Bearing Capacity of Footings on Clays Improved by Stone Columns : A Numerical Study

CP301 Project

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INTRODUCTION

The stability and load-bearing capacity of foundations are critical factors in the design and construction of any structure, particularly when dealing with weak and compressible soil such as clays. In such instances, traditional foundation systems may not provide adequate support, leading to settlement issues and potential structural failures. To address these challenges, engineers and researchers have explored various ground improvement techniques to enhance the load-bearing capacity of soil.

One such technique gaining prominence is the use of stone columns, also known as granular piles, as a ground improvement method. Stone columns are constructed by inserting compacted stone aggregate into the soil, creating a composite foundation system that improves both the shear strength and compressibility characteristics of the ground.

This report focuses on the numerical study conducted to investigate the bearing capacity of footings on clays improved by stone columns. Through numerical analyses, this study seeks to evaluate the effectiveness of stone columns in enhancing the bearing capacity Subsequent sections of this report will explore the methodology, results, and implications of the numerical study.

<u>OBJECTIVE</u>

The objective of this study is to investigate and analyse the effect of stone columns on clayey soils using numerical simulations conducted with OPTUM G2 software. The specific goals are as follows:

1. **<u>Numerical Simulations</u>**: Utilise OPTUM G2 software to conduct numerical simulations of the soil-structure system, for finding Nc,Nq,Ny in the presence of stone columns.
2. **<u>Modelling of software Schematic Drawing</u>**: Develop detailed finite element models and analyse and record the different-different values in different conditions.
3. **<u>Shear Stress Distribution</u>**: Analysed the distribution of shear stresses within the soil mass and at the interface between the stone columns and the surrounding soil.
4. **<u>Ultimate Bearing Capacity</u>**: Determine the ultimate bearing capacity of footings on clayey soils improved by stone columns, considering factors such as soil properties.

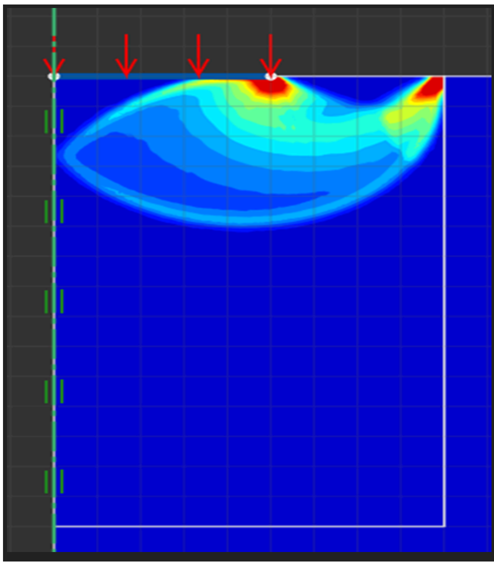
By achieving these objectives, this study aims to enhance understanding of the role of stone columns in improving the performance of foundation systems on clayey soils.

METHODOLOGY

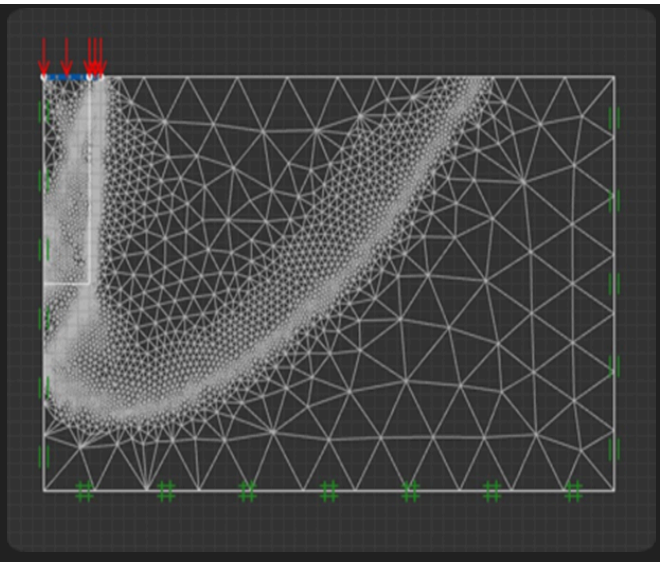
Numerical Modeling Setup:

1.) **Software Selection:** Utilising numerical modelling software **OPTUM G2** which enables us in the creation of sophisticated models capable of capturing the complex behaviour of the foundation system.

2.) **Finite Element Model Development**: Developing a detailed finite element model involves discretizing the domain into finite elements,nodes and meshes. Accurately representing the geometry and material properties of the foundation elements (footings and stone columns) also incorporating both the upper and lower bound theorem of soil mechanics.



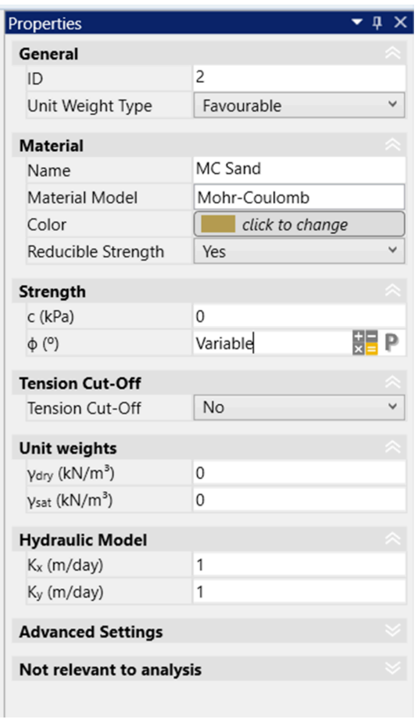
SHEAR DISSIPATION

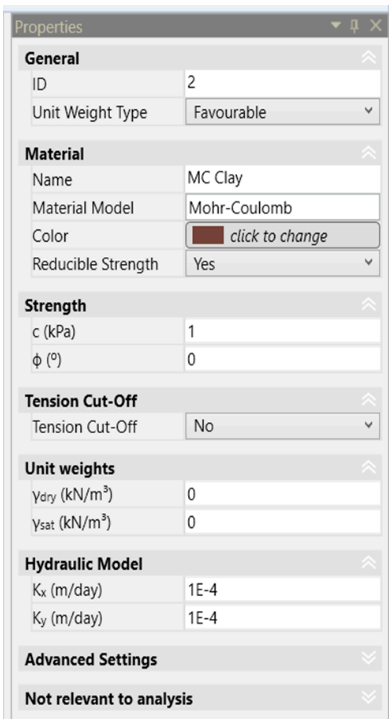


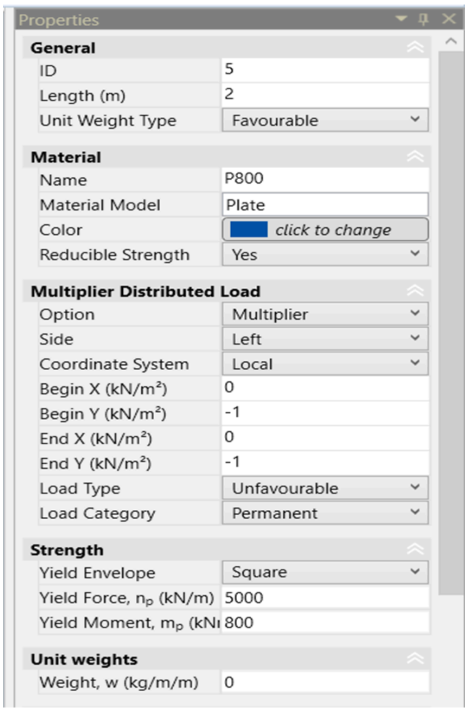
MESH ANALYSIS

Constitutive Modelling:

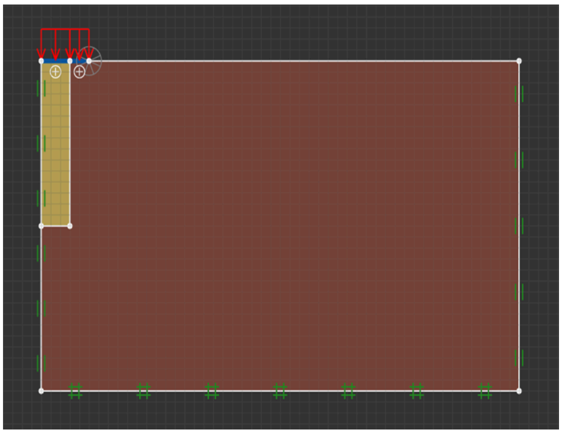
1.) **Soil Models**: Choosing soil models here like Mohr-Coulomb involves considering the soil's behaviour under various loading conditions, including its nonlinear stress be

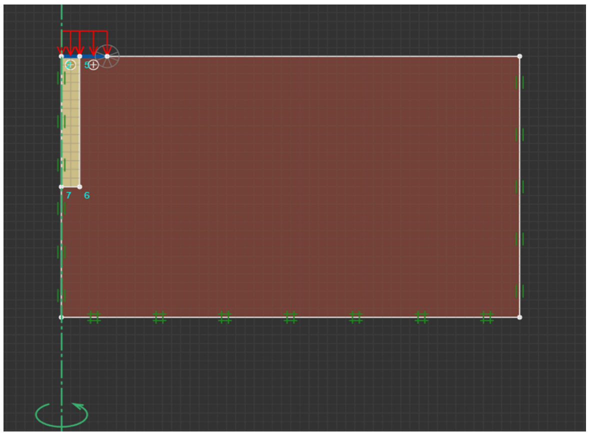






2.) **Modelling Stone Columns**: Representing stone columns as discrete elements assuming it to be a sand material as we have taken sand as a material instead of stone as both the particles have same compressive strength and assuming same failure according to Mohr's coulomb failure mechanism.





This is Schematic drawing of a model in software of Strip Stone column and Circular stone column respectively and below is the attached drawing of pile representing the_A & B variables.

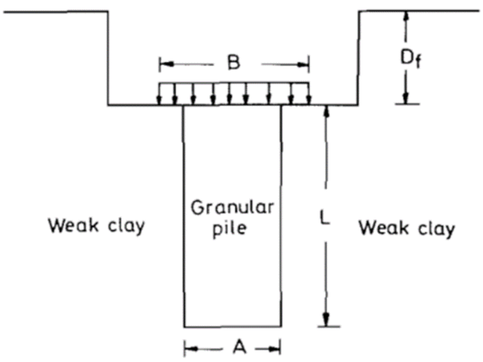
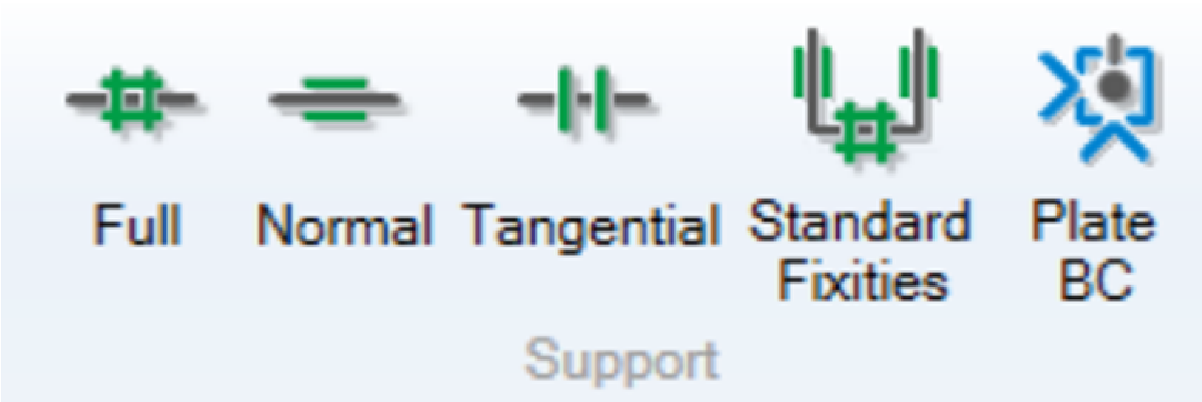


FIG. 1. Granular pile in weak clay.

3.) **Boundary Conditions and Loading Scenarios**: Defining boundary conditions by using the full and tangential support in the **OPTUM G2** software which ensures constraining the displacement in particular direction, considering factors like ground surface conditions.



Analysis of Collapse Load:

Collapse Load Equation: Utilising the established equation for determining the collapse load involves incorporating bearing capacity factors and soil parameters (e.g., cohesion, undrained shear strength, unit weight) into the analysis.

$$Q_u = c\,N_c + q\,N_q + 0.5\,\gamma\,B\,N_\gamma$$

We've established that the values of the fact that N_q and N_γ are smaller than N_c implies that the cohesion term in the final bearing capacity equation is more important than the contributions made by the applied load intensity and the soil's self-weight. Therefore the ultimate bearing capacity will be equal to

$$N_c = q_u / c$$

$$(c=1, q=0, \gamma=0)$$

Similarly we have evaluated Nq, Nγ results for strip stone Column & Nc for circular stone column

Parametric Studies: Conducting parametric studies investigates how various factors, such as stone column width ,soil properties, influence the collapse load, providing insights into the system behaviour and optimising design parameters.

Validation Analysis:

Model Validation: Validating the numerical model involves comparing its predictions with available analytical solutions, experimental data from the research paper of M. R. MADHAV AND P. P. VITKAR to ensure its accuracy and reliability.

Its results are further compared below in the results section.

PROCEDURE FOLLOWED

1. Firstly, creating a modelled structure in the optum g2 software .
2. Then we have to feed the values of material properties for the material that we are using to create the modelled structure. Like feed the properties of, plate ,sand {considering that sand and the granular material failure plane is same) and clay to get the desired results.
3. After feeding the material properties, begin the test using the Limit Analysis Method. Apply the load on the footing using the plate and then proceed for the test. The test has to be done separately for upper bound and lower bound values.
4. Since we have to obtain the Nc values for different values of phi,we change the value of phi each time the test for one phi value gets completed.
5. Then finally we can plot the graph for the obtained values of Nc.
6. Repeating the same process for the circular stoned column

Similarly we have evaluated Nq, Ny results for strip stone Column and Nc for circular stone columns

Results Interpretation and Discussion:

- Numerical Results Analysis: Analysing the numerical results evaluates the effectiveness of stone columns in enhancing the bearing capacity of footings on clayey soil, identifying trends and critical factors influencing the system's performance.

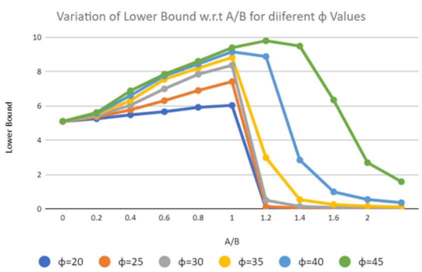
Results and graphs obtained for the Nc values of the strip column :

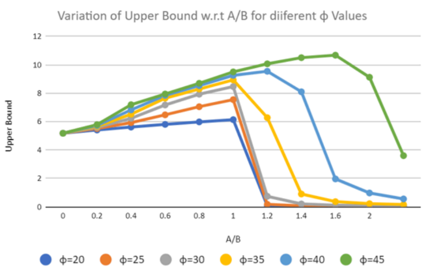
Variation of different ϕ values w.r.t to A/B Ratio

{ for Nc }

				ϕ=20		ϕ=25		ϕ=30		ϕ=35		ϕ=40		ϕ=45	
	A	B	A/B	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB
STAGE 1	0	5	0	5.177	5.1	5.177	5.1	5.177	5.1	5.177	5.1	5.177	5.1	5.177	5.1
STAGE 2	1	5	0.2	5.405	5.254	5.508	5.349	5.577	5.422	5.657	5.495	5.724	5.543	5.784	5.615
STAGE 3	2	5	0.4	5.612	5.476	5.922	5.767	6.227	6.04	6.516	6.313	6.824	6.608	7.189	6.883
STAGE 4	3	5	0.6	5.802	5.661	6.475	6.304	7.169	6.989	7.647	7.55	7.844	7.746	7.942	7.84
STAGE 5	4	5	0.8	5.978	5.918	7.047	6.894	7.927	7.837	8.292	8.199	8.53	8.433	8.694	8.598
STAGE 6	5	5	1	6.136	6.031	7.545	7.417	8.465	8.364	8.93	8.823	9.252	9.146	9.498	9.387
STAGE 7	6	5	1.2	0.059	0.052	0.17	0.14	0.737	0.513	6.273	2.99	9.542	8.875	10.067	9.787
STAGE 8	7	5	1.4	0.032	0.029	0.07	0.059	0.201	0.154	0.899	0.546	8.097	2.855	10.5	9.479
STAGE 9	8	5	1.6	0.024	0.022	0.047	0.041	0.111	0.09	0.362	0.257	1.962	1	10.675	6.342
STAGE 11	10	5	2	0.019	0.017	0.032	0.028	0.062	0.054	0.156	0.123	0.553	0.369	3.6	1.592

Variation of Lower bound and upper bound for different ϕ values { for Nc }





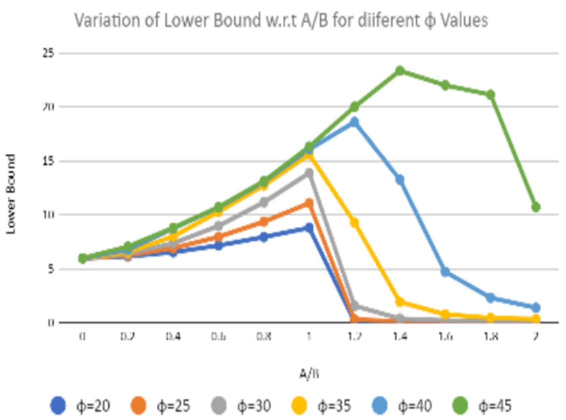
Results and graphs obtained for the Nc values of the circular column :

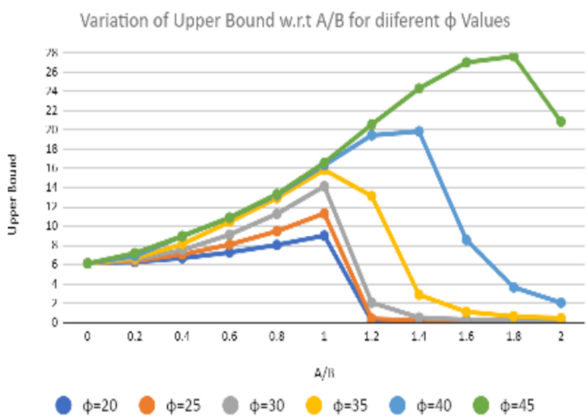
Variation of different ϕ values w.r.t to A/B Ratio

{ for Nc }

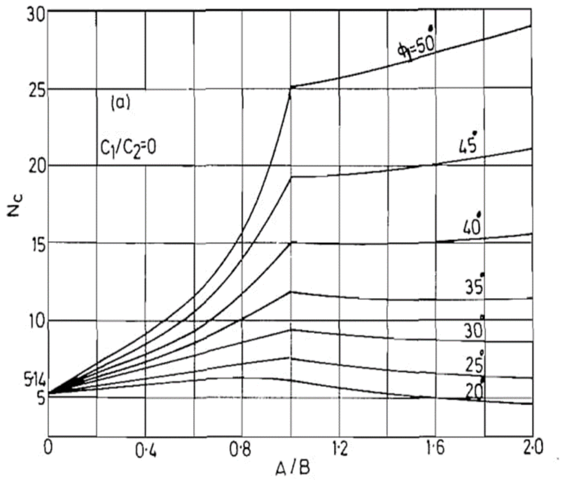
				ϕ=20		ϕ=25		ϕ=30		ϕ=35		ϕ=40		ϕ=45	
	A	B	A/B	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB
STAGE 1	0	5	0	6.097	5.961	6.097	5.961	6.079	5.961	6.079	5.961	6.079	5.961	6.079	5.961
STAGE 2	1	5	0.2	6.232	6.126	6.332	6.224	6.46	6.353	6.626	6.516	6.851	6.74	7.159	7.041
STAGE 3	2	5	0.4	6.631	6.526	7.004	6.896	7.478	7.359	8.091	7.982	8.909	8.714	8.93	8.775
STAGE 4	3	5	0.6	7.232	7.143	8.046	7.942	9.074	8.955	10.404	10.268	10.826	10.656	10.86	10.699
STAGE 5	4	5	0.8	8.007	7.929	9.439	9.349	11.24	11.141	12.873	12.706	13.199	13.015	13.291	13.101
STAGE 6	5	5	1	8.975	8.792	11.281	11.063	14.115	13.851	15.811	15.563	16.303	16.05	16.555	16.285
STAGE 7	6	5	1.2	0.092	0.085	0.337	0.291	2.007	1.558	13.099	9.252	19.421	18.567	20.534	19.981
STAGE 8	7	5	1.4	0.048	0.044	0.124	0.11	0.459	0.372	2.828	1.918	19.82	13.235	24.292	23.314
STAGE 9	8	5	1.6	0.036	0.033	0.079	0.071	0.234	0.197	1.044	0.766	8.547	4.712	26.997	21.978
STAGE 10	9	5	1.8	0.031	0.029	0.062	0.056	0.158	0.136	0.58	0.443	3.597	2.303	27.631	21.091
STAGE 11	10	5	2	0.028	0.026	0.052	0.048	0.122	0.108	0.391	0.32	1.996	1.383	20.838	10.697

Variation of Lower bound and upper bound for different φ values { for Nc }

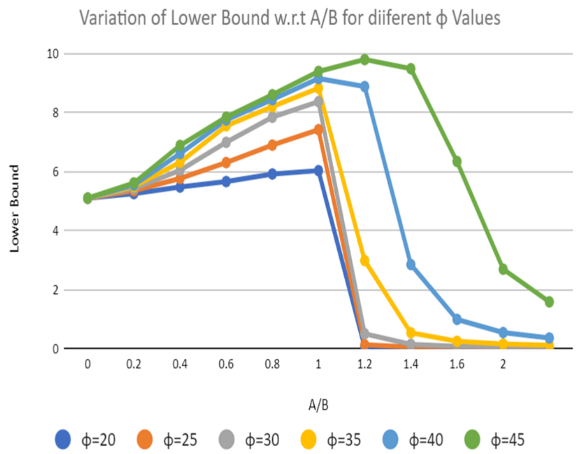




Comparing the results obtained to the research paper published by M. R. MADHAV and P. P. VITKAR



(a)



(b)

On comparing the graph that we have obtained with the one given in the research paper ,we can see that Nc value increases in both the graphs initially up to A/B ratio=1. Then ,after A/B = 1, the value of Nc decreases in our case while it increases in the graph given in the research paper. This is because the assumptions that we made to calculate the results vary from the assumptions made in the research paper to obtain the results. Moreover, we have used finite element analysis method to obtain the results which are more practical. Hence some variation can be observed in the graph.

CONCLUSION

This numerical study is conducted to investigate the bearing capacity of footings on clays improved by stone columns has provided valuable insights into the effectiveness of this ground improvement technique. The main findings and conclusions drawn from this study are as follows:

1.) Bearing Capacity Improvement: The results demonstrate that the use of stone columns can significantly enhance the bearing capacity of footings on clay soils. The improvement in bearing capacity is attributed to the increased shear strength and reduced settlement provided by the stone columns.

2.) Effect of Column Parameters: The parametric analysis shows that the variation in the width of the pile of the stone columns has a significant influence on the bearing capacity improvement.

3.) Failure Mechanisms: The numerical simulations provided insights into the failure mechanisms and observed that failure typically occurs through a combination of shear failure along the footing-soil interface and shear deformation within the soil mass.

Validation: The numerical results were validated against available experimental data and analytical solutions, demonstrating good agreement and validating the accuracy of the numerical model developed in this study.

Future Work:

The completion of this project lays the groundwork for further exploration and refinement in the field of geotechnical engineering. Future endeavours could include:

1. **Variation of Cohesion (ϕ)**: Expand the scope of the study by investigating the effect of different values of cohesion (ϕ) on the behaviour of stone columns in cohesive soils. By gradually increasing the cohesion angle (e.g., 5, 10, and 15 degrees), a more comprehensive understanding of the interaction between stone columns and the soil can be obtained.

2. **Exploration of Stone Column Depth**: While this project focused on varying the width of the stone column, future research could explore the impact of varying the depth of the stone column. Investigating different depths allows for a more thorough assessment of the optimal dimensions of stone columns for enhancing the bearing capacity of footings on clayey soils, considering factors such as load distribution and settlement reduction.

3. **Experimental Verification**: Validate the numerical results obtained in this study through practical laboratory testing of

stone columns using physical samples. Experimental verification provides an opportunity to corroborate the findings of numerical simulations, enhancing capabilities of numerical models.

By addressing these avenues for future research, further advancements can be made in understanding the behaviour of stone columns in cohesive soils, ultimately contributing to the development of more effective and reliable ground improvement strategies.