Innovations

Behaviour of Raft Foundations in the Alluvial Region of India

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Abstract:
A comprehensive study was conducted to investigate the behaviour of raft foundations in the alluvial region of India, considering key factors such as raft foundation design, soil characteristics, and load distribution. Raft foundations are commonly employed to distribute the load of a structure over a larger area, thereby minimizing the risk of settlement and ensuring structural stability. The study employed the use of Pasternak foundation models, which consider the interaction between the soil layers and the raft. This model considers the stiffness and damping characteristics of the soil, providing a more accurate representation of the behaviour of raft foundations. To analyse the raft foundation's response in alluvial soil, the study utilized the thick plate theory. This theory assumes the raft to be infinitely rigid, enabling a more realistic portrayal of the foundation's behaviour under varying loading conditions. The findings of the study indicated that raft foundations in alluvial soil experienced significant settlements due to the soil's low bearing capacity and compressibility. The Pasternak foundation models proved valuable in understanding stress distribution and settlement behaviour in such soil conditions. The study's outcomes offer insights that can enhance the design and construction of more efficient and reliable raft foundations in the alluvial regions of India. By incorporating the knowledge gained from this research, engineers and architects can optimize the stability and performance of structures in these areas. Moreover, the study highlights the importance of considering site-specific soil characteristics, such as alluvial soil properties, when designing raft foundations. By accounting for the unique behaviour of alluvial soil, engineers can mitigate potential issues and ensure the long-term durability of structures in this region.

Keywords*: raft foundation, Pasternak foundation, thick plate, Alluvial soil*

Introduction

The study aims to investigate the behaviour of raft foundations in the alluvial region of India, considering various analytical methods and techniques. Raft foundations play a vital role in ensuring the stability and performance of structures by distributing the load over a larger area, particularly in regions with alluvial soil, which is known for its soft and compressible nature. The conventional method of analysing raft foundations has been widely used in the past. However, this method often oversimplifies the soil-structure interaction, neglecting important factors that influence the foundation's behaviour. To address these limitations, alternative approaches such as the non-rigid or elastic method, Finite Element Method (FEM), and Finite Grid Method (FGM) have gained prominence. The non-rigid or elastic method considers the flexibility of both the raft and the soil, providing a more accurate representation of their interaction. This method incorporates the concept of Pasternak foundation models, which account for the stiffness and damping characteristics of the alluvial soil. Finite Element Method (FEM) and Finite Grid Method (FGM) are numerical techniques that can simulate complex soil-structure interactions. FEM breaks down the foundation and soil into smaller elements, solving the governing equations for each element to obtain an overall behaviour. On the other hand, FGM discretizes the soil and raft into a grid, allowing for the analysis of stress and settlement distribution. By applying these advanced analytical methods, the study aims to provide a comprehensive understanding of raft foundation behaviour in alluvial soil. It seeks to assess factors such as settlement, stress distribution, and load-bearing capacity, with a focus on the stability and performance of structures in the alluvial region of India. The findings of this study have the potential to enhance the design and construction practices for raft foundations in alluvial regions. By incorporating the knowledge gained from advanced analytical methods, engineers can develop more accurate and reliable designs, ensuring the long-term durability and safety of structures in alluvial soil conditions.

Modelling of raft with Finite element

Modelling a raft foundation using the Finite Element Method (FEM) involves dividing the foundation and surrounding soil into discrete elements to analyse their behaviour under different loading conditions. FEM is a numerical technique widely used for structural analysis and provides a detailed understanding of stress distribution, deformation, and settlement.

The process of modelling a raft foundation with FEM typically includes the following steps:

- Geometry and Mesh Generation: The geometry of the raft foundation is defined, including its shape, dimensions, and any irregularities. The model is then discretized by generating a mesh, dividing the foundation and soil into smaller finite elements. The type and size of the elements depend on the complexity of the analysis and desired accuracy.
- Material Properties: The material properties of the raft foundation and soil layers are assigned to the corresponding finite elements. These properties include elastic modulus, Poisson's ratio, shear modulus, and other relevant parameters that describe the mechanical behaviour of the materials.
- Boundary Conditions: Boundary conditions are applied to simulate real-world scenarios. Fixed supports, applied loads, and constraints representing interactions with the surrounding structures, or the ground are specified. These conditions ensure the model accurately represents the foundation's behaviour.
- Load Application: The loads acting on the raft foundation, such as dead loads, live loads, and soil pressures, are applied to the model. The magnitude, distribution, and nature of the loads are considered based on design requirements and project-specific conditions.
- Solution and Analysis: The FEM software solves the equations representing the behaviour of the finite elements, calculating the displacements, stresses, and strains within the model. The results provide insights into the response of the raft foundation under different loading scenarios.
- Evaluation and Design Optimization: The results obtained from the FEM analysis are evaluated to assess factors like settlement, stress concentrations, and bearing capacity. Based on these findings, design modifications can be made to optimize the performance and stability of the raft foundation.

Through FEM modelling, engineers gain valuable insights into the behaviour of raft foundations, allowing them to make informed decisions regarding design improvements and ensure the structural integrity and safety of the foundation. FEM provides a powerful tool for analysing complex soil-structure interactions and aids in optimizing the design of raft foundations for various loading conditions.

In this, with the help of Finite element method the raft which is assumed as a plate and soil as elastic foundation have been transformed into a matrix structural analysis. The raft or plate have been transformed into a mesh of finite elements which are interconnected at the corners or nodes and the soil has been modelled in form of isolated springs like Pasternakfoundation. This analysis of raft with the help of finite element is based on theory of thick plates resting on Pasternak foundation as shown in Figure 1. Transverse shear deformation of the plate is considered during analysis with FEM. It is assumed that the deflection in the plate is very small as compared with the thickness of the plate.

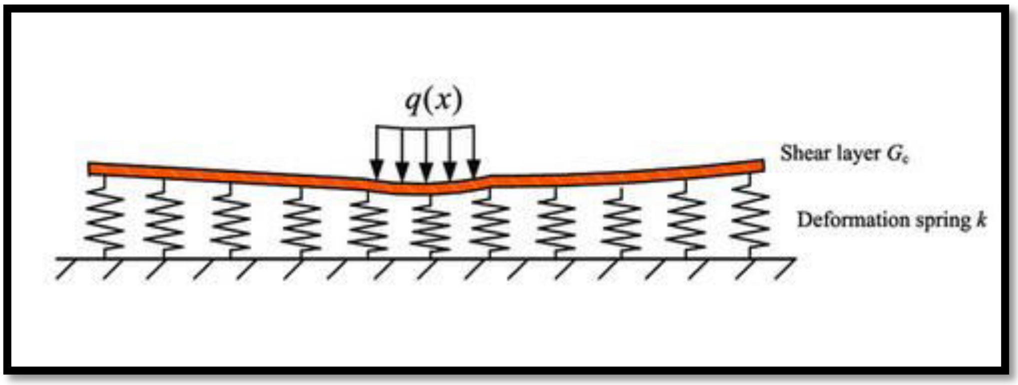


Figure -1, Pasternak foundation Model

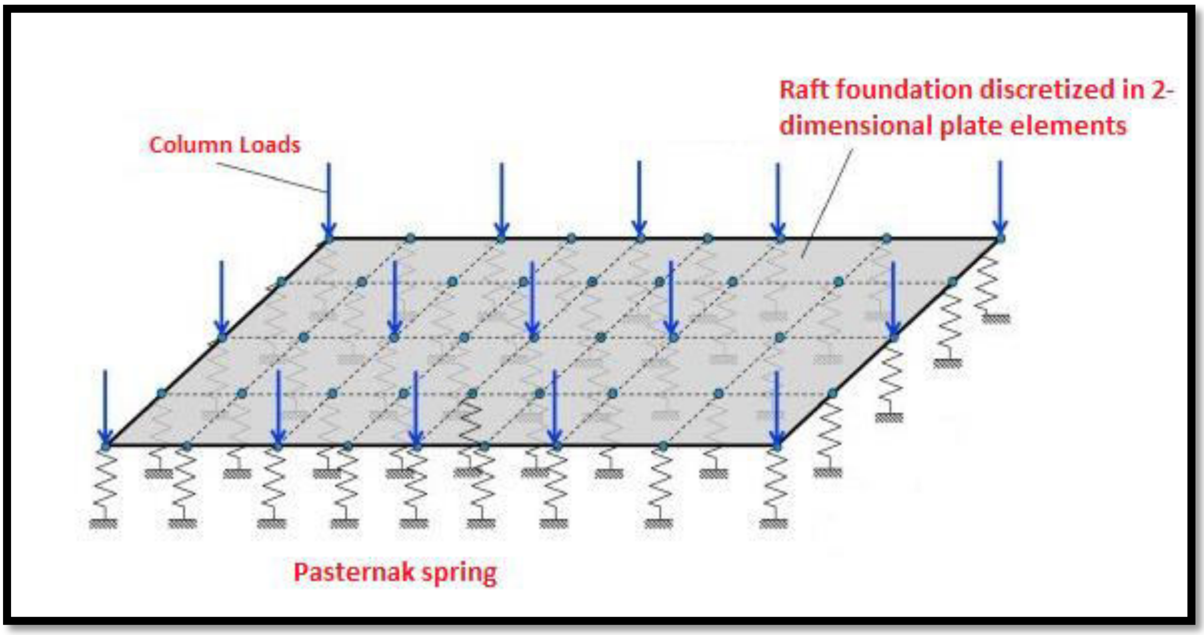


Figure-2, Structural idealisation of raft and supporting soil

Parametric Study

A parametric study was conducted to investigate the behaviour of raft foundations in the alluvial region of India. The study aimed to analyse the impact of various design parameters on the performance of raft foundations in alluvial soil conditions. Factors such as raft dimensions, soil properties, and loadings were varied systematically to assess their influence on settlement, stress distribution, and bearing capacity. The study utilized advanced analytical methods, such as finite element analysis, to simulate and analyse the behaviour of raft foundations. The findings from this parametric study provide valuable insights for optimizing the design and construction practices of raft foundations in the alluvial region of India, ensuring their stability and performance in this specific geological setting.

The effect of following parameters will be studied on the rectangular raft foundation system using Finite element method.

1. Raft Thickness (0.45m, 0.9m, 1.5m)
2. Modulus of subgrade reaction (40000, 100000, 200000, 400000) kN/m3,
3. Loads of Column on Raft (three load patterns LP-I, LP-II, LP-III as indicated in Figure 3)

The effect of variation of raft thickness and soil modulus on specific load patterns have been studied. Different raft dimensions have been taken for different Load Patterns for the study, Raft dimension of 10 x 10 has been considered for load pattern I, Raft dimension of 15 x 12 for load pattern II and Raft dimension of 20 x 14 for load pattern III.

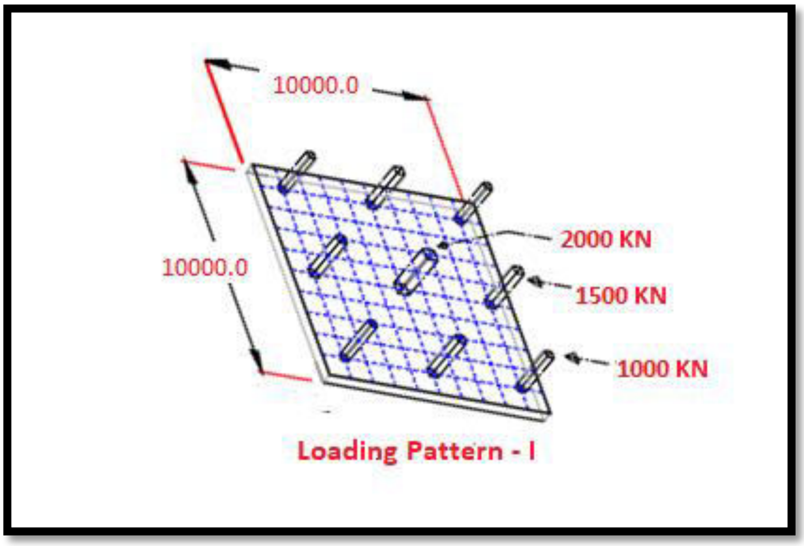


Figure-3, Shows Loading pattern 1

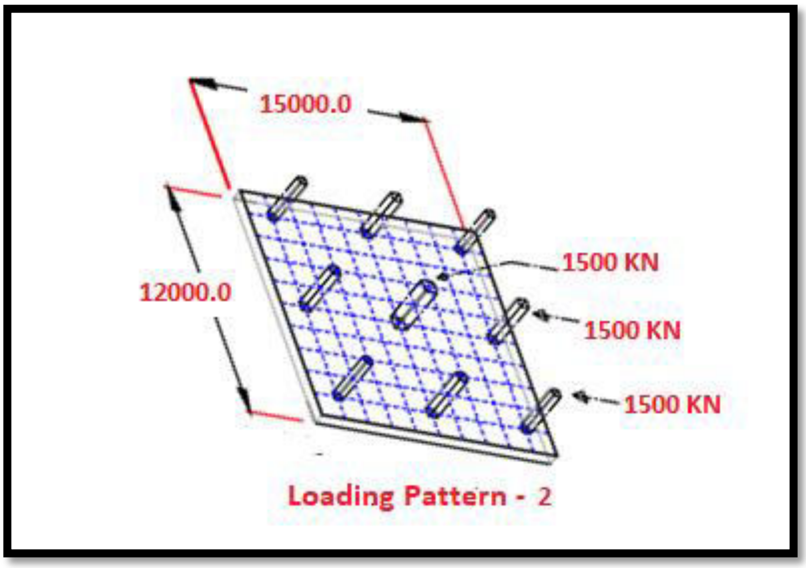


Figure-4, Shows Loading pattern 2

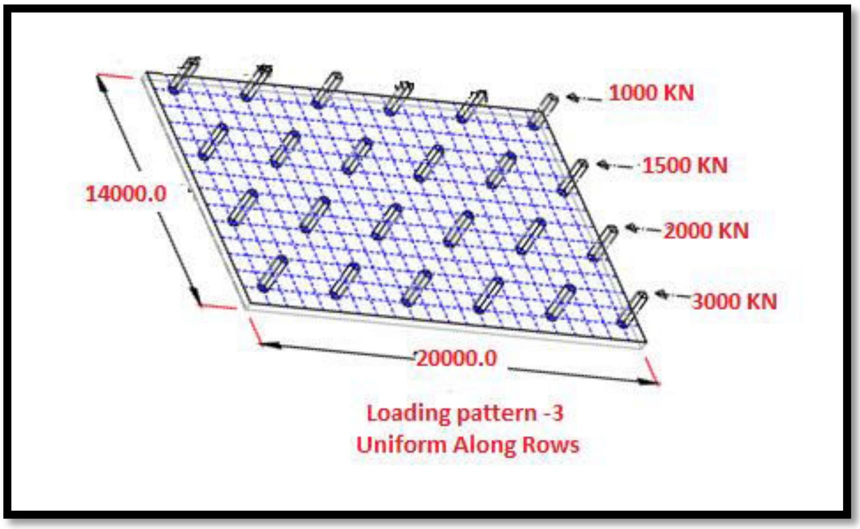


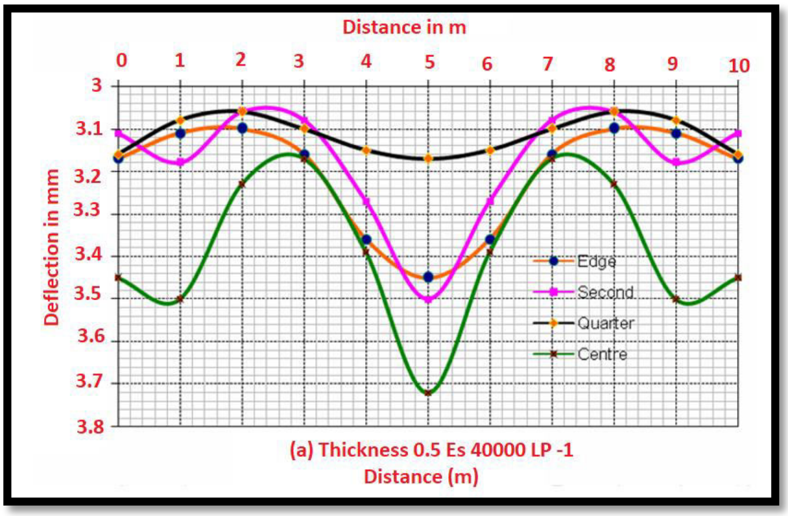
Figure-5, Shows Loading pattern 3

Loadingpattern, I

In Figure 6 (a) deflection pattern at different position in the raft has been presented and in Figure 6 (b) deflection along central line at different thickness of raft has been compared. figure shows deflection at the centre line is more, as the thickness of the raft increases the deflection curve becomes flat. For different thickness of raft, Maximum deflection with the help of soil modulus has been shown in table- 2. With increase in raft thickness and soil modulus it was seen that maximum deflection decreases. Bending moment at different thicknesses of raft has been shown in Figure -7. It can be seen from the figure that, there is no effect of thickness of raft on Bending moment.

Table-2 Comparison of Maximum Deflection

Raft Thickness (m)	Maximum Deflection (mm) for soil Modulus			
	40000	100000	200000	400000
o.5	**4.84**	**2.43**	**1.32**	**0.84**
1.0	**4.66**	**2.32**	**1.23**	**0.75**
1.5	**4.75**	**2.36**	**1.12**	**0.56**



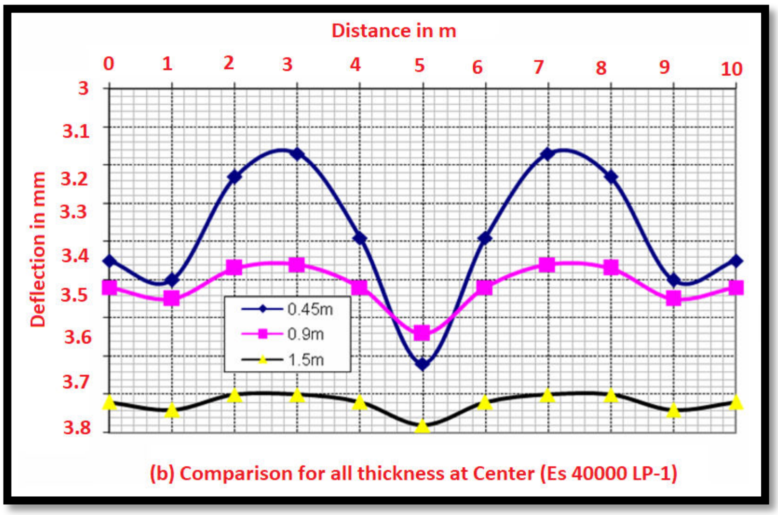
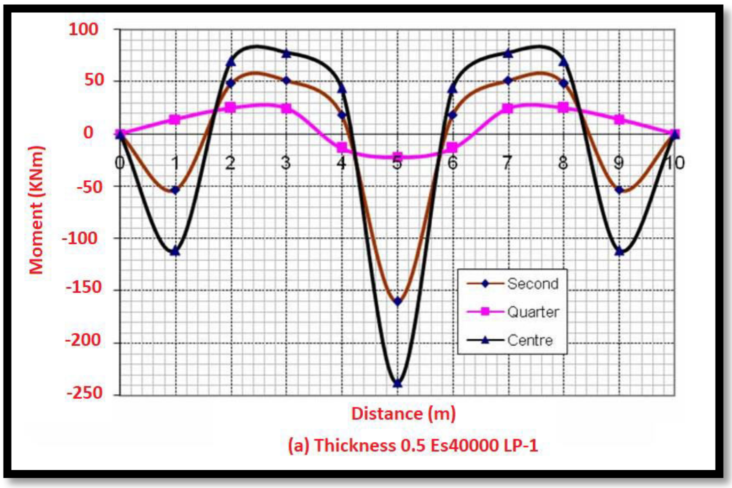


Figure -6, Deflected shapes at Loading pattern -1



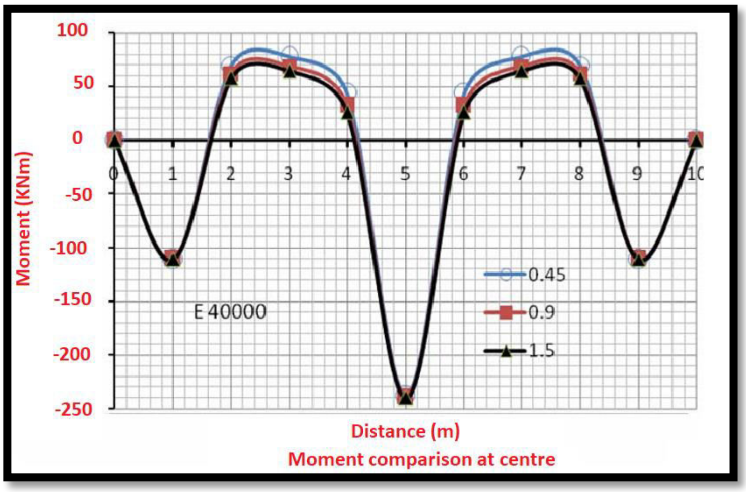


Figure -7, Moment diagram for Loading patten -1

Loading pattern II

In Figure 8 and Figure 9, the effect of variation of raft thickness on deflection and bending moment has been shown. In Table -3, the effect of variation of raft thickness and soil modulus on maximum deflection has been shown, Table shows that with increase in soil modulus, there is decrease in maximum deflection. In Table-4 the effect of variation of raft thickness on Bending moment has been shown. Table -4 shows that with variation in raft thickness, the positive Bending moment increases and negative Bending moment decreases, but in case of variation of soil Modulus this is opposite.

Table -3, Effect of soil modulus and thickness on Deflection

Soil Modulus	Maximum Deflection in mm		
	0.5 m	1.0 m	1.5 m
40000	3.23	3.10	3.50
100000	1.54	1.60	1.56
200000	1.12	1.14	1.12
400000	0.53	0.51	0.56

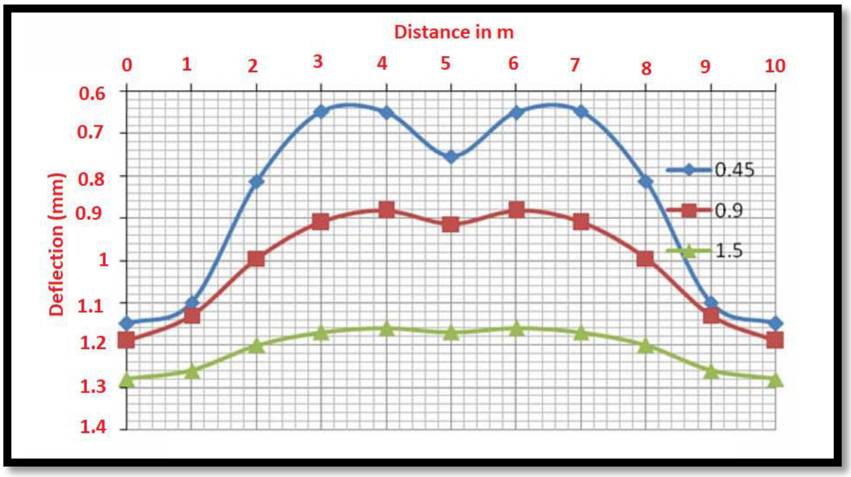


Figure -8, Comparison for all thickness at Loading pattern -II

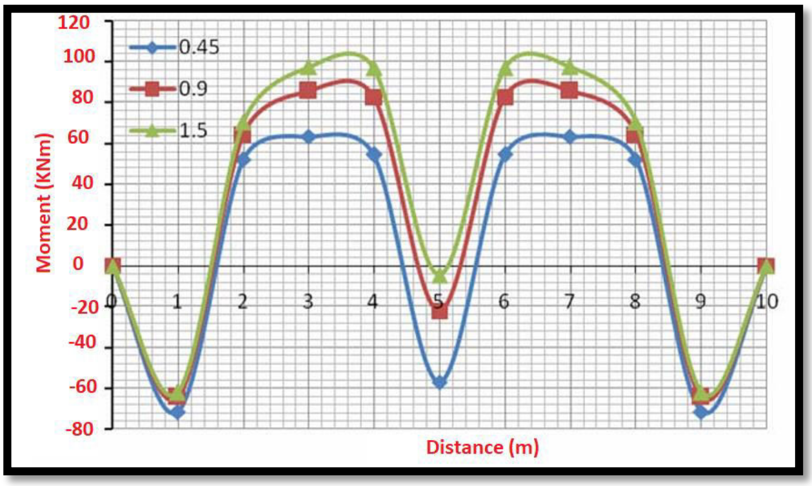


Figure- 9, Combined thickness at centre at Loading pattern -II

Table 4, Effect of Thickness

Raft Thickness	Max. Positive BM			Max. Negative BM		
	Second	Quarter	Centre	Second	Quarter	Centre
o.5	80.56	47.65	68.65	-77.04	0	-75.54
1.0	95.09	71.23	90.65	-71.65	0	-70.11
1.5	99.98	89.87	99.31	-69.21	0	-66.05

Loading pattern III

In Figure 10 and Figure 11, effect of variation of raft thickness on deflection and Bending Moment have been shown. In Table -6, Effect of variation in raft thickness on deflection and Bending moment have been shown. Table shows thatwith increase in raft thickness the deflection in raft is decreasing and the positive bending moment is increasing with increase in raft thickness and negative bending moment remain constant with variation in raft thickness.

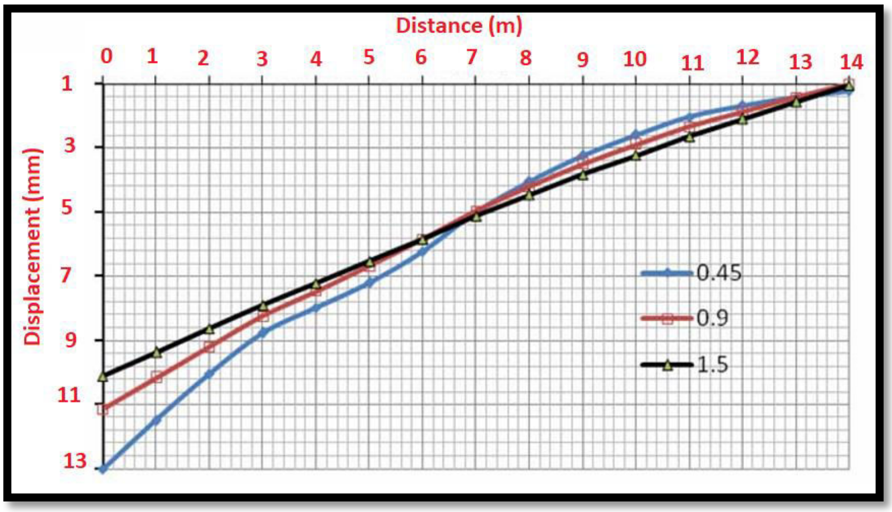


Figure- 10, Thicknesses of raft at Edge

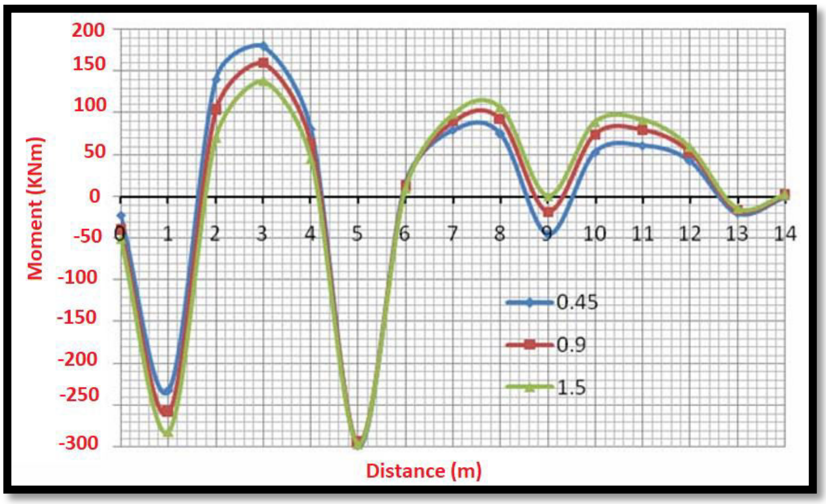


Figure -11, comparisons of raft thickness at Loading pattern III

Table -6 Comparison of maximum values of raft all thickness at LP-III

Raft Thickness	Maximum values		
	Deflection (mm)	Positive BM (KNm)	Negative BM (KNm)
0.5	15.00	180.34	-300.32
1.0	12.13	210.82	-310.43
1.5	11.23	235.06	-305.32

Conclusions

The study on the behaviour of raft foundations in the alluvial region of India provides significant insights into their performance in this specific soil condition. The findings indicate that raft foundations in alluvial soil experience notable settlements due to the soil's low bearing capacity and compressibility. The utilization of advanced analytical methods, such as finite element analysis, enables a better understanding of stress distribution and settlement behaviour. This study's outcomes contribute to the optimization of raft foundation design and construction practices in the alluvial region, ensuring the stability and performance of structures. By considering site-specific factors, such as alluvial soil properties, engineers can mitigate potential issues and enhance the durability of structures in these areas. Further research and implementation of the study's recommendations will lead to more efficient and reliable raft foundation designs in the alluvial regions of India.

In this study, raft foundation system has been studied in alluvial region and the effect of variation of raft thickness, soil modulus and load pattern on raft have been observed. It can be seen from the above studies that, deflection in the raft is increasing at lower soil modulus and increasing at higher soil modulus at a given raft thickness. It can also be seen that, with variation in thickness of the raft, positive bending moment is increasing, and negative bending moment is decreasing. In case of soil modulus, positive bending moment are decreasing with increasing soil modulus and Negative bending moment is reducing with increasing soil modulus.

References

1. *Franke E, El-Mossallamy Y, Wittmann P (2000) Calculation methods for raft foundation in Germany. In: Hemsley JA (ed) Design applications of raft foundation. Thomas Telford, London, pp 283–322*
2. *Burland J (1977) Piles as settlement reducers. In: Proceedings on 19th National Italian geotechnical conference Padova, Italy, vol 2, pp 21–34*
3. *Viggiani C. (2001) Analysis and design of piled raft foundations. First Arrigo Croce Lecture, RivistaItaliana Di Geotechnica, pp 47–75*
4. *El-Mossallamy Y, Lutz B, Richter Th (2006) Innovative application and design of piled raft foundation. In: 10th international conference on piling and deep foundations, Amsterdam, Netherlands*
5. *Burland JB, Broms BB, de Mello VFB (1977) Behavior of foundations and structures. In: Proceedings of 9 ICSMFE, Tokyo 2, pp 495–546*
6. *Padfield CJ, Sharrock MJ (1983) Settlement of structures on clay soil. Construction Industry Research and Information Institute, Special Publication 27, CIRIA Ed, London*
7. *Indian Standard Code of Practice of design and construction of raft foundation, IS 2950 (Part I), 1973.*
8. *International conference on planning and design of tall buildings, Le high University 1972 - System and concepts foundation design -Technical Committee 11.*
9. *Design of combined footings and mats, ACI Committee 336, ACI Journal October 1966, Revalidated 1980.*
10. *Some Aspects of Interactive Structural Design, F. Sawko and R.J. Cope, The structural engineer, June 1974.*
11. *Some recent foundation research and its application in Design, Meyerhof, The Structural En- gineer, 1953.*
12. *Structural Failure in Residential Buildings, Schild. Oswald, Rogier, Schwciket, Schn A Puuff, Vol 111, Basements, and adjoining structures.*
13. *Method of determination of modulus of subgrade reaction (K Value) of soils in field, IS 9214, 1979.*
14. *Method of tests for soils, Part XI, Determination of shear strength parameters of specimen tested in unconsolidated undrained triaxial compression test without the measurement of pore water pressure, IS: 2720 (Part XI), 197 1.*
15. *Method of test for soils, Part XII, Determination of shear strength parameters of soil from con- solidated undrained triaxial test with measurement of pore water pressure (first version), IS: 2720 (Part XII) 198 1.*
16. *"Raft Analysis and Design, Some practical examples", J.A. Hooper, The Structural Engineer, August 1984*
17. *"Bending of Beams Resting on Isotropic Elastic solids", A.S. Vesic, Jounurl Engineering Mechanics Division, ASCE, Vol87 EM2, April 1961.*
18. *"Estimating the settlements of foundations on sand ALPAN", I, Civil Engineering and Public Work Review, London, Vol. 59, November 1964.*
19. *Reinforced Concrete Designers Handbook, Charles E. Reynold, and James C. Sleedman 10th Edi- tion, 1988.*

20. *Suggested Analysis and design procedure for combined footings and mats, Report of ACI committee 336 DOC NO. ACI 336 2 R 88, (available in ACI manual 93)*
21. *"Geotechnique Today", Proceedings of Indian Geotechnical Conference 1992, Calcutta, December 18-20th, 1992.*
22. *Thirteenth international conference on soil mechanics and foundation engineering, Delhi, January 1994*
23. *Design of Foundation Systems, N.P. Kurian, Narosa Publishing House, New Delhi, 1993.*
24. *Proceedings of eleventh international conference on Soil Mechanics and Foundation Engineering, San Francisco, 1988*
25. *Pile Foundation Analysis and Design, H.G. Poulos and E.H Davis, 1980*
26. *Soil structure interaction. The real behaviour of structures, Institution of Structural Engineers, The Institution of Civil Engineers, UK. International Association of Bridge and Structural Engineers, 1989.*
27. *Beedle LS et al. (2007:13, 14) The Skyscraper and the City: Design, Technology, and Innovation, Books 1. Lewiston, NY: The Edwin Mellen Press*
28. *Challinger D. (2008:4) From the Ground Up: Security for Tall Buildings CRISP Report. Alexandria, VA: ASIS Foundation Research Council*
29. *Chatterjee K (2015) Soil liquefaction and bearing capacity at a building site in Lucknow, India under earthquake conditions Disaster Advances Vol. 8 (5) May (2015)*
30. *Cubrinovski M (2011) Foundations on Deep Alluvial Soils Technical Report Prepared for the Canterbury Earthquakes Royal Commission University of Canterbury, Christchurch*
31. *Gangisetty K V et al. (2018), Issues in Design of Tall Concrete Buildings in India with Reference to Is 16700: 2017 Code, (International Conference on Advances in Construction Materials and Structures (ACMS-2018)*
32. *Hall Jr JR. (2005:2) High-Rise Building Fires. Quincy, MA: National Fire Protection Association; August*
33. *Harry G. Poulos (2011) The Design of High-Rise Building Foundations Coffey Geotechnics, Sydney, Australia Geotec Hanoi October ISBN 978-604-82-000-8*
34. *Mir M. Ali (2012) Tall Buildings and Urban Habitat of the 21st Century: A Global Perspective Buildings 2012, 2, 384-423;*
35. *Polous H (2010) The design of foundations for high-rise buildings, Proceedings of ICE, Civil Engineering 163 November Pages 27–32 Paper 10-00005*
36. *Polous H2011 October the Design of High-Rise Building Foundations,INTERNATIONAL CONFERENCE GEOTEC HANOI 2011 "Geotechnics for Sustainable Development", in Hanoi, 6th-7th October 2011*
37. *Shukla A et al. (2019) Critical analysis of rural-urban transitions and transformations in Lucknow city, India Remote Sensing Applications: Society and Environment 13 445–456*