Optimization of Stone Column Made by Waste Material of Local Available Stone in Rajasthan to Help the Sustainable Development: An Numerical Study

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Optimization of Stone Column Made by Waste Material of Local Available Stone in Rajasthan to Help the Sustainable Development: An Numerical Study

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Abstract: An unreinforced sand bed and a geogrid-reinforced sand bed were both set over a group of floating stone columns in soft clay, and the results of a variety of computer models were compared and contrasted with the findings of an experiment. 3D-FEA simulations were carried out with the mechanical structural simulation software Ansys APDL (Version 18.2) for the goal of modeling the stone column structures made in soft clay/snad with or without support structure. This was done to get the desired result. When geogrid is submitted to a finite-element analysis, it is analyzed as though it were made of an elasto-plastic material. Because it was gathered from the immediate vicinity in Rajasthan, the stone that ended up being used for the simulation was considered to be an unnecessary byproduct of the production process. The choice to use the waste materials as column material for the stone was motivated by the desire to increase the level of sustainability achieved by the project. Both an unreinforced sand bed (USB) and a geogrid-reinforced sand bed (GRSB) may be thought of as having a critical thickness that was calculated using FEA simulation results and it was 20% to 30% of the footing diameter of the stone bed. When in present study thickness is increased beyond this point, there is only a marginal increase in the bearing capacity. In present study the settlement of the stone column was also studied and the proper analysis was performed to find the effect of the settlement on the stone column structure during facing the maximum load conditions. The role of the diameter of the stone column paly crucial role was concluded by the FEA study set for the present study. This yields the value for the ideal length of the group. When compared to the plastic strain that occurs in the geogrid planar sheet, the plastic strain that takes place in the material that makes up the stone column is far higher.

Keywords: FEA, Sustainable development, Stone Column, Waste material, geo grid textile

1. Introduction

Buildings that are built on soft geology face the danger of encountering problems such as excessive settlement, significant lateral displacement of the soft layer that lies underneath the structures, as well as global or local instability. These problems can be caused by a number of factors. These problems might perhaps originate from the soft stratum. It may be possible to resolve these concerns by doing ground improvement with an emphasis on the granular column method. Both the quantity of total settlement that takes place during loading and the time it takes to complete the consolidation process will be reduced as a result of this. Because the columns are there, a composite material is formed as a result. This material is more rigid than the original soil, and it receives its load capacity as a result of the confinement provided by the dirt that is all around it. It is possible for the capacity of granular columns to be drastically decreased if insufficient lateral confinement is present when the columns are placed in exceptionally soft clay, particularly in the top region of the columns. This is because the capacity of the columns is directly proportional to the amount of lateral confinement that is present[1-3)].

Stone columns have the potential to increase the shear strength of soft clays that fall somewhere in the range of 7 to 50 kPa when they are erected in compliance with the specifications of IS 15284 Part I (BIS 2003). Over the course of the last three decades, several researchers working in the field of academics have carried out a wide range of studies in order to acquire a better knowledge of the performance characteristics of stone column-improved ground[4-7)].

When it comes to boosting the strength and stability of geotechnical structures, geosynthetics are, for the most part, the materials of option to use. One of the most efficient strategies for boosting the strength attributes of softer soils is to strengthen the soil itself through soil reinforcement. When it comes to boosting the inherent tensile and compressive strengths of hard soils, one of the most effective approaches that is now at one's disposal is to reinforce the soil. One of the most efficient ways to improve the performance of columns in extremely soft soil foundations, or even to make their application practicable at all in very soft soils, is to encase granular columns in the appropriate geo-synthetic material. This is one of the most effective ways to improve the performance of columns. To increase the performance of columns in exceptionally soft soil foundations, this is one of the most effective strategies to improve column performance. The performance of columns may be improved in this way, which is one of the most effective ways to improve their performance. In addition to this, encasing inhibits the lateral pushing of stones into the soil that surrounds them, which also functions in the opposite direction. This is because the soil acts as a barrier between the stones and the soil. This is due to the manner that the procedure works, which is as follows:[8-10].

If the bulging of the stone columns can be avoided, it is possible, according to certain sources, that the bearing capacity of the structure may be enhanced even more, while at the same time the settlement can be reduced even further. It is feasible to use geosynthetic sheets in a horizontal orientation in order to generate a reinforced layer in the granular columns. This may be done by placing the sheets in the appropriate direction[11-13].

In order to investigate the impact that long-term drained settlement has, Wood et al. (2000)[14] utilized a series of model experiments that were carried out on a collection of floating stone columns. The following was included in these simulations of actual experiments: In addition to carrying out discrete calculations, Shahu and Reddy (2011) [15] carried out a number of research lab tiny model studies in order to examine the numerous factors that influence the load - carrying capacity and settling of the stone columns. Their goal was to identify the factors that have the greatest impact on these two aspects of the stone columns. The objective of these studies was to explore the myriad of elements that impact the stone columns' bearing capacity as well as their rate of settlement. In addition to this, they made the observation that the outcomes of a finite-element numerical analysis may not be accurate due to problems with mesh convergence and mistakes made during the process of establishing constitutive model parameters. The majority of the time, a sand bed cushion is placed over the stone columns in order to both establish a drainage channel and equally disperse the pressures that are being forced on the building. This helps ensure that the building remains stable. This is done in order to guarantee that the building will not lose its steadiness. (Mitchell 1981)[16].

Raithel and Kempfert (2000)[17, 29,30,31] are the ones who came up with the idea of publishing a closed-form analytical approach for calculating and building a geotextile-encased column foundation. By using this method, it was feasible to determine the stresses and deformations that were present in the encased column as well as in the soft soil. The technique that was suggested by Raithel and Kempfert (2000) is, in essence, the one that EBGEO decided to settle on as their preferred method. Because the method assumes that the soft soil and the columns would both settle to the same level, the equations that have been presented require an iterative solution in order to be solved. The computations that were done by Raithel and Kempfert (2000) were done for the long-term drained situation at the point where the maximum settlements and ring tension forces were achieved. These computations were done at the point where the maximum settlements and ring tension forces were achieved. In addition to this, it is assumed that the column will, at some point in time, arrive to a condition of active lateral pressure. If anything like this happens, the active earth pressure coefficient, also known as KAC, will be relevant. In addition to this, it is anticipated that the linear elastic properties of the geosynthetic encasement will be present. Castro and Sagaseta (2011)[18] also provided an analytical method in their contribution . This technique included the employment of a unit cell for an end-bearing column that was encased in granular material as well as the soil that surrounded it, as well as the consolidation process.

There is not a lot of data to suggest that increasing the bearing capacity of the foundation by adding planar geosynthetics to this sand layer in order to strengthen it can increase the foundation's load-carrying capacity (Abdullah and Edil 2007[19]; Deb et al. 2011[20]). The generation of two-dimensional numerical models for a thin layer and bilayer edirectory sandy substrate was accomplished through the use of a lumped parameter technique. These models were developed using numerical simulation software (Deb et al., 2007). It was stated by Arulrajah et al. (2009)[21] that a Geogrid-soil platform was used in Malaysia in place of stone columns. The vast majority of numerical calculations begin with the presumption that the geosynthetic sheet is elastic. The quantifiable data from full-size or small laboratory scale models can be reproduced quite well by 2D numerical studies, however it is advised that you perform 3D analysis instead. Elasto-plasticity, not elasticity, characterizes geosynthetic sheets. The majority of the experiments made use of stone columns that were placed on a solid stratum. Without taking into account the influence of the group. Accuracy needs finite-element analysis convergence. All of these concerns are discussed in detail in this work. The objective of present study was to develop a 3D FEA model to optimize the stone column using waste materials available in Rajasthan. Total three type of stones were simulated for the present study. Ansys FEA (Version 18.2) software was used for the present study.

2 Material and method

Sand, clay, waste stone particles gathered from the local region of Rajasthan, and geo grid sheets were used for the examination in this current work. In the investigation of stone columns, the foundation was fabricated using clay, and the blanket was fabricated using sand. For the purpose of this research, marble waste, stone waste, and granite waste were chosen as the three different types of stone waste materials to investigate. Clay parameters were defined with the use of ASTM D4318[22,23], including the liquid limit, which was set to 40-45%, the plastic limit, which was set to 20-23%, and the plasticity index, which was set to 20%. For the purpose of this investigation, the size of the soil particles was measured and regulated, and a sieve with a pore size of 75 micro meters was utilized to ensure homogeneity in the experimental bed setup.

For the purpose of this research, crushed stone aggregates derived from waste materials were chosen, and the size of the stone particles was determined according to the findings of earlier studies conducted by[20] and[24, 25]. In the research on stone columns, the researchers used a particle size range that went from 2 to 8 millimeters[20,24,25]. Stone aggregate has a coefficient of uniformity (COU) of 2.5, according to measurements taken. The sand particle size was adjusted such that it would fit through a sieve measuring 5 millimeters. The sand came from the immediate area where it was gathered. The experimental test chamber was configured to have dimensions of (1 meters by 1 meters by 1 meters), in accordance with the work of Debnath et al. (2017)[26]. The properties of the materials required for the present study was shown in table 1.

Table 1 Properties required for FEA simulation of Stone Column[27 26, 32,33]

Materials	Strength (MPa)	Poisson Ratio	Density	Angle
Sand	17.4	0.35	1444	37.1
Clay	11.0	0.47	1180	0.0
Geogrid	20.0	0.30	1900	0
Stone (Normal)	44.0	0.30	2800	0.30

3 Experiment setup

For all of the experiments, a square steel tank with dimensions of 1000 millimeters on each side and a height of 1000 millimeters was used to establish the test setup (Figure 1). In the beginning, a single layer of thick polythene sheeting was used to cover the interior walls of the test tank. This was done in order to reduce the amount of water that was lost due to friction. Throughout each and every one of the trials, the tank was coated with pliable clay at a thickness of one hundred millimeters to ensure that the volume and concentration of the water remained unchanged. When the tank had been completely stuffed with clay, a piece of plastic was laid on top of it, and it was kept in that state for a whole week[26]. Self-consolidation of the sand bed was assumed in the present study across all simulation and experiment studies.

To make the holes for each stone columns, steel pipes were used having the inner diameter equal to 48.5 mm and outer diameter equal to 50 mm and make the holes in the send bed to fill the stone particles in these holes with care and safety. After making the hole using these steel hollow pipes, the stone was filled in these columns and make experiments. Above the holes, make 50 mm send bed to make the structural analysis more accurately.

In order to get the desired outcomes, this needed to be done. It was necessary to use a helical steel auger in order to pull the dirt from inside the steel pipe, therefore that was the method that was used. This auger had a diameter that was only a hair smaller than the inside diameter of the steel pipe it was attached to. A total penetration depth of 300 mm was reached in present study using previous published literature[26]. This was accomplished by simultaneously boring with an auger.

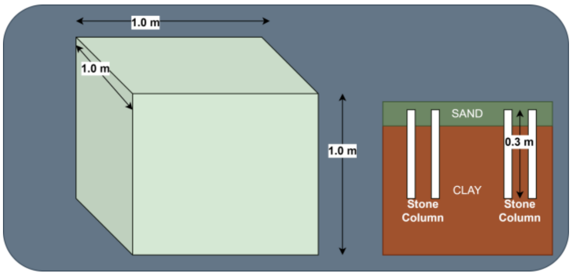


Fig.1 Experiment Setup Dimensions[26]

It was determined that the technique outlined by [24] would be the most effective way to crush the stone particles into the hole. The calculation of the necessary weight of stone, assuming a relative density of 70%, was performed using the volume of the hole as the foundation for the calculation. The weight of the stone was divided up in a six-way split before being distributed. After that, stone aggregates were placed within the pipe, and then the pipe was gently removed while making sure that there was a space of 5 millimeters so that clay would not get inside. Stone aggregates were initially compacted with a steel tamper measuring 15 millimeters in diameter, and then with a steel tamper measuring 25 millimeters after the removal process was finished. This was done in order to achieve a unit weight of 15.8 kN/m3, which is equivalent to a relative density of 70%. This procedure was carried out until the stone column reached the apex of the clay bed. Image 2 from International Standard 15284 Part I (BIS 2003) illustrates a group of 12 stone columns that were used in an inquiry on the performance of the three center columns. This feature of the group is depicted in plan view in the figure.

Following this, a layer of geogrid cut into the shape of a circle was applied to the top of the layer of sand in the center of the group of stone columns. After all was said and done, a layer of additional sand that was the appropriate thickness was spread on top of the geogrid layer. This method was carried out several times in order to get the appropriate height. The robust steel plate that served as the base had a diameter of 200 millimeters and a thickness of 16 millimeters when it was initially constructed. In each and every one of the research projects, the footing was positioned perfectly in the middle of the pile group.

4 FEA simulation

In order to conduct the research, Ansys Desing Model software was used to make the 3D CAD model and then making the mesh domain of the full 3D CAD model as shown in following figure (Figures 3), and the ANSYS 18.2 software was utilized to do an analysis of the data obtained from those models. Mohr-elasto-plastic Coulomb's failure criterion and a non-associated flow rule were utilized in order to simulate the behavior of all of the various Soils specially local Region of (Rajasthan), such as waste of stones gathered from local area, local sand, local available clay etc. This allowed the behavior of these soil materials to be represented accurately. This was done in an effort to mimic the manner in which they behaved. (Liu et al. 2007[28]) When doing a simulation of the geogrid reaction using linear elasticity, it is possible that an erroneous response would be created. This is something that has been seen. As a consequence of this, an elasto-plastic constitutive model was applied so that an explicit simulation of the behavior of the geogrid could be carried out. In order to simulate the nonlinear elasto-plastic behavior of the material while taking into account its isotropic hardening, a constitutive model has to be built. The ANSYS modeling software was used to create this representation of the system. This step was necessary in order to bring the model to life. In addition to this, the total strain was broken down into the elastic strain and the plastic strain (Hussein and Meguid 2016)[29].

In order to better explain its characteristics, the biaxial geogrid was modeled as a flat sheet for the purpose of the finite-element analysis. In order to simulate the actual response of the soil-geogrid system, the thickness of the geogrid was decreased by the same amount as the thickness of the ribs that it contained. This was done so that the simulation would be as accurate as possible. For the sake of this investigation, biaxial geogrid was represented as a planar sheet, and the thickness of the geogrid was lowered to 80 percent of what its true rib thickness would have been.

The FEA modeling steps were shown in table 2 and the grid independence test was shown in figure 3. The Stone column arrangement used for the FEA simulation was shown in figure 2.

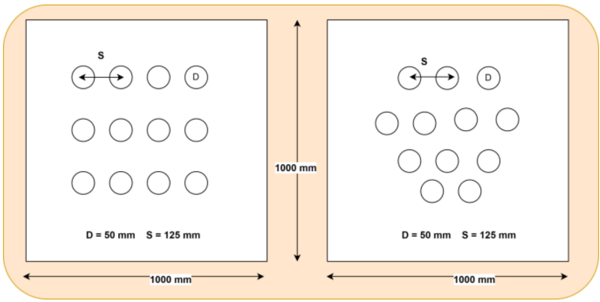


Fig.2 Arrangement of Stone Columns for the FEA simulation

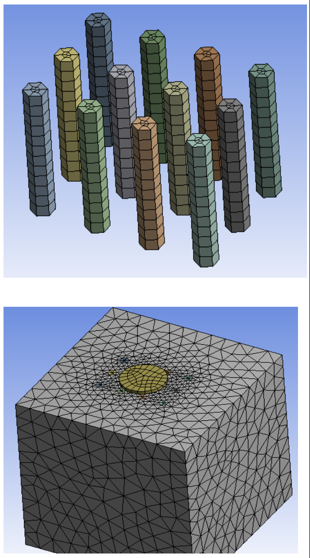
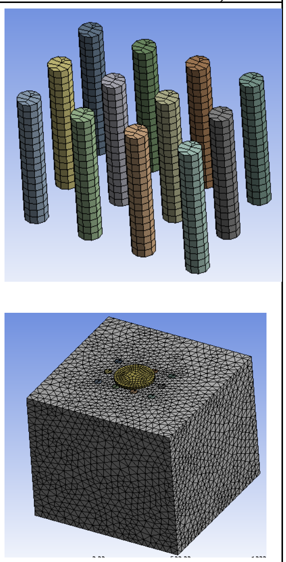
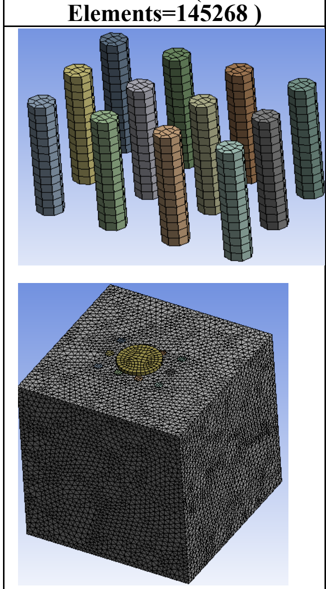
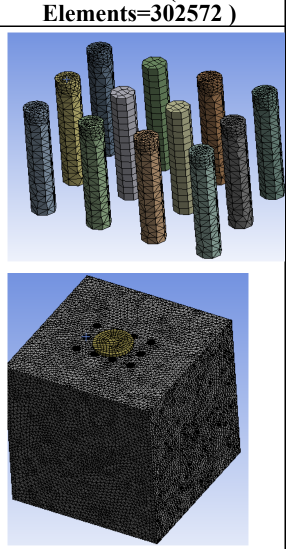
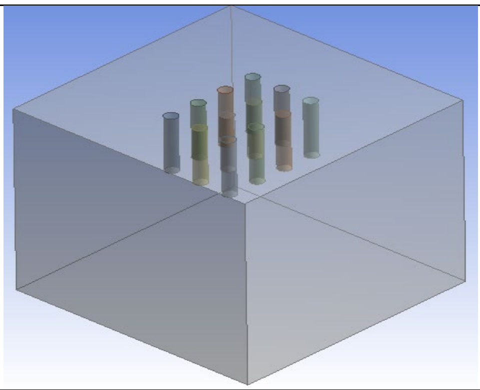
Grid Size 1 (No of Elements=33061)	Grid Size 2 (No of Elements=56206)
	
Directional Deformation =1.5 mm	Directional Deformation =2.1 mm
Grid Size 3 (No of Elements=145268)	Grid Size 4 (No of Elements=302572)
	
Directional Deformation =2.0 mm	Directional Deformation =1.97 mm

Fig.3 Grid Independence Test for Present FEA study

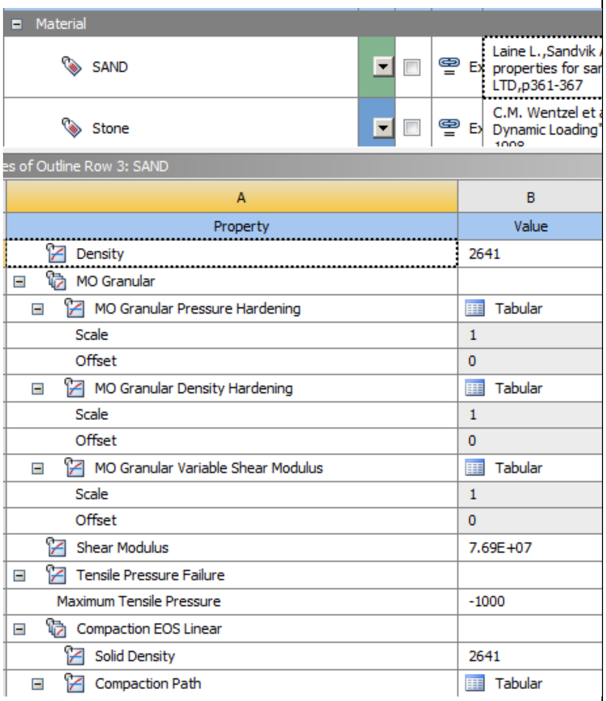
As seen in the figure 3, the grid size after 50K cells does show the steady results for deformation in the stone columns made in rectangular. The stone properties for grid independence test were set for “normal stone”. Ansys Explicit Dynamics module was used for the FEA simulation for the present study. As per requirement the grid refinement was done for z direction due to loading direction. Relevance Center method was used to refine the grid size in the present study.

Table 2 FEA modeling Steps

Step-I: CAD Model



Step-II Engineering Data

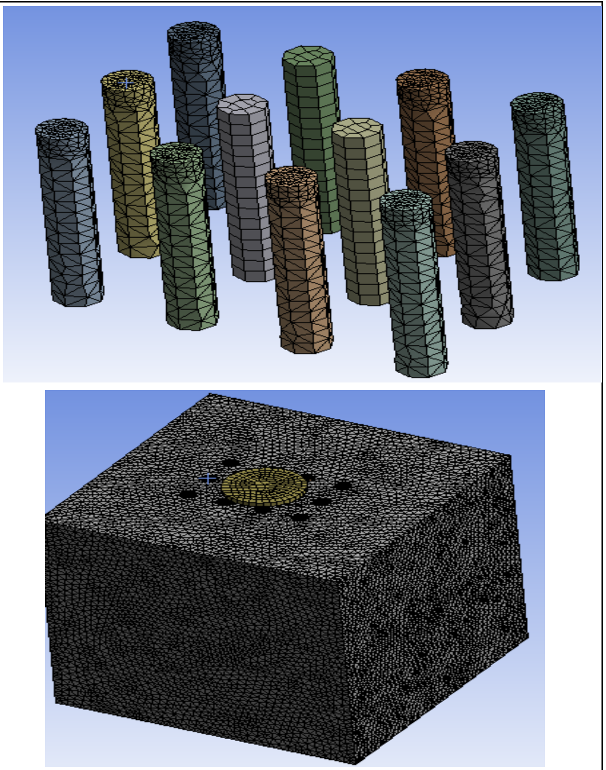


Material		
SAND		Laine L.,Sandvik / properties for sar / LTD,p361-367
Stone		C.M. Wentzel et / Dynamic Loading

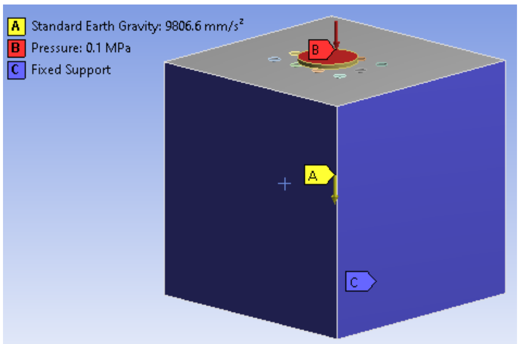
es of Outline Row 3: SAND

A	B
Property	Value
Density	2641
MO Granular	
MO Granular Pressure Hardening	Tabular
Scale	1
Offset	0
MO Granular Density Hardening	Tabular
Scale	1
Offset	0
MO Granular Variable Shear Modulus	Tabular
Scale	1
Offset	0
Shear Modulus	7.69E+07
Tensile Pressure Failure	
Maximum Tensile Pressure	-1000
Compaction EOS Linear	
Solid Density	2641
Compaction Path	Tabular

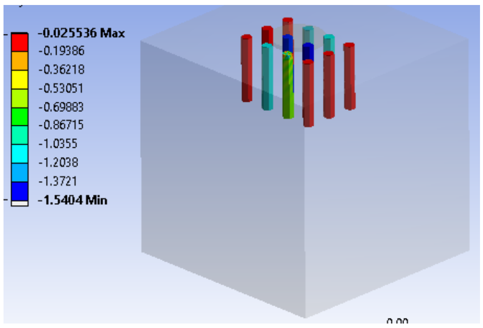
Step-III: Discritization



Step-IV: Boundary Conditions



Step-V: Results (Deformation)



5 Result and Discussion

In this study, a normal sand bed was modelled, and its results were compared to those of a geogrid-made send bed in order to determine which produced the best outcomes with stone columns. In the current study, the findings of experiments were compared with the results of

FEA simulations. The FEA analysis simulation was carried out with the help of the Ansys FEA programme. In the next part, the findings of experiments and simulations are compared with one another, albeit with some variances. 5.1 Compare the different Stone particle made SC (Stone Column) Figure 4 displays the various types of stone columns that were discussed in this section and were constructed using waste materials from the local area. For the construction of the stone columns, we made use of four distinct kinds of stone materials. The first SC-I was filled with waste from regular stone, the second SC-II was filled with waste from marble, the third SC-III was filled with waste from granite, and the fourth SC-IV was filled with a hybrid of waste from all four types of stone. According to what was discovered in this section, the hybrid SC-IV variation of stone columns showed the best settlements results when compared with other types of stone columns. The reason was very clear evidence that a hybrid made of all different types of waste stone can withstand higher pressure than regular stone columns. The results were then compare with different Geo grid application with SC-IV in figure 5.

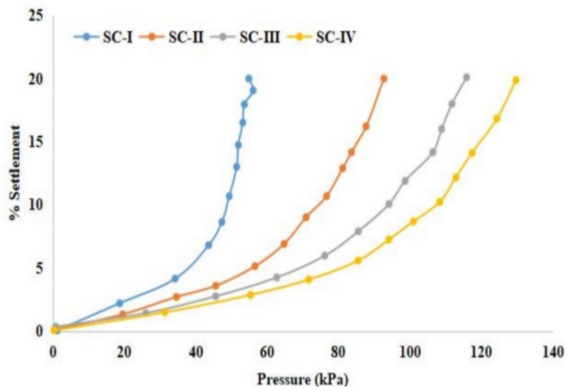


Fig.4 Impact of Pressure on Settlement for different Stone Columns

The hybrid stone column displays the finest settling for the largest pressure bearing capability, as seen in figure 4. Marble and granite stone scraps were used in the construction of the hybrid.

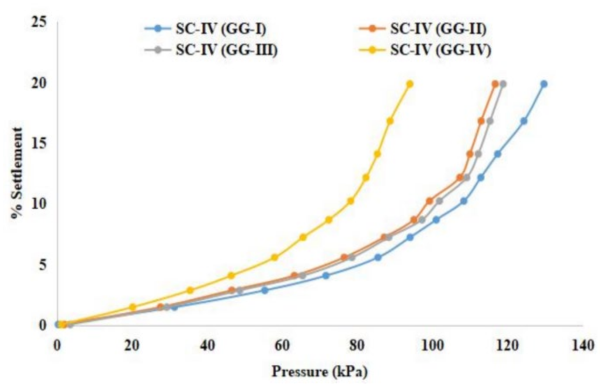


Fig.5 Impact of Geo Grid sheet thickness on Settlement for Hybrid Stone Columns

As seen in figure, the thickness of the geo grid can make the stone column more robust, as seen in the figure 5 the best geo grid stone column was shown in SC-IV with 10 mm geo grid sheet thickness (GG-I)

6 Conclusion

The purpose of this project was to construct a FEA simulation model in order to determine the optimal design of a stone column structure that was produced with local accessible materials in local send/clay. This was done in order to find the optimal design. In this particular research endeavor, the Ansys APDL solver was chosen to model the stone column. The current investigation was broken up into two distinct sections: in the first, a basic stone column was modeled to test how different kinds of stones would fit into the holes; in the second, geo grid materials were chosen to see how they would affect the bearing capacity of the stone columns. Both sections were designed to complement one another. Within the scope of this part, simulations were carried out on four distinct geo grid material types. The findings manifested themselves as a settling of the stone column form in relation to the amount of pressure that was generated on the stone columns. Only sections I and II were employed as variable parameters in this analysis; geometrical design factors were held constant throughout the course of this investigation. As can be seen in figure 4, the hybrid stone column has the most refined settling while maintaining the capacity to withstand the greatest amount of strain. Stone debris, including bits of marble and granite, were included into the hybrid's creation. Stone columns may be made more resistant by increasing the thickness of the geo grid. As can be seen in figure 5, the best geo grid stone column was presented in SC-IV with a geo grid sheet thickness of 10 millimeters (GG-I).

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