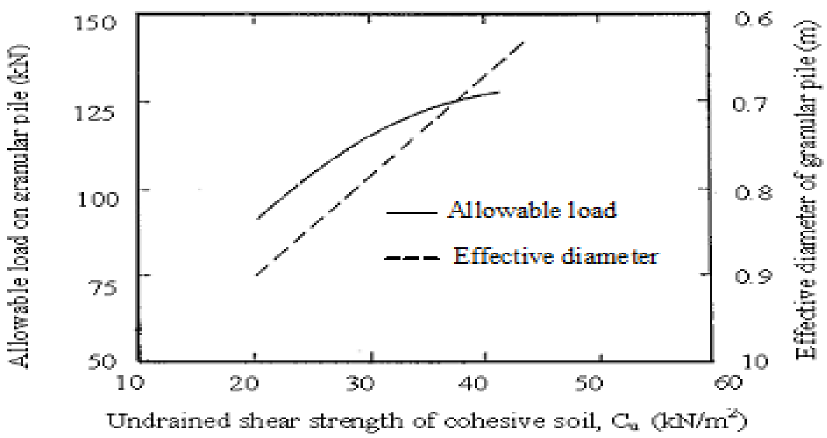

Figure 3. Relation between undrained shear strength of cohesive soil at point of maximum radial resistance and allowable working load on granular pile [19]

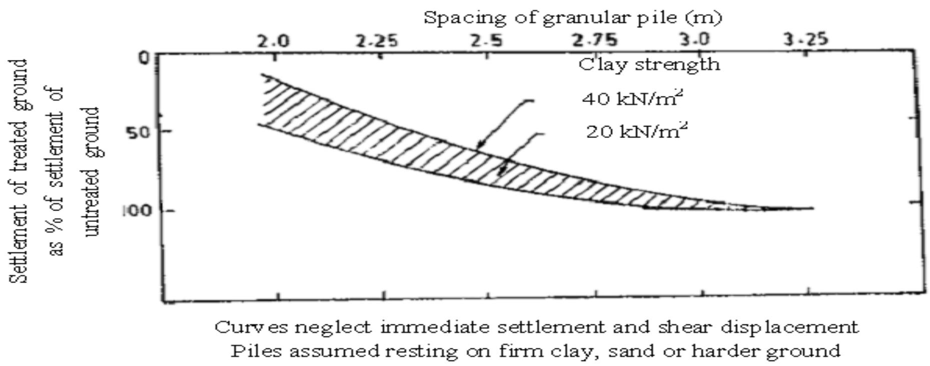

Figure 5. Spacing of granular pile and settlement of treated ground in uniform soft clay [5]

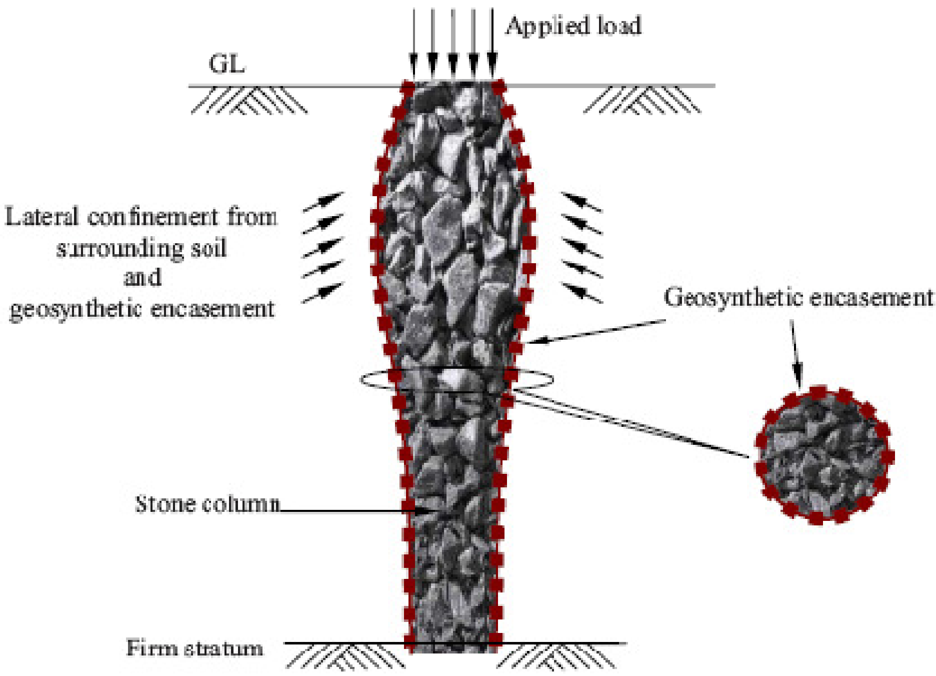

Figure 6. Schematic of geosynthetic encased stone column [15]

Van Impe and Silence [20] were probably the first to recognize that columns could be encased by geotextile. They produced an analytical design technique that was used to assess the required geotextile tensile strength. In the 1990s, a seamless geotextile sock was developed for column encasement. Columns were generally installed using a displacement technique. Earlier, details on this technique were provided by Kempfert et al. [9]. Later, Raithel et al. [16] produced an analytical design technique for assessing column settlement based on geotextile stiffness. An update, including use on recent projects in Europe, was provided by Alexiew et al. [1] and in South America by de Mello et al. [3]. Wu and Hong [21] reported an analytical method that investigated the stress–strain relation of granular columns reinforced with horizontal disks or external encapsulation. Murugesan and Rajagopal [13]; [14] performed model tests and numerical analyses to study the behavior of a single geosynthetic-encased stone column with a limited zone of soil influence (a tributary area approach to column group behavior). Khabbazian et al. [11] carried out 3D finite element analyses to simulate the behavior of a single geosynthetic-encased stone column in a soft clay soil using the computer program ABAQUS. The influence of geosynthetic stiffness, column diameter, and the stiffness and friction angle of the column material were studied in the numerical analyses. Gniel and Bouazza [4] developed the method for the encasement construction. The technique comprises overlapping the geogrid encasement by a nominal amount and relying on interlock between the stone aggregate and section of overlap to provide a level of fixity similar to welding. Laboratory model tests

were carried out on single encapsulated sand column for collapsible soil by Ayadat and Hanna [2]. The axial stress-strain relations of embedded granular columns encapsulated with flexible reinforcement were evaluated using an analytical procedure based on the cavity expansion method by Wu et al. [22]. Equivalent shear strength parameters for composite column were evaluated by Malarvizhi and Ilamparuthi [11] based on triaxial tests.
Most of the previous studies have focused on the effect of geosynthetic encasement on the capacity of a stone column under a short-term column loading condition. Studies comprising long-term embankment loading applications are rarely undertaken. In this research work described the laboratory model tests on sand column for different area replacement ratio. Three dimensional numerical analysis is also being performed for the embankment loading considering different parameters.

II. LABORATORY MODEL TESTING

Experiments were carried out on 50, 75 & 100 mm diameter sand columns surrounded by soft clay in cylindrical tank of 450 mm high and a diameter 260 mm to represent the required unit cell area of soft clay around each column assuming triangular pattern of installation of columns. Tests with column area alone loaded were used to find the limiting axial stress.

2.1. Properties of Clay, Sand Column and Geotextile

Clay of low to medium plasticity was collected from the Vesu village area of Surat city in India for forming the soft clay bed. The index properties tests showed that the fine contents are 80% out of which clay is 30%. The liquid limit and plasticity index are 49% and 29% respectively. This soil is classified as clay of low to medium plasticity (CL) as per unified soil classification system. The undrained shear strength of clay obtained from vane shear test was 8 kN/m^2 at 38% water content. The bulk unit weight at 38% water content was 18 kN/m^3. River sand of size less than 4.75 mm was used for the sand column. The angle of internal friction and the Poisson's ratio reported are 32° and 0.30 respectively. Three different types of geosynthetic used in the study having initial modulus 7.50, 12.70 & 48 kN/m.

2.2. Influence of Stiffness of Geosynthetic Reinforcement

The vertical stress corresponding to 30 mm settlement in the sand column reinforced in various geosynthetics is plotted against the modulus of the geosynthetic in Figure 7. From the figure it can be seen that the increase in the modulus of the geosynthetic results in an increase of the vertical stress on the column. The hoop stresses in the geosynthetic lead to an increase in the confining stress in the sand columns. Hence geosynthetics with a higher modulus will induce larger confining stress, leading to a stiffer and stronger response of the sand columns.

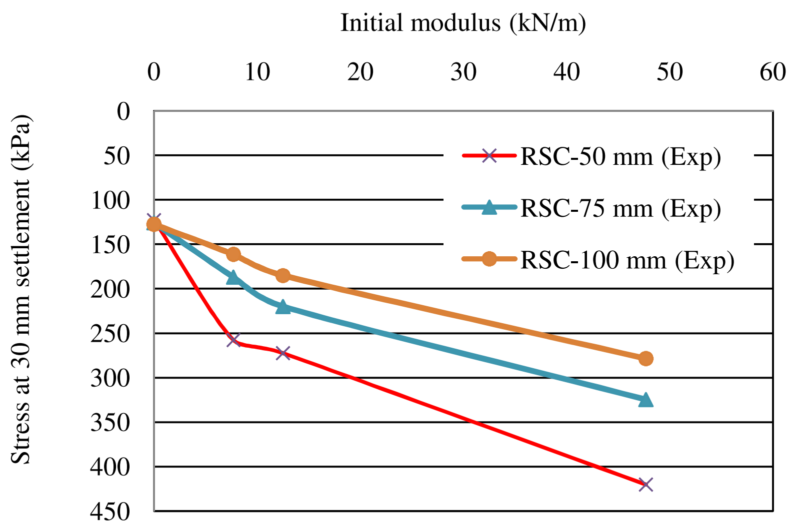

Figure 7. Influence of modulus of encasement on performance of reinforced sand column

2.3. Influence of Diameter of Sand Column

It can be seen in Figure 8, the reinforced sand columns (RSC) have developed much higher stress than the ordinary sand columns. The stress developed in the RSC decreased with an increase in the diameter of the column. Similar observation was made by Murugesan and Rajagopal [15] in their study.

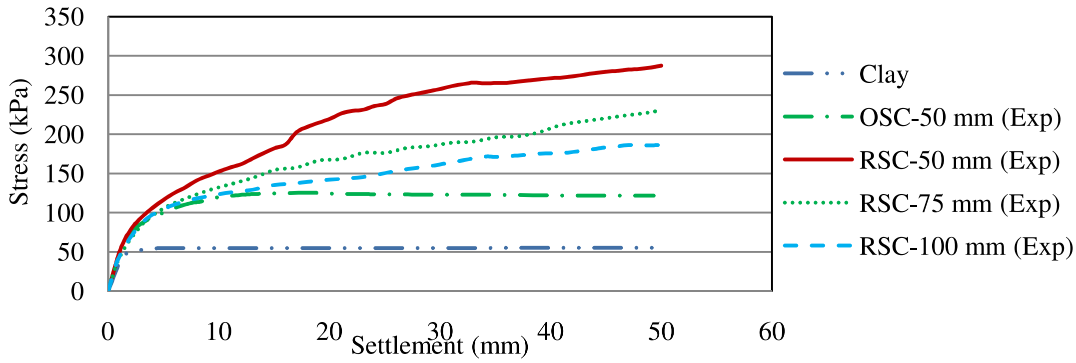

Figure 8. Stress-settlement response of sand columns reinforced with soft grid

2.4. Bulging of Sand Column

Reduction in maximum lateral bulging (occurring near the top portion) due to the reinforcement of various stiffness values is illustrated in Figure 9 for sand columns of 50 and 75 mm diameters. It can be concluded that the maximum bulge diameter of sand column reduces with the application of reinforcement.

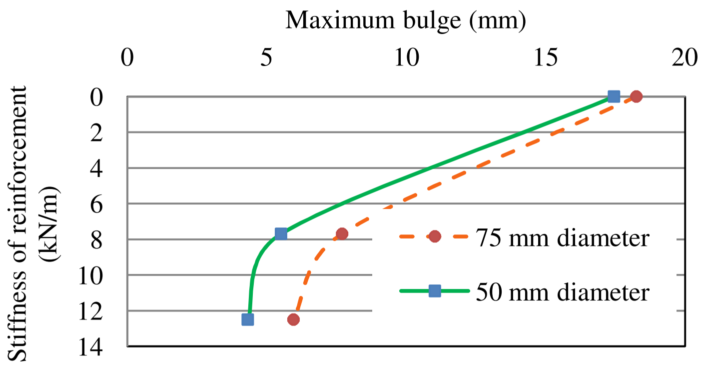

Figure 9. Influence of reinforcement stiffness on maximum lateral bulging

III. NUMERICAL ANALYSIS OF EMBANKMENT

Three dimensional (Figure 10) numerical analysis was performed considering the effect of various parameters like modulus of the soft soil, modulus & spacing of columns, geosynthetic encasement length & stiffness, and average construction rate on maximum settlement on the embankment crest (S_{max}).

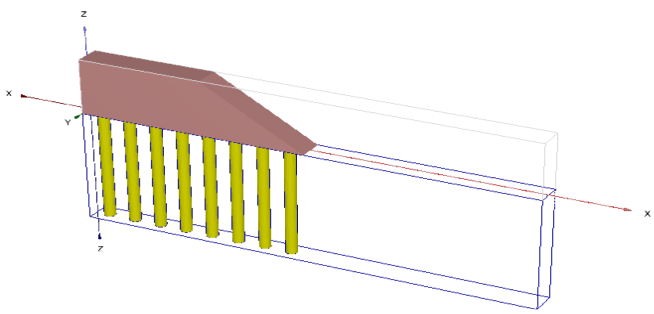

Figure 10. Three dimensional model of the embankment supported by reinforced stone column

3.1. Effect of Geosynthetic Tensile Stiffness

Geosynthetic tensile stiffness, J, is an important material property of the geosynthetic. Depending on the type of the geosynthetic used, the tensile stiffness can vary significantly. In this study, the tensile stiffness varied from 1000 to 12,000 kN/m. Figure 11 presents the maximum post-construction settlement. An increase of the tensile stiffness led to a decrease of the maximum post-construction settlement. It was observed that as tensile stiffness increase from 1000 to 6000 kN/m, about 25% reduction in maximum settlement occurred.

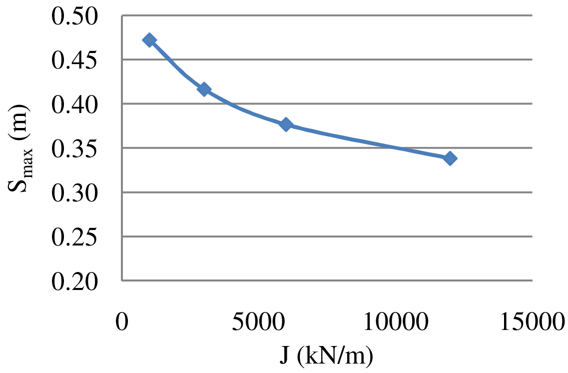

Figure 11. Maximum settlement versus tensile stiffness

3.2. Effect of Soft Soil Elastic Modulus (E_S)

Soft soil is characterized as high compressibility, which is quantified by an elastic modulus in this study. The maximum settlement on the crest of the embankment is presented at different elastic moduli of the soft soil in Figure 12. It can be seen that an increase of the soft soil modulus reduced the maximum settlement on the crest. The degree of the reduction in the settlement gradually decreased as the modulus of the soft soil increased.

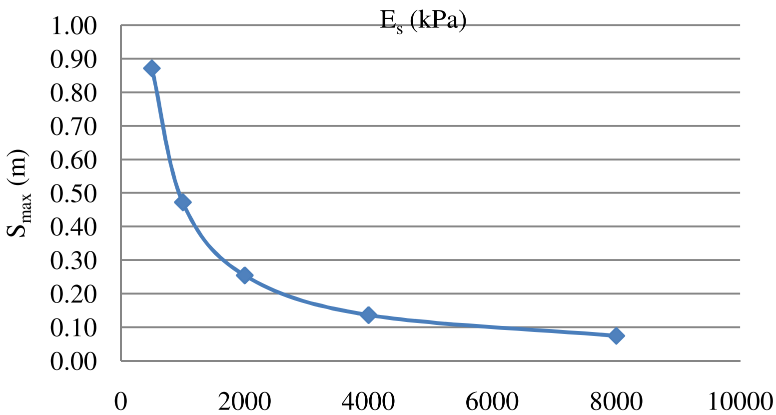

Figure 12. Maximum settlement versus soil modulus

3.3. Effect of Column Elastic Modulus (E_C)

The effect of the elastic modulus of the columns on the maximum settlement is presented in Figure 13. It shows that within the variation range of the column modulus, the column modulus had a limited influence on the maximum post-construction settlement. An increase of the column modulus from 35000 to 45000 kPa only led to less than 4 mm reduction in the maximum settlement. The major reason for this phenomenon may be because the columns were stiff enough as compared with the soft soil and the stable soil arching was formed. The high modulus ratio made the columns behave as rigid supports with respect to the soft soil.

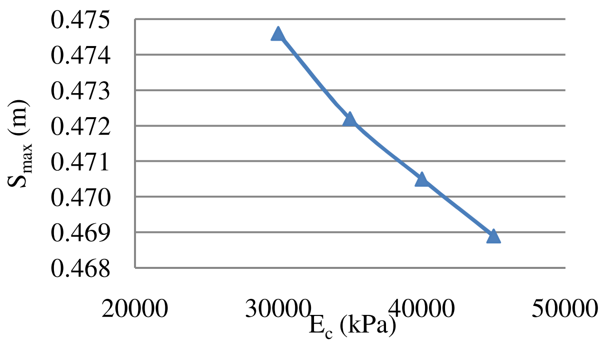

Figure 13. Maximum settlement versus column modulus

3.4. Effect of Column Spacing

Column spacing is another important design parameter. Once the column size is determined, the column spacing is directly related to the area replacement ratio of the columns (e.g., larger spacing of columns leads to a smaller area replacement ratio). Figure 14 show that the column spacing had a significant influence on the maximum post-construction settlement. The maximum post-construction settlement was almost doubled as the column spacing increased from 1.5 to 2.5 m.

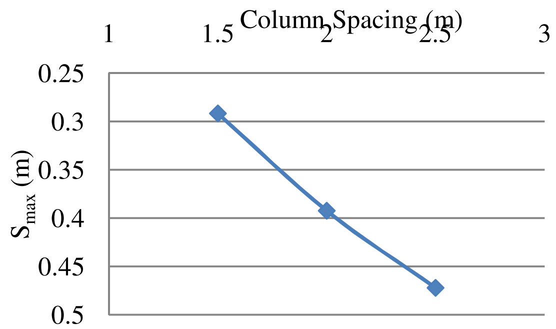

Figure 14. Maximum settlement versus column spacing

3.5. Effect of Construction Rate (CR)

In addition to material properties, column arrangement & geometry, construction can have a significant influence on the performance of the embankments. One of the most important construction parameters, the average construction rate, was investigated herein. The average construction rate was defined as the thickness of the lift built within a unit time. In the baseline case, the average construction rate was 1 m/month. The average construction rate was increased to two times (i.e., 2 m/month) & four times (i.e., 4 m/month) to represent fast construction. The influence of the average construction rate on the maximum post-construction settlement is presented in Figure 15, which show that the higher construction rate induced the larger maximum post-construction settlement. The lower average construction rate allowed more time for the dissipation of excess pore water pressure.

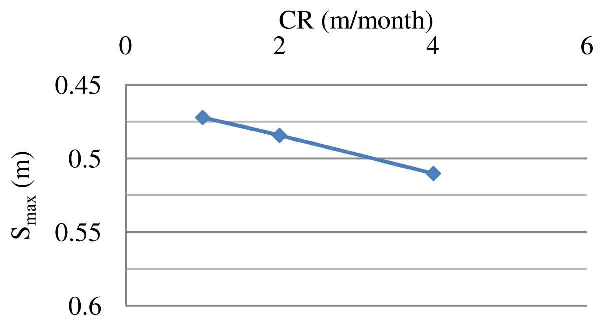

Figure 15. Maximum settlement versus average construction rate

IV. CONCLUSIONS

Following conclusions are drawn from the experimental and numerical analysis of reinforced stone column.

(1) The load capacity of the sand column can be increased by all-round reinforcement by geosynthetic. By geosynthetic reinforcement, it is found that the sand columns are confined and the lateral bulging is minimised.

(2) The elastic modulus of the geosynthetic reinforcement plays an important role in enhancing the load carrying capacity of the reinforced columns. The confining pressures generated in the sand columns are higher for stiffer reinforcements.

(3) The performance of reinforced sand columns of smaller diameters is superior to that of larger diameter sand columns because of mobilisation of higher confining stresses in smaller sand column. The higher confining stresses in the column leads to higher stiffness of smaller diameter reinforced columns.

(4) The geosynthetic reinforcement of the stone column decreases the embankment load transferred to the clay layer, thus decreasing the excess pore-water pressure generation. The overall effect of reinforcement is to reduce the settlement of the soft ground.

(5) In addition to the material properties and the column arrangement and geometry, the construction rate has a significant influence on the reinforced stone column supported embankment and should be considered in the design of the reinforced stone column embankment.

(6) The elastic modulus of the soft soil and the spacing of columns are the two most important design parameters for the performance (except the consolidation) of the reinforced stone column embankment.

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