iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** VIII **Month of publication:** Aug 2023

DOI: https://doi.org/10.22214/ijraset.2023.55475

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue VIII Aug 2023- Available at www.ijraset.com

A Parametric Study on Raft Foundation in Loose Sand Considering Soil Structure Interaction

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Abstract. An extensive study is performed on the behavior of raft foundation considering soil structure interaction. The foundation is modelled using SAFE2016 software considering thick plate. A parametric study is carried out on raft foundation using finite element method considering static load condition. Several parameters, such as thickness of raft, modulus of subgrade reaction, load pattern, soil condition affect the soil-raft-structure response. The study revealed the analysis of the structure on raft foundation system considering the raft and soil properties. Displacement of raft foundation is decreased as increased in raft thickness. However, displacement of raft foundation is increased as decreased in subgrade modulus. Maximum soil pressure is decreased with increase in raft thickness. Soil pressure is increased with the increase of subgrade modulus. Punching shear ratio for raft foundation is decreased as increased in raft thickness. Punching shear ratio for raft foundation is decreased slightly as increase in subgrade modulus. Thickness of raft is important for designing raft foundation. The soil conditions are affecting the raft characteristics like deflection, soil pressure, punching shear. Increase of edge distances from the center of column decreases the upward soil pressure intensity.
Keyword: soil structure interaction; raft foundation; punching shear; subgrade modulus; deflection; static load.

I. INTRODUCTION

Introduction of this paper has been divided and presented in the following two subsections.

A. Prologue

When the external load applied to the structure, the structure deflects. It influences the foundation to deflect. The underlying and surrounding soil deflects due to the deflection of foundation. This is known as soil structure interaction (S.S.I). The mat foundation considered as raft foundation. It is a combined footing that may cover the entire area under a structure supporting several columns and walls. Raft foundation preferred for soils that have low bearing capacity, however that can support high column and wall load. When spread footing would have to cover more than the half of building area, raft foundation might be economical. Mat foundation, supported by pile , reduce settlement of a structure built over highly compressible soil. Where water table is high rafts are often placed over piles to control buoyancy [Bowles, E. J., (1997). Raft foundations have shown better performance during earth quake and it is considered as an effective foundation system for multistoried structure. Soil structure interaction is neglected for light structure such as low rise building and simple rigid retaining wall. The effect of soil structure interaction becomes important for heavy structures resting on relatively soft soil. Soil structure interaction plays an important role particularly when subjected to seismic excitation.

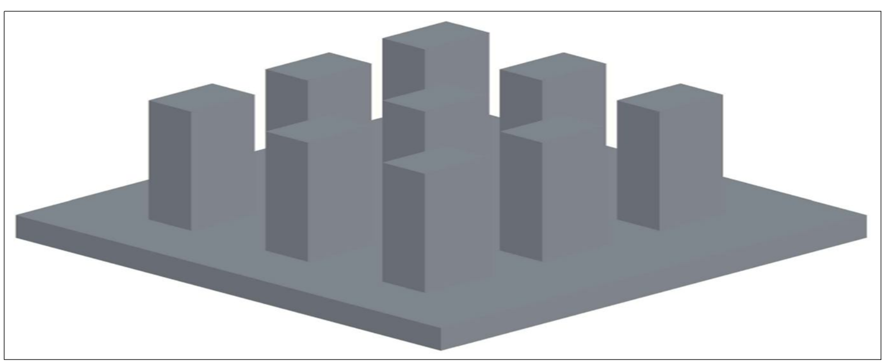


Fig 1. Raft foundation

B. Raft Foundation

Designing a raft foundation is a difficult task where requirement is to balance the cost of design, the need of adequate safety and, above all, acceptance of the design by the client and the professional community in general.

In recent years, mat foundations are very widely used in the construction of high-rise buildings as they are usually found to be economical in cases where the base soil has a low bearing capacity and column loads are very large [Punekar.S. et al. (2017).]. Mat foundation is one of the effective shallow foundations, which carries the load to the soil without any differential settlement in the soil. It may be used where more than 50% of the area is covered by conventional spread footings [Srilakshmi, G. and Rekha, B., (2011).]. For fairly small and uniform column spacing and when the supporting soil is not too compressible, a flat concrete slab having uniform thickness throughout (a true mat) is most suitable. This type of mat can be used in ground conditions where large settlements are not anticipated and hence a high degree of stiffness is not required. The slab is of uniform thickness and reinforced to resists bending moment [N.V.Manjunath et al. (2018)]. A slab and beam type of raft is likely to be more economical for large column spacing and unequal column loads, particularly when the supporting soil is very compressible [Barry, R., (1996)]. Ojha et al. (2022) studied for loose soil, pressure distribution beneath the raft is lower at edge and increasing towards the center. In the present study it is aimed to determine the effect of following parameters on the square raft foundation using finite element analysis such as thickness of mat, modulus of subgrade reaction, load pattern, soil condition. In this study, it is determined that these three parameters affect the various parameters like punching shear, bending moment, soil pressure and deflection.

II. FINITE ELEMENT ANALYSIS AND MODEL VERIFICATION:

Finite Element Method consider the raft as flexible plate and considered the contact pressure, as the raft will be subjected to bending due to loads coming from the columns as well as the loads due to the contact pressures or the reactive pressures.

The present work deals with the designing of raft by the 'Finite Element' method software "SAFE" is used in the present work. In the analysis, SAFE converts the object-based model created by the user into a finite element model, called the analysis model. The finite element mesh used in the analysis is a rectangular mesh based on a maximum acceptable element size.

Table 1. Design parameter

Parameters	Values
Effective bearing stress of soil	q_{all}- 60 KN/m^2
Subgrade modulus	(60X3)X40= 7200 KN/m^2
Concrete Strength	25 Mpa
Reinforcement steel-strength	415 Mpa

Table 2. Column load

Columns types	D.L(kN)	L.L(kN)
Corner Column	390	294
Side Face Column	556	441
Side Face Column	531	420
Center Column	768	630

Table 3. Measured and predicted observations for different parameters of raft foundation.

Parameters	Measured observation	Predicted observation
Deflection	7.05 mm	7.20 mm
Maximum soil pressure	51 kN/m^2	52 kN/m^2
Punching shear ratio	0.62	0.60
Bending moment	129 kN-m	136.2 kN-m

At first model verification is carried out to verify credibility and numerical ability of the finite element model. The various parameter of raft foundation i.e displacements, soil pressure, punching shear and bending moment are obtained from the literature which are tabulated in table 3. A total four parameters are modelled and evaluated by field data. Based on available data numerical models are developed and solved by finite element approach. The design parameters are adopted from the values reported in Hassan Mohamed and Nasser (2018). Remaining of design parameters are the diameter of reinforcement and nominal cover adopted from IS456-2000. The predicted values for load cases are tabulated in table 3. The results show that the predicted values of different parameters are almost same with measured values. The validation lends credence to use of the numerical model in obtaining the soil structure interaction of raft foundation. Several research studies on raft foundation have been performed. In all studies the superstructural analysis was not accounted for this analysis. How ever to designing raft foundation soil foundation interaction including superstructural analysis is essential. A few other research studies incorporated superstructure in their analysis, however foundation is replaced by linear spring. Major drawbacks of this model are associated with the designing of foundation and soil non linearity in soil raft foundation system. In order to get new insights, a comprehensive assessment of behavior of raft for various structure and soil parameters are suggested.

In the present study it is aimed to determine the effect of following parameters on the square raft foundation using finite element analysis-Thickness of mat, Modulus of subgrade reaction, Load pattern, Type of soil etc. In this study it is determined that these three parameters affect the various parameter like punching shear, bending moment, soil pressure, deflection etc. Superstructural loads are axial column forces and column base transferred moments. Thick plate option has been taken into considerations readily available in most recent and pioneer mat foundation analysis and design by Finite Element Method named SAFE. Three-dimensional analysis model support reactions i.e. axial forces and base moments have been transferred to finite element mat foundation analysis software SAFE. The interaction among structures and their foundation and the soil below the foundation alter the actual behavior of the structure considerably than what is obtained from the consideration of structure alone. Finally design implifications are suggested based on the influence of the several parameters on the observed responses.

III. PARAMETERS

Primarily, the building was modelled in STADD Pro software. The loads are calculated from the support reaction summary. General ranges of the relevant parameters for raft are summarized in table 4. Based on this parameters raft is modelled. Loads are applied on the raft in the form of dead load, live load and surface load. In the present study it is aimed to determine the effect of following parameters on the square raft foundation using finite element analysis- Thickness of mat, Modulus of subgrade reaction, Load pattern. In this study it is determined that these three parameters affect the various parameters like punching shear, bending moment, soil pressure, deflection etc. The raft is analyzed for three different values of subgrade reactions which are outlined in table. The soil condition is considered as loose sand. And other design parameters are tabulated below table 5.

Table 4. Parameters of raft foundation

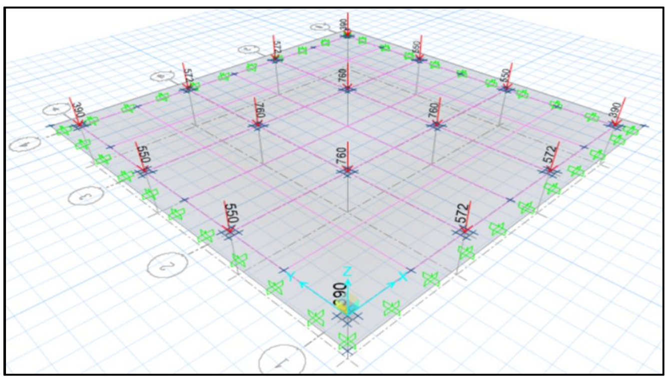
Parameters	Values
Load combination	1.5 DL+ 1.5LL
Parking load	5 kN /m^2
Strength of steel fy	415 N/ mm^2
Strength of concrete fck	30 N/ mm^2
Load pattern	4X4
Thickness of raft	0.15m, 0.3m, 0.45m, 0.6m
Column size	(450x450) mm
Unit	Metric
Diameter of reinforcement	12 mm
Nominal cover	50mm
Modulus of elasticity(E)	5000($\sqrt{fck}$) = 22360 N/mm^2
Grade of steel	Fe500
Fy	500
Fu	545
Modulus of subgrade reaction (k_s)	5000, 8400, 12700

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue VIII Aug 2023- Available at www.ijraset.com

Table 5. Design parameters

Parameters	Values
Types of foundation	Square Raft
Length of raft	20 m
Breadth of raft	20 m
Edge distance of raft	1 m on all sides
No. of bays along X direction	2,3
No. of bays along Y direction	2,3
Bay length in all direction	9m,6 m
Material	M20 concrete

Effects of raft parameters are studied considering four thickness value, namely 150mm, 300 mm, 450mm, 600mm, which cover a general range of raft thickness value in practice. Impact of thickness is examined considering a general range of subgrade modulus values. This study considers three different modulus of subgrade reaction values, namely 5000, 8400, 12700 for loose sand. The raft is modelled in clay soil also. The shear strength parameters are considered to examine the effect of a variety of soil stiffness. For loose sand condition the safe bearing capacity is 858 kN/m^2. Modulus of subgrade reaction is 4260 kN/m^3.



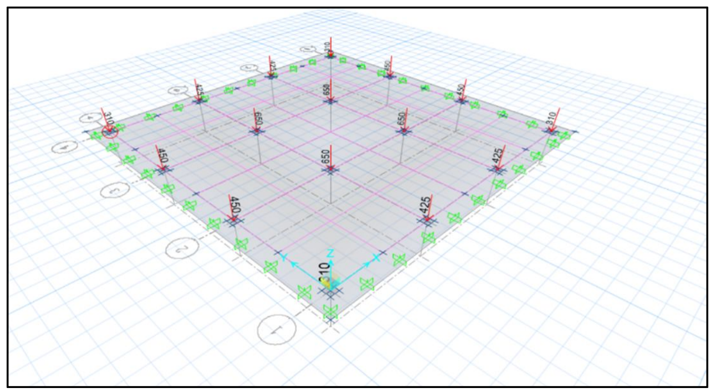


Fig.2. The dead load pattern for 4x4 load pattern   Fig.3. The live load pattern for 4x4 load pattern

IV. RESULT AND DISCUSSION

Considering the real situation where the selected parameters vary within a certain range, a study of the raft soil interaction response is carried out in order to gain further insight into the functional performance of the raft structure.

A. *Effect on Displacements*

Deflection should be checked in raft foundation. In this analysis maximum deflection has been checked using SAFE software. Deflection of raft foundation is decreased as increased in raft thickness (t_S) as shown in fig 4. However, displacement of raft foundation is increased as decreased in subgrade modulus. Deflection at Centre is higher than at the edge. Raft foundation is unsafe when the thickness (t_S) is less, however the foundation becomes safe considering higher values of raft thickness. As the number of columns increased the deflection is also increased compared to as 3x3 load pattern

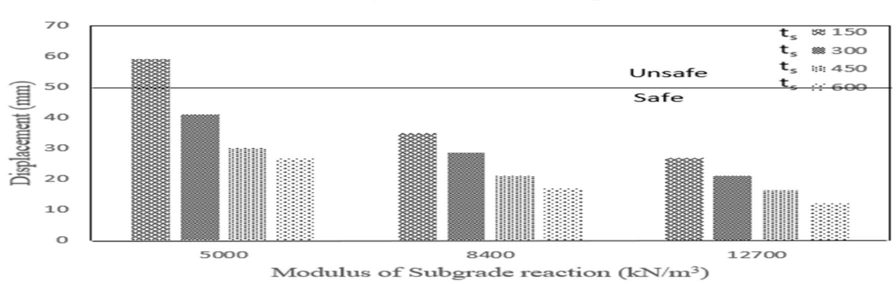


Fig. 4. Effect on deflection due to change in raft thickness (t_s) and modulus of subgrade reaction subjected to 3x3 load pattern

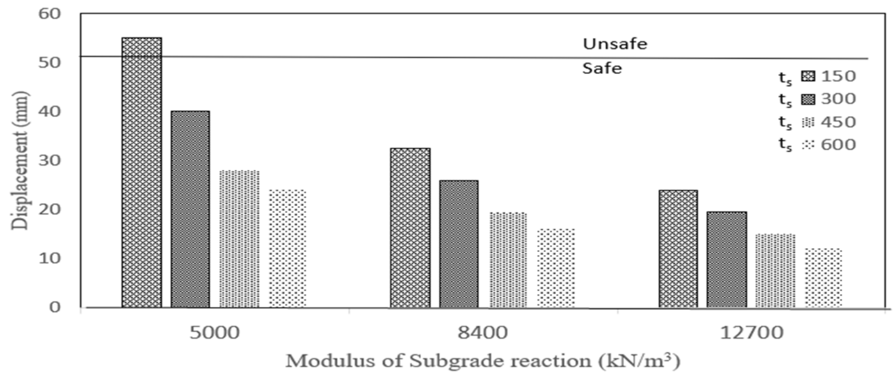


Fig. 5. Effect on deflection due to change in raft thickness (t_s) and modulus of subgrade reaction subjected to 4x4 load pattern

B. *Effects on Soil Pressure*

The net upward soil pressure should be checked in the raft foundation. Maximum soil pressure decreased as increased in raft thickness (t_S). However, soil pressure is increases with the increase of subgrade modulus as shown in fig 6. Raft foundation is unsafe when soil modulus increases. However, the foundation becomes safe with higher value of raft thickness (t_S). In 4x4 load pattern as the number of columns increased the soil pressure is also increased compared to as 3x3 load pattern.

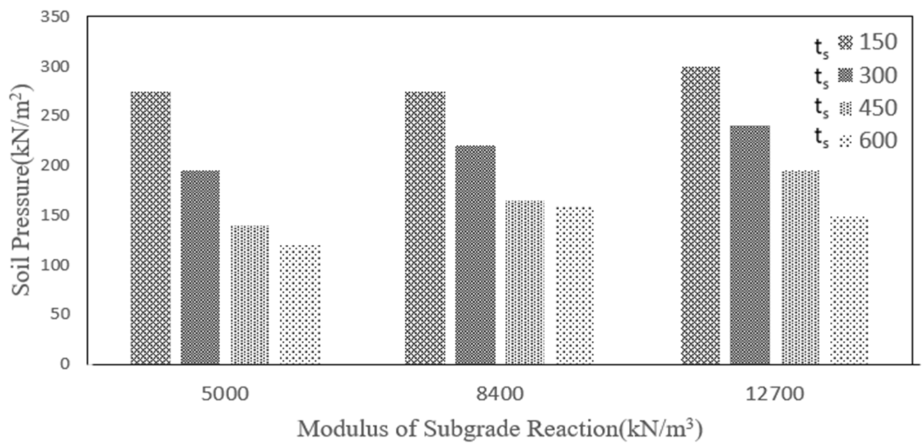


Fig. 6. Effect on soil pressure due to change in raft thickness (t_s) and modulus of subgrade reaction subjected to 3x3 load pattern

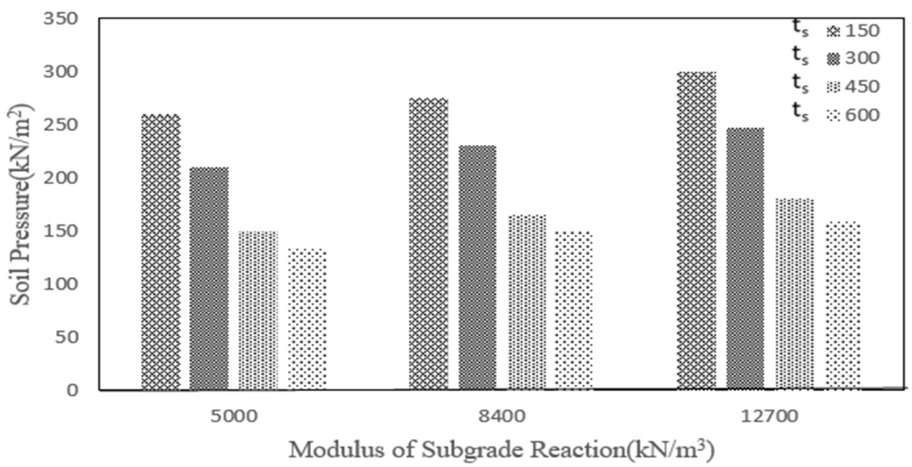


Fig. 7. Effect on soil pressure due to change in raft thickness (t_s) and modulus of subgrade reaction subjected to 4x4 load pattern

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C. Effects on Punching Shear

Punching shear is most important parameter in raft foundation design. The raft foundation is safe against punching shear when punching shear ratio is less than 1. The maximum punching shear observed in the center of the column. Punching shear ratio for raft foundation is decreased as increased in raft thickness (t_S). However, punching shear ratio for raft foundation is decreased slightly as increase in subgrade modulus as shown in fig 8 and fig 9. Raft foundation is unsafe when thickness is less, however the foundation becomes safe considering higher values of raft thickness (t_S). When column load is increased punching shear ratio remain same. Punching shear ratio slightly affect with increase in load.

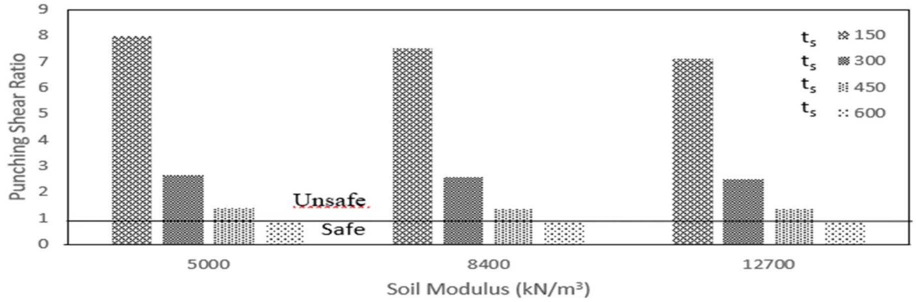

Fig. 8. Effect on punching shear due to change in raft thickness (t_s) and modulus of subgrade reaction subjected to 3x3 load pattern

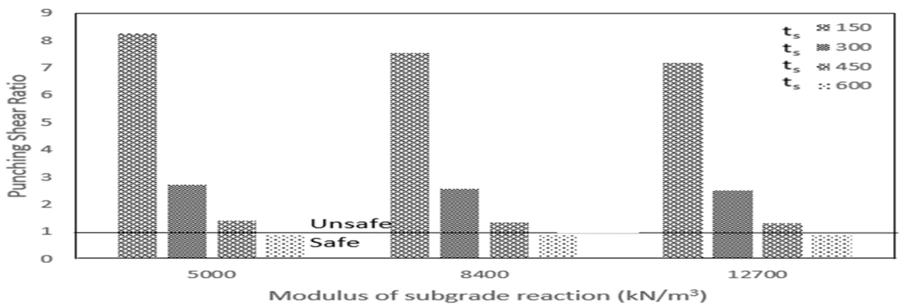

Fig. 9. Effect on punching shear due to change in raft thickness (t_s) and modulus of subgrade reaction subjected to 4x4 load pattern.

D. Effects on Bending Moment

In SAFE software, the raft is automaticity divided to different strips. Each direction has a column strip and middle strips. The moments analyzed by SAFE software are the strip moments per one meter width of the strip. In x-strips, the column strips have a dimension of 1.2meter width and the middle strips have a dimension of 1.2 meters width. Moments computed are analyzed base on one meter unit width of the strip. In y-strips, the column strips have a dimension of 1.2 meters width and the middle strips have a dimension of 1.2 meters width. Moments computed are analyzed base on one meter unit width of the strip. Maximum bending moment observed at center of raft. Maximum bending moment in both x and y direction are increases with increased thickness of raft(t_S). However, bending moments in x and y direction decreased with increased in subgrade modulus as shown in fig10, fig 11, fig 12 and fig 13. We know bending moment=load x perpendicular distance, as the load increases bending moment also increases. here number of column increased load also increased. Hence bending moment is increased.

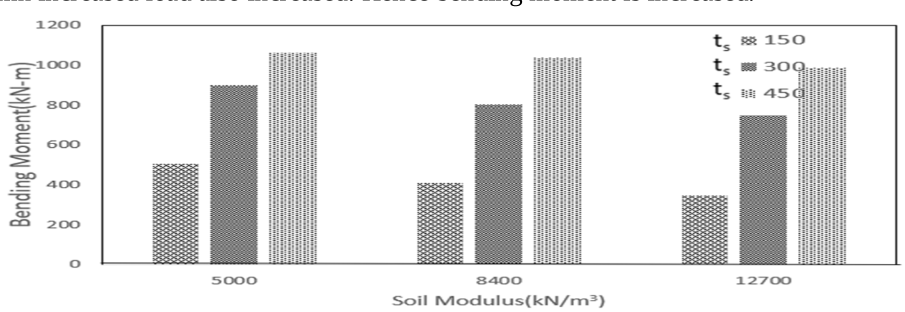

Fig. 10. Effect of maximum positive bending moment in x direction due to change in thickness (t_s) and modulus of subgrade reaction in sand

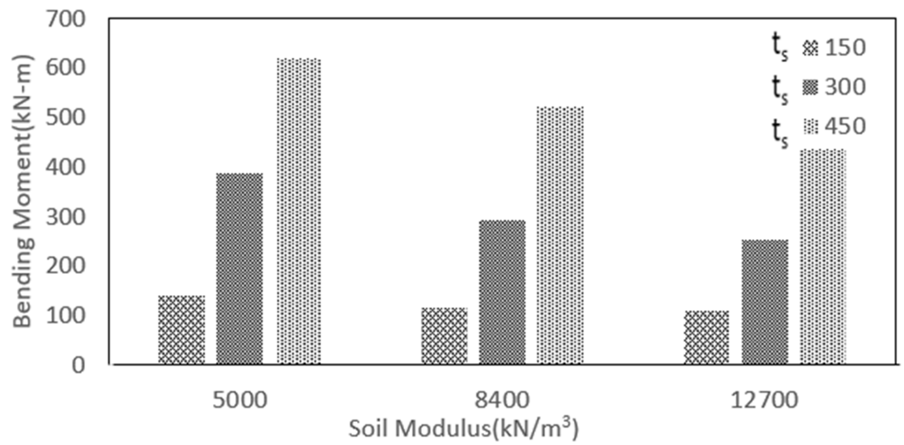

Fig. 11. Effect of maximum negative bending moment in x direction due to change in thickness (t_s) and modulus of subgrade reaction in sand.

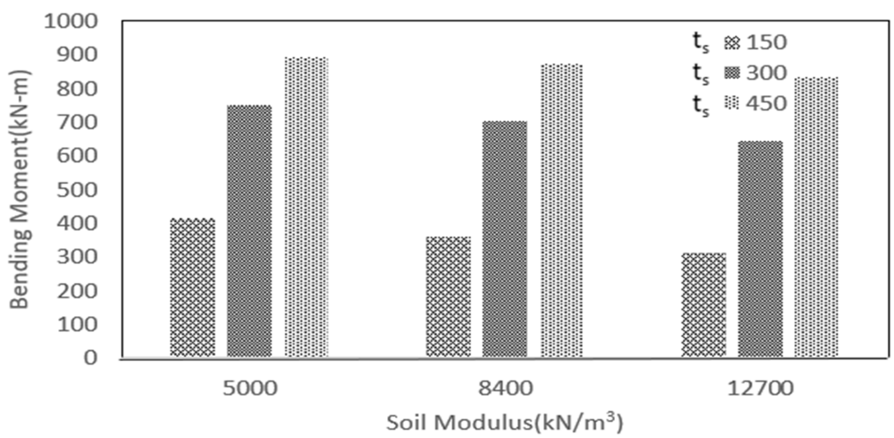

Fig. 12. Effect of maximum positive bending moment in y direction due to change in thickness (t_s) and modulus of subgrade reaction in sand.

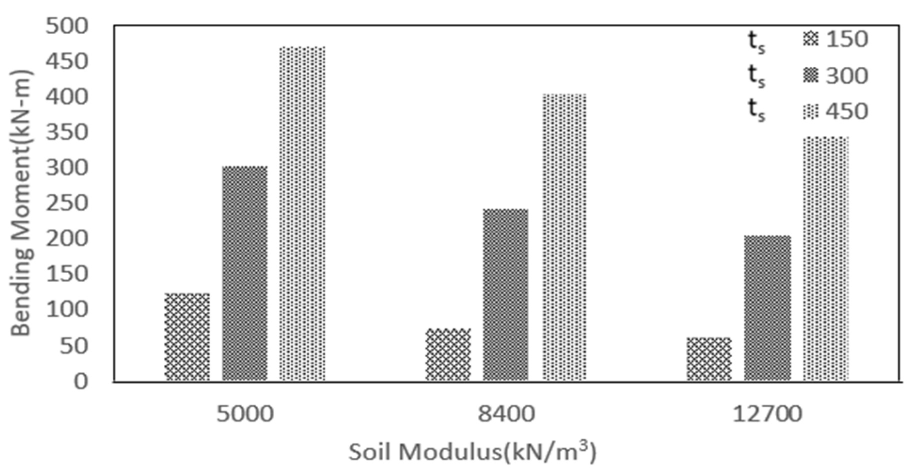

Fig. 13. Effect of maximum negative bending moment in y direction due to change in thickness (t_s)and modulus of subgrade reaction in sand.

V. CONCLUSION

A parametric study is carried out for different parameters to determine the effect of soil structure interaction subjected to different types of loads. The foundation is modelled using safe software considering thick plate. Based on results, the following conclusions can be drawn.

1) Measured parameters (such as displacements, soil pressure, punching shear and bending moment) are in good agreement with predicted value.
2) Displacement of raft foundation is decreased as increased in raft thickness. However, displacement of raft foundation is increased as decreased in soil modulus.
3) Raft foundation is unsafe when the thickness is less, however the foundation becomes safe considering higher values of raft thickness.
4) Maximum soil pressure decreased as increased in raft thickness. However, soil pressure increases with the increase of subgrade modulus.
5) Raft foundation is unsafe when soil modulus increases. However, the foundation becomes safe with higher value of raft thickness.
6) Punching shear ratio for raft foundation is decreased as increased in raft thickness. However, punching shear ratio for raft foundation is decreased slightly as increase in subgrade modulus.
7) Maximum punching shear observed at the center of raft foundation. Raft foundation is unsafe when thickness is less, however the foundation becomes safe considering higher values of raft thickness.
8) Maximum bending moment observed at center of raft. Maximum bending moment in both x and y direction are increases with increased thickness of raft. However, bending moments in x and y direction decreased with increased in subgrade modulus.
9) When number of column is increased the total load also increased. And displacement, maximum soil pressure, bending moment is also increased.

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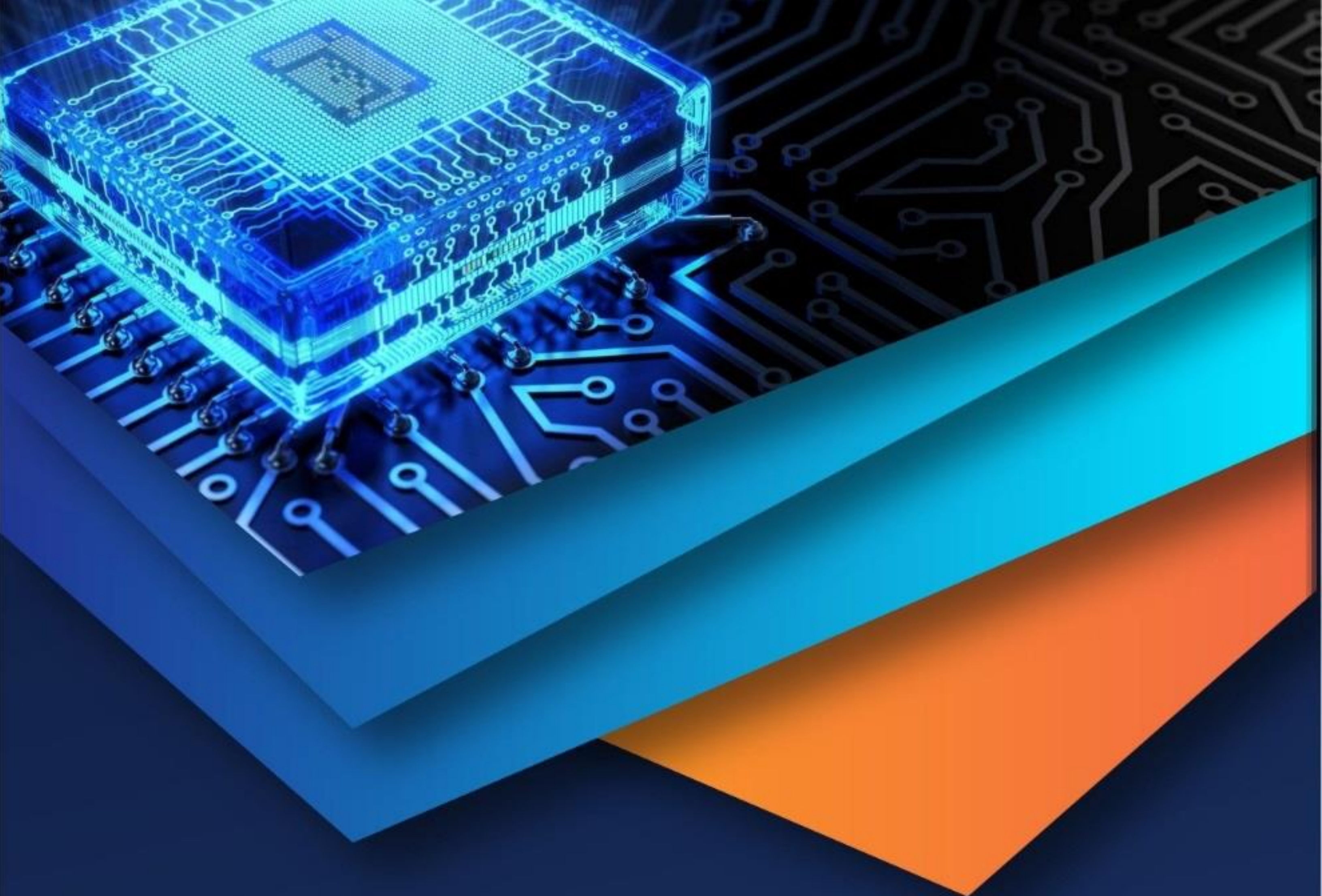

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