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Parametric Study of Stone Column using PLAXIS 2D

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Abstract. When important structures are constructed on very soft soil, soil stabilizing methods are adopted. The stone column is one of the soil's stabilizing methods that is used to increase the strength of soil and decrease the settlement of soil. The key objective of this paper is to study the influence of key parameters on the settlement and loading behavior of a column. In this study, a series of numerical analysis has been performed by using PLAXIS 2D (Finite element method software) in axisymmetric model to understand the effect of key parameters. PLAXIS is a software based on finite element method technique, and used to do numerical analysis. Mohr-Coulomb model, an Elasto-plastic model is used in this study for simplifying the simulation and behavior of soft clay. In this study settlement profile of soil is considered to understand the effect of slenderness ratio, undrained shear strength of soft soil, internal friction angle of the column, modular ratio and area replacement ratio of the column. A comparison of soil stabilization in the form of soil settlement profile with variation is considered. It is seen that increasing undrained shear strength of soft soil and internal friction angle of column material enhanced the load bearing capacity. Increasing the modular ratio led to a decrement in load bearing capacity. Also, L/D = 4 is found to be optimum for a floating sand column.

Keywords: Stone Column, Settlement Behaviour, PLAXIS.

1 Introduction

When we discuss the problem in dealing with soil, Clay is named to be the most obnoxious one. Low undrained shear strength of soft soils makes it difficult for them to serve the purpose of the structure. This may lead to failure of structure or lack in serviceability of the structure. Both conditions are highly undesirable. In pursuit of finding the solutions to these situations many techniques have been developed, known as Ground Improvement techniques. Now a days, ground improvement has proven to be way more economical than shifting location due to the mammoth surge in land prices. The ground improvement technique known as Granular Column, also known as Sand Column, Stone Column or Granular Pile has been serving as a life saviour as a panacea to the problems created by soft soil. It can be practiced by three methods: “Reinforcement”, “Improvement”, “Treatment” or combination of these. Previously only aggregate used to be used as fill, hence granular fill or granular column are also known as stone column. But nowadays various cohesionless materials are getting used

Balaam & Booker (1981) observed that stone column reduces settlement to 40% and rate of settlement also increases. Alamgir et al. (1996) observed that shear stress was maximum at top and at soil column interface, and decreasing with depth and radial distance. stress in column and soil was the same at surface. Poorooshasb & Meyerhof (1997) concluded that most governing parameters in stone column is area replacement ratio and the compaction of column material which ultimately leads to providing stiffens and strength to the soil. Fattah et al. (2011) concluded that area replacement ratio is the most influential parameter on bearing capacity. Madun et al. (2018) conducted a numerical analysis using PLAXIS 2D and Response Surface Methodology (RSM). Numerical modelling was done by scaling down 25 times and observed that bearing capacity increases with diameter of stone column and settlement reduces with the increasing length of stone column. One of the major conclusions achieved was desirability for optimum design. Since effectiveness of column depends on various parameters hence for an optimised design, effect of key parameters must be understood well.

2 Numerical Modelling

In this study, numerical analysis has been carried out by using PLAXIS 2D having axisymmetric model. Dimension of soil model is considered to be 300mmx300mm to analyze the load deformation curve of stone column. As there is no undulation in the ground surface, hence, no. of boreholes was used as one. The boundary condition for the sides were set to restrained in x-direction while bottom was restrained in x and y-direction both.

In order to analyze the settlement performance and deformation of surrounding soil and stone column respectively, five variables are taken into consideration. These five variables are Slenderness ratio (L/D Ratio), Undrained Shear strength, Modular Ratio (Ratio of modulus of elasticity of materials of stone column to modulus of elasticity of surrounding soil i.e. soft soil), Area Replacements Ratio in %, and Loading area. To analyze the model, unit cell concept is used. Settlement at surface and failure was observed. Assuming Elasto-Plastic behavior, Mohr-coulomb model is adopted for analysis. Granular column is assumed to be drained and soft soil as undrained. For the calculation and specifications IS 15284(Part 1):2003 is used. Assuming arrangement of stone columns in square pattern with 4 mm diameter of each column and 32 mm spacing. Equivalent diameter is calculated using following formula

$$de = 1.03S \quad (1)$$

Where de= equivalent diameter of single column and S = spacing between columns. From the above equation the equivalent diameter of single column is calculated to be 37mm. The output is generated by addition of two phase in staged construction mode of model. Constant parameters in structure mode, to analyze deformation of stone

columns were diameter of stone column (which is taken as 37mm) and line load (500 kN/m). The variable parameters in stone column for the consideration of different curve plot were length to diameter ratio (L/D ratio= 3, 4, 5 and 6), Modulus of elasticity of sand in stone column (E_s= 12000kPa, 20000kPa, 28000kPa) and angle of friction of sand in stone column (26, 35 and 40 degrees).
The following Table 1 gives a summary of all properties used in numerical modelling.

Table 1. Material Properties used in Modelling.

Parameters	Soft Soil	Sand
γ_{dry} (kN/m³)	14.4	15.50
γ_{sat} (kN/m³)	24.4	25.5
C_u (kPa)	30, 40 and 50	-
μ	0.4	0.3
E (kPa)	4600	12000, 20000 and 28000
Φ (degree)	-	26, 35 and 40
Ψ (degree)	-	0, 5 and 10

Model taken as axis symmetric model in PLAXIS 2D, element 15 noded and element size is 8.943×10^{-3} (see in Fig. 1 and Fig. 2)

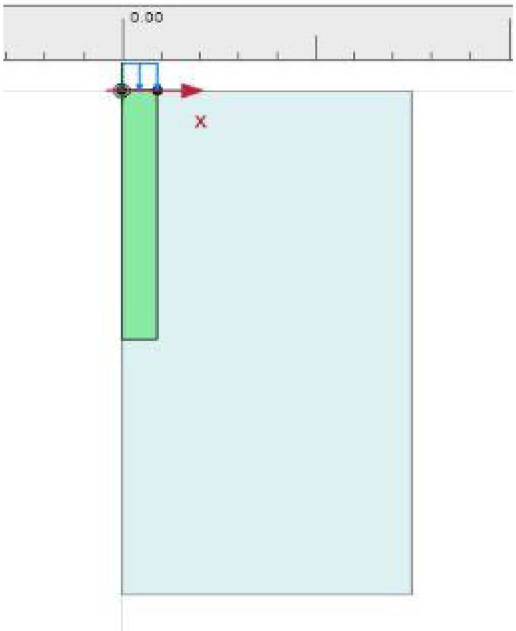

Fig. 1. Pictorial representation of soil stratigraphy used as a soft soil and stone column with line load.

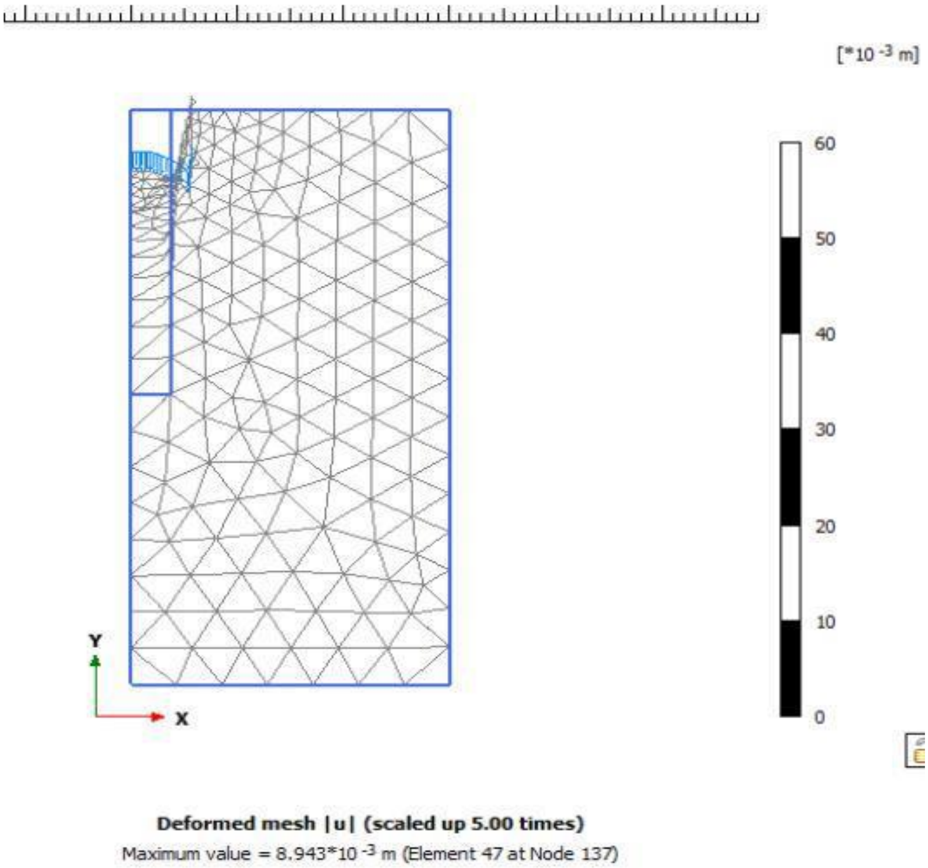

Fig. 2. Deformation of axially loaded stone column after calculation analysis in staged calculation.

3 Validation

Validation has been done with the model used by Naseer et al. (2019). A single column with diameter 37mm and height 150 mm was tested in cylindrical tank of diameter 0.3 m and height of 0.3m. A uniformly distributed load of 500kN/m is applied (Naseer et al., 2019). Application of load was assumed to be on column only. A schematic diagram of setup is presented in Fig. 3. Present modelling results are in well agreement with author as shown in Fig. 4.

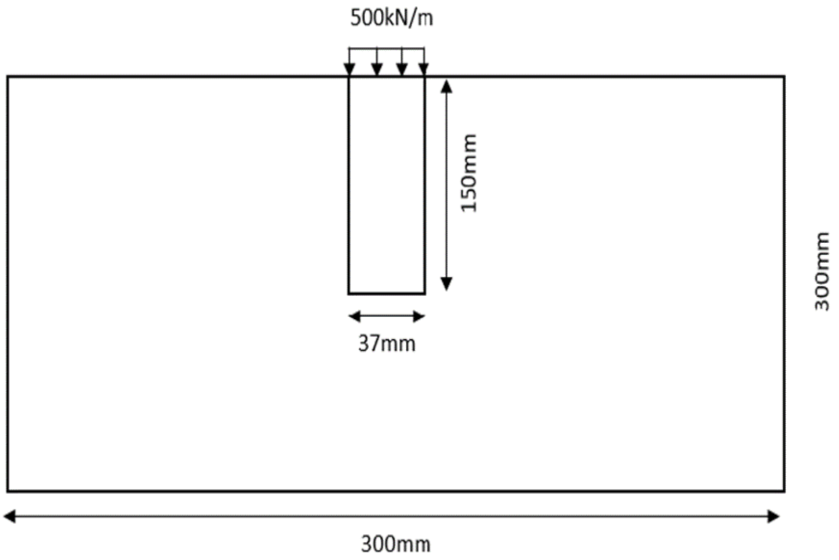

Fig. 3. Schematic diagram of setup by Naseer et al. (2019).

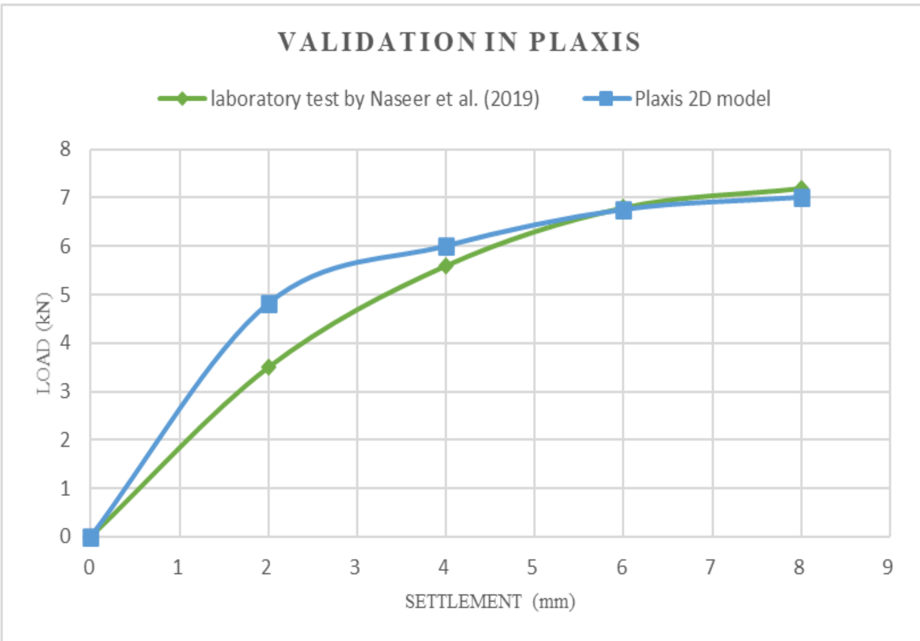

Fig. 4 . Validation of numerical model.

Material properties used are listed in table below (Table 2)

Table 2. Material Properties used in Model by Naseer et al. (2019)

Parameters	Soft Soil	Sand
γ_{dry} (kN/m^3)	14.4	15.50
γ_{sat} (kN/m^3)	24.4	25.5
C_u (kPa)	30	-
M	0.4	0.3
E (kPa)	4600	12000
Φ (degree)	-	26

4 Results and Discussion

4.1 Influence of shear strength of soft soil (Cu)

Undrained shear strength of soft soil is changed for a value of 30 kPa, 40 kPa and 50 kPa. Simultaneously, Esc=12MPa and ϕ=26̊ is constant.

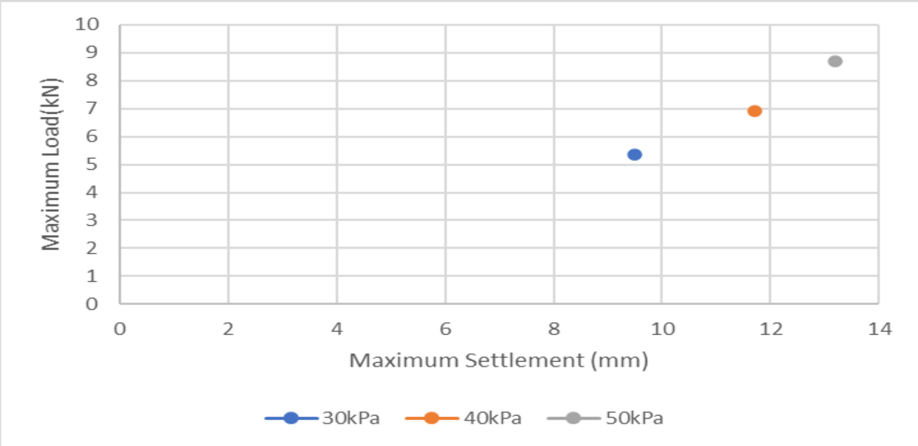

Fig. 5 Effect of undrained shear strength of soft soil on maximum load and maximum settlement.

It is observed that with increase in undrained shear strength of a soil, load carrying capacity of column increases. It may be because of passive resistance offered to the radial bulging of column. More shear strength of soil will offer more resistance to radial bulging, hence more stiffness to the column and leading to higher load carrying capacity. Also, lesser radial bulging of column will lead to more transfer of vertical stress and vertical deformation leading to more ultimate settlement. Hence at higher value of undrained shear strength of soft soil, maximum of passive resistance offered to the column hence load bearing capacity increases. Increasing area of column also doesn't make much difference at a normal loading value when Cu is high.

4.2 Influence of slenderness ratio of column

To investigate influence of slenderness ratio, L/D ratio has to be changed and rest of the parameters has to be unchanged. When only column assumed to be loaded, for Cu = 30 kPa of soft soil, L/D ratio of column is varied as 3,4,5 and 6.
Also, stress analysis has been done and quantified with the term Stress Concentration Ratio (SCR), denoted as n. SCR is defined as ratio of stress taken by column to stress taken by surrounding soil. It is observed that the stress concentration ratio increased rapidly between L/D ratio 4 to 5. Though peak is observed between 5 to 6. It can be concluded that L/D ratio is optimum between 4 to 5. Also, maximum SCR value obtained is around 2.8. Fig. 6 shows the SCR behavior with varying L/D ratio of system.

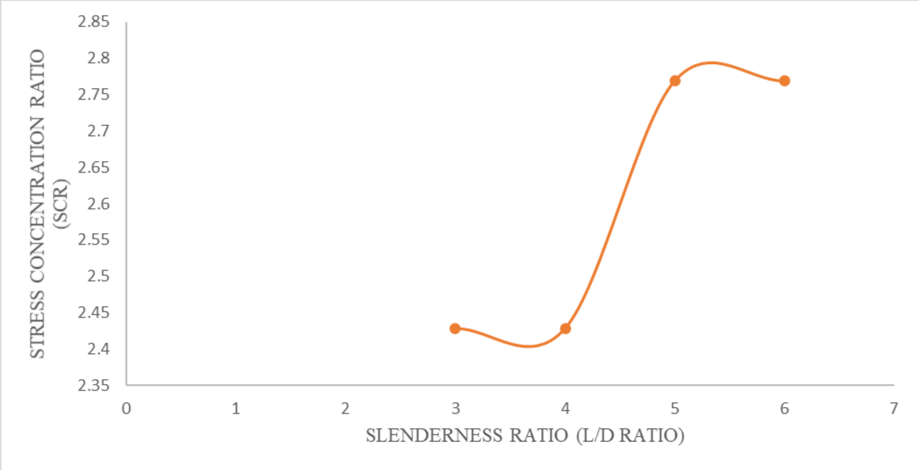

Fig. 6. Effect of L/D ratio on SCR when Cu=30 kPa and Ar= 0.38%

4.3 Influence of Internal Friction Angle of Stone Column (Φ)

Angle of internal friction of column directly relates to the strength of column. It signifies the interlocking and hence shear strength of column. Since stone columns are not binded by any adhesive, internal friction angle is key to effectiveness of stone column. It is dependent on compaction during installment, grain size distribution and arrangement of grains.

To study the influence of ϕ on a column, rest parameters were kept constant. Meanwhile ϕ will be increased from 26 degrees to 35 degrees to 40 degrees. L/D ratio is adopted as 4, Ar = 1.5%, Cu=30kPa, Esc =12MPa and ψ=1- ϕ.

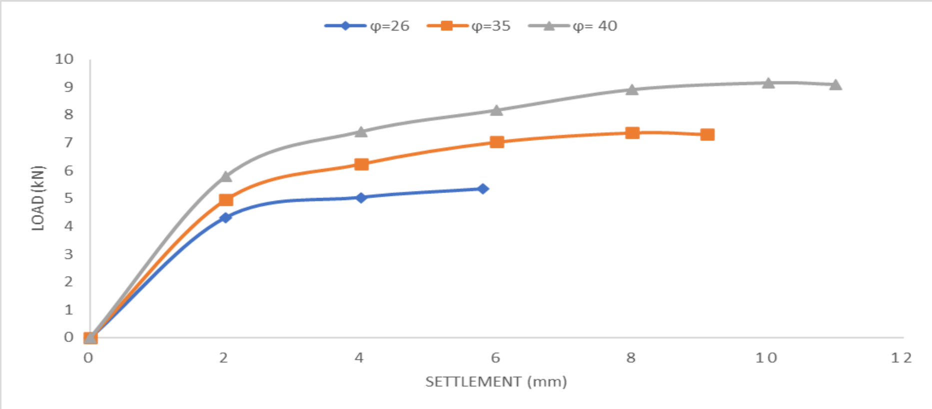

Fig.7. Effect of ϕ, when L/D ratio = 4 and Cu= 30kPa with Ar=1.5%

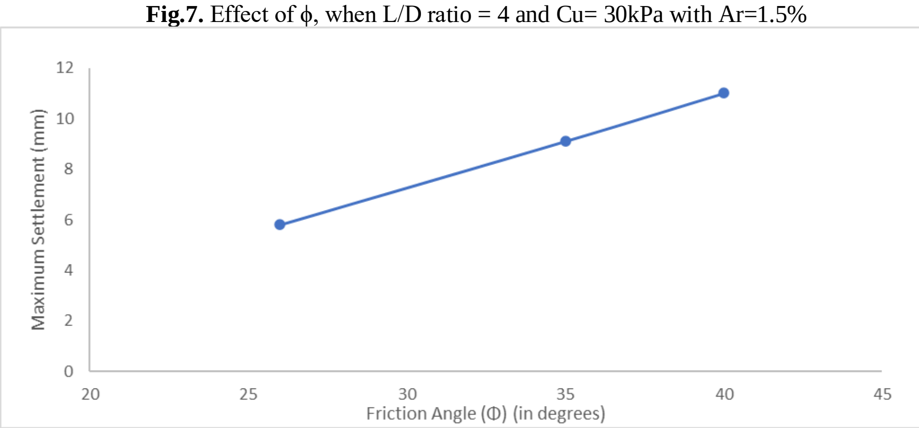

Fig. 8 Effect of ϕ on maximum settlement when L/D ratio = 4 and Cu= 30kPa with Ar=1.5%

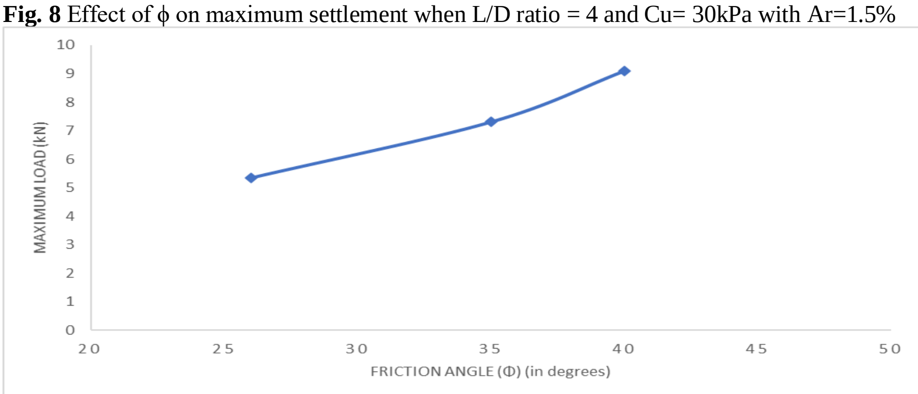

Fig. 9 Effect of ϕ on maximum load when L/D ratio = 4 and Cu= 30kPa with Ar=1.5%

It is observed that increment of ultimate settlement is quite linear with increase of ϕ (Fig. 8). Also, with increase in ϕ, ultimate load carrying capacity has also increases initially with mild slope and later slope becomes steeper (Fig. 9).

It is known that as load is applied to the column, grains of column undergoes a vertical deformation which triggers radial bulging. This bulging is prevented by passive resistance provided by soil. Depth up to which axial load transfers, tends to move radially. When ϕ increases, transfer of load will be more, because of more interlocking and shear strength. Hence passive resistance will appear to be deeper with more ϕ.

4.4 Influence of Modular Ratio (m)

To understand the effect of modular ratio, all the parameters were kept constant and modular ratio kept on varying to the value 2.6, 4.34 and 6.08. Parameters kept constant are L/D ratio =4, Cu= 30kPa, Es=4600 kPa, $\phi=26^{\circ}$ and Ar=1.5%. While Esc is varied to a value of 12000 kPa, 20000kPa and 28000 kPa.

Modular ratio is ratio of Young's modulus of elasticity of grain used in column to the modulus of elasticity of soft soil.

$$m = \frac{E_{granular\ column}}{E_{soft\ soil}} \tag{2}$$

It is observed that with increase in Esc ultimate settlement corresponding to a load, also increased. This may be due to the reason that when Esc increases, self-weight of column will also increase, which ultimately add up to the axial loading. Due to this reason vertical settlement will increase for unchanged value of load when Esc will increase. It is observed that for first 8000kPa increment in Esc, settlement increased by 18.96 % while for next 8000kPa, stress increased with 9.13% only (Fig. 10). Also ground heaving is seen occurring at 2.7D away from the column while radial bulging. But ground heaving can be seen reducing with increasing Esc, that means radial bulging also reduced to some extent. But maximum vertical deformation can be seen increasing with increasing Esc, that means punching is also playing role in failure. Hence an interesting conclusion came here is that, with increasing Esc radial bulging decreases and punching starts become active.

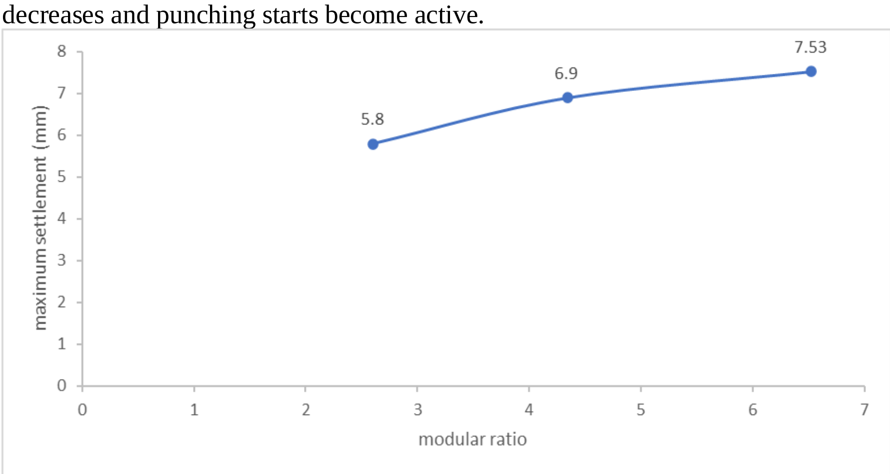

Fig. 10. Effect of modular ratio on settlement

5 Conclusions

1. For Cu= 30kPa, 40kPa and 50 kPa, the SCR increased rapidly between L/D ratio 4 to 5. Also increase in the Cu increases load carrying capacity of the column.
2. With increasing value of ϕ, depth at which passive resistance becomes zero, also deepens. While increment of ultimate settlement is quite linear and ultimate load carrying capacity has also increases initially with mild slope and later slope becomes steeper.
3. It is observed that for first 8000Kpa increment in Esc, settlement increased by 18.96 % while for next 8000Kpa, stress increased with 9.13% only.
4. When Esc increases, vertical settlement at any instant and Ultimate settlement corresponding to a load both increases. Though maximum load isn't much affected but ground heaving (occurring at 2.7D away) kept on reducing and punching seen to be arising.

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