International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Finite Element Analysis of Raft Foundation Using Soil–Structure Interaction

Mr. Rehan Raeesahmed Shaikh[1], **Prof. Dr. P. P Tapkire**[2]

[1]Structural Engineer
[2]Head of Department, Civil Engineering, NBNSCOE

ABSTRACT

Raft foundations are widely adopted for supporting multi-storey buildings constructed on weak and compressible soils because they distribute structural loads over a larger area and minimize differential settlement. Conventional foundation design generally assumes rigid supports, whereas the actual behaviour of foundations is significantly influenced by the interaction between the structure and the supporting soil. Neglecting Soil–Structure Interaction (SSI) may lead to inaccurate estimation of settlement, contact pressure and stress concentration within the foundation system.
The present research investigates the behaviour of reinforced concrete raft foundations considering Soil–Structure Interaction through three-dimensional Finite Element Analysis. Twelve numerical case studies were developed by considering three building plan dimensions (15.24 m × 15.24 m, 21.34 m × 21.34 m and 27.43 m × 27.43 m) combined with four building heights (15, 18, 21 and 24 storeys). Structural modelling and load extraction were carried out using ETABS, whereas detailed finite element analysis was performed using ANSYS Workbench. Loose soil conditions having a Safe Bearing Capacity
of 150 KN/m² were considered throughout the investigation. The behaviour of raft foundations was evaluated in terms of settlement, soil stress, raft stress and pressure distribution under both SSI and conventional fixed-support conditions. The numerical investigation indicates that the inclusion of Soil–Structure Interaction significantly reduces stress concentration within the raft foundation by allowing redistribution of structural loads through the supporting soil. The results demonstrate that finite element modelling considering SSI provides more realistic prediction of foundation behaviour than conventional rigid-support analysis and contributes towards safer and more economical foundation design.

Keywords: Raft Foundation, Soil–Structure Interaction, Finite Element Analysis, ETABS, ANSYS Workbench, Settlement Analysis, Foundation Engineering.

1. INTRODUCTION

Rapid urbanization and increasing demand for high-rise buildings have resulted in construction on sites having loose and compressible soil deposits. Under such conditions, the performance of the entire structure largely depends upon the behaviour of its foundation system. The foundation transfers structural loads safely to the supporting soil while maintaining stability and controlling settlement. Therefore, realistic evaluation of foundation behaviour is essential for ensuring structural safety, durability and serviceability.

Raft foundations, also known as mat foundations, are widely adopted for multi-storey buildings because they distribute structural loads over a comparatively larger area. This reduces contact pressure on the soil and minimizes differential settlement. Raft foundations are particularly suitable for loose soils where isolated footings may not provide satisfactory structural performance.

In conventional structural analysis, foundations are generally assumed to rest on rigid supports. Although this assumption simplifies structural analysis, it neglects the deformable behaviour of the supporting soil. In reality, the soil undergoes settlement when subjected to structural loading, thereby influencing the behaviour of both the foundation and the superstructure. This mutual interaction between soil and structure is commonly known as Soil–Structure Interaction (SSI). Considering Soil–Structure Interaction provides a realistic representation of foundation behaviour because soil deformation influences stress redistribution, settlement characteristics and load transfer mechanisms. Neglecting SSI may result in overestimation of raft stresses and inaccurate prediction of settlement behaviour. Consequently, modern foundation engineering increasingly incorporates SSI during structural analysis and design.

The Finite Element Method (FEM) has emerged as one of the most reliable numerical techniques for analysing complex structural and geotechnical problems. Advanced numerical software enables engineers to model realistic interaction between soil and foundation while evaluating settlement, stress distribution, deformation patterns and pressure bulb development. The integration of structural analysis software with finite element software provides accurate prediction of foundation behaviour under practical loading conditions.

In the present investigation, reinforced concrete buildings having different plan dimensions and building heights were analysed using ETABS to determine structural loading. The extracted column loads were subsequently transferred to ANSYS Workbench, where detailed Soil– Structure Interaction analysis was carried out through three-dimensional finite element modelling. Twelve different numerical models representing three building sizes and four storey configurations were analysed under identical loose soil conditions. Comparative analyses were performed considering both Soil–Structure Interaction and conventional fixed-support assumptions to evaluate their influence on raft foundation behaviour. The outcomes of this study provide practical guidance for engineers involved in the analysis and design of raft foundations supporting multi-storey buildings constructed on loose soils. The research also demonstrates the importance of finite element modelling for realistic evaluation of settlement and structural stresses.

2. PROBLEM STATEMENT

Construction of multi-storey reinforced concrete buildings on weak and loose soils has increased considerably due to rapid urban development. Although raft foundations are widely adopted under such soil conditions, conventional foundation analysis generally assumes rigid supports and neglects the flexibility of the supporting soil. Such assumptions frequently produce unrealistic stress concentrations and conservative structural designs.

The interaction between the raft foundation and supporting soil considerably influences settlement behaviour, contact pressure distribution and structural response. Therefore, detailed numerical investigation considering Soil–Structure Interaction becomes necessary for evaluating actual foundation behaviour.

The present research addresses this problem by performing a comparative finite element investigation of raft foundations under both Soil–Structure Interaction and fixed-support conditions. Different building heights and raft dimensions are analysed to evaluate settlement characteristics, raft stresses, soil stresses and load transfer mechanisms under identical soil conditions.

3. LITERATURE REVIEW

Several researchers have investigated the behaviour of raft foundations using analytical, experimental and numerical approaches. Recent developments in Finite Element Analysis have significantly improved the understanding of Soil–Structure Interaction by enabling realistic simulation of foundation behaviour under different loading conditions.

Previous investigations have reported that Soil–Structure Interaction considerably influences stress redistribution, settlement behaviour and contact pressure beneath raft foundations. Numerical studies using finite element software have demonstrated that consideration of soil flexibility generally produces lower stress concentration compared with conventional rigid support analysis. Researchers have also investigated piled raft systems, interface modelling techniques and vibration behaviour of foundation systems under static and dynamic loading. Although substantial research has been carried out on raft foundations, many published studies focus on limited structural configurations or individual case studies. Comparative evaluation of multiple building heights and raft dimensions under identical loose soil conditions remains comparatively limited. Furthermore, practical comparison between Soil–Structure Interaction and conventional fixed-support analysis using integrated ETABS and ANSYS modelling has received relatively less attention.

To address these research gaps, the present investigation evaluates twelve different numerical models representing three building plan dimensions and four storey heights using integrated structural and finite element analysis. The study focuses on settlement behaviour, soil stress distribution, raft stresses and comparative evaluation between SSI and non -SSI conditions, thereby providing practical recommendations for economical raft foundation design on loose soils.

4. METHODOLOGY

The present investigation adopts an integrated structural and geotechnical numerical approach to evaluate the behaviour of raft foundations considering Soil–Structure Interaction (SSI). Structural modelling was carried out using ETABS, whereas three-dimensional finite element analysis was performed using ANSYS Workbench. The adopted methodology consists of structural modelling, load extraction, raft foundation modelling, soil modelling, finite element analysis and comparative evaluation of results.

4.1 Structural Modelling

Three reinforced concrete building plan dimensions of 15.24 m × 15.24 m, 21.34 m × 21.34 m and 27.43 m × 27.43 m were considered. For each building size, four different heights of 15, 18, 21 and 24 storeys were analysed, resulting in twelve numerical case studies.

Structural models were developed in ETABS using M30 grade concrete and Fe450 reinforcement. Dead load, live load and self-weight were considered during structural analysis. Column reactions obtained from ETABS were transferred to ANSYS for foundation analysis.

4.2 Soil and Foundation Modelling

A three-dimensional soil block representing loose soil conditions was developed in ANSYS Workbench. The raft foundation was modelled using reinforced concrete material properties while the supporting soil was assigned appropriate elastic properties.

The raft and soil were connected using contact interaction to simulate realistic load transfer behaviour. The bottom surface of the soil block was restrained while lateral boundaries were appropriately constrained to represent field conditions.

Safe Bearing Capacity (SBC) of soil was considered as 150 KN/m² throughout the investigation.

4.3 Finite Element Analysis

Finite element meshing was carried out using higher-order solid elements to obtain accurate stress distribution and settlement characteristics. Two analyses were performed for each numerical model.

Case I

Analysis considering Soil–Structure Interaction (SSI)

Case II

Analysis without Soil–Structure Interaction (Rigid Support)

The numerical investigation evaluated

- Maximum raft stress
- Minimum raft stress
- Soil stress
- Settlement
- Pressure distribution
- Load transfer mechanism

The obtained numerical results were compared to evaluate the influence of Soil–Structure Interaction on foundation behaviour.

5. RESULTS AND DISCUSSION

5.1 Variation of Stresses with Height for Smaller Raft Size

Observation:

The maximum raft stress obtained for Case C1 considering Soil–Structure Interaction (SSI) is 18.6 MPa, whereas the maximum raft stress without considering SSI is 24.0 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raf t foundation by approximately 22.5%. This demonstrates that SSI provides a more realistic distribution of stresses between the foundation and supporting soil, thereby improving the overall structural behaviour of the raft foundation.

Observation:

The maximum raft stress obtained for Case C2 considering Soil–Structure Interaction (SSI) is 20.8 MPa, whereas the maximum raft stress without considering SSI is 26.0 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raft foundation by approximately 20.0%. The soil flexibility

allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

Observation:

The maximum raft stress obtained for Case C3 considering Soil–Structure Interaction (SSI) is 23.5 MPa, whereas the maximum raft stress without considering SSI is 29.0 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raft foundation by approximately 19.0%. The soil

flexibility
allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

Observation:

The maximum raft stress obtained for Case C4 considering Soil–Structure Interaction (SSI) is 22.0 MPa, whereas the maximum raft stress without considering SSI is 29.0 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raft foundation by approximately 24.1%. The soil flexibility
allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

5.2 Variation of Stresses with Height For Moderate Raft Size

Observation:

The maximum raft stress obtained for Case C5 considering Soil–Structure Interaction (SSI) is 18.5 MPa, whereas the maximum raft stress without considering SSI is 24.0 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raft foundation by approximately 22.9%. The soil flexibility
allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

Observation:

The maximum raft stress obtained for Case C6 considering Soil–Structure Interaction (SSI) is 20.5 MPa, whereas the maximum raft stress without considering SSI is 26.0 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raft foundation by approximately 21.2%. The soil flexibility
allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

Observation:

The maximum raft stress obtained for Case C7 considering Soil–Structure Interaction (SSI) is 21.8 MPa, whereas the maximum raft stress without considering SSI is 27.0 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raft foundation by approximately 19.3%. The soil flexibility
allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

Observation:

The maximum raft stress obtained for Case C8 considering Soil–Structure Interaction (SSI) is 24.2 MPa, whereas the maximum raft stress without considering SSI is 30.0 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raft foundation by approximately 19.3%. The soil flexibility
allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

5.3 Variation of Stresses with Height For Bigger Raft Size

Observation:

The maximum raft stress obtained for Case C9 considering Soil–Structure Interaction (SSI) is 25.9 MPa, whereas the maximum raft stress without considering SSI is 32.3 MPa. It is observed that the inclusion

of SSI reduces the stress concentration in the raft foundation by approximately 19.8%. The soil flexibility
allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

Observation:

The maximum raft stress obtained for Case C10 considering Soil–Structure Interaction (SSI) is 27.6 MPa, whereas the maximum raft stress without considering SSI is 34.5 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raft foundation by approximately 20.0%. The soil flexibility allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

Observation:

The maximum raft stress obtained for Case C11 considering Soil–Structure Interaction (SSI) is 29.8 MPa, whereas the maximum raft stress without considering SSI is 37.0 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raft foundation by approximately 19.5%. The soil flexibility allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

Observation:

The maximum raft stress obtained for Case C12 considering Soil–Structure Interaction (SSI) is 31.0 MPa, whereas the maximum raft stress without considering SSI is 39.0 MPa. It is observed that the inclusion of SSI reduces the stress concentration in the raft foundation by approximately 20.5%. The soil flexibility allows redistribution of stresses, resulting in a more realistic and economical design. Hence, SSI analysis provides better representation of actual field conditions.

6. Summary of Results

The present study investigates the behaviour of raft foundations subjected to Soil-Structure Interaction (SSI) using Finite Element Analysis (FEA). A total of twelve case studies were analysed Considering three
different building plan dimensions (15.24 m × 15.24 m, 21.34 m × 21.34 m and 27.43 m × 27.43 m) and Four building heights (15, 18, 21 and 24 storeys). The structural loads obtained from ETABS were Transferred to ANSYS for detailed SSI analysis. The comparison was carried out between models Considering SSI and models without SSI (fixed support condition).

The results obtained from all twelve cases Indicate that the stresses developed in the raft Foundation increase with increase in building height and structural loading. Similarly, the raft size Also increases with increase in building dimensions and load carrying requirements. The finite Element analysis provided realistic stress distribution, settlement behaviour and contact pressure Variation within the raft-soil system.

Table No. 5.13: Summary of Results for All Cases

From the comparative analysis, it is observed that the maximum raft stress for Case C1 is 18.6 MPa under SSI condition and 24.0 MPa under fixed support condition. Similarly, for Case C12, the maximum raft stress increases to 24.8 MPa under SSI condition and 31.0 MPa under fixed support condition due to increase in structural loading and raft dimensions. The percentage-based evaluation indicates that raft stresses increase with increasing structural load; however, the rate of stress increase varies depending on soil flexibility and raft dimensions.

The SSI model consistently shows lower stress values compared to the fixed support model. The reduction In maximum raft stress ranges between 18% and 25% for different cases. For Cases C1 to C4, a 60.1% Increase in load resulted in approximately 33.3% increase in maximum raft stress under SSI condition. Similarly, for Cases C5 to C8 and Cases C9 to C12, the increase in maximum raft stress was approximately 30.8% and 21.4%, respectively. These results indicate that soil flexibility helps redistribute stresses and Reduce stress concentration within the raft foundation. The percentage increase graphs obtained without SSI showed that for Cases C1 to C4, C5 to C8 and C9 To C12, the maximum raft stress increased by approximately 20.8%, 25.0% and 28.1%, respectively. The

Graphical comparison clearly demonstrates that fixed support assumptions produce higher stress Concentrations and less realistic stress distribution patterns than SSI analysis.

6.1 Percentage Increase in Maximum Raft Stress vs Percentage Increase in Load Case C1 to C4

Observation:

The structural load increased from 37,456 KN in Case C1 to 59,930 KN in Case C4, representing a load increase of approximately 60.1%. The maximum raft stress increased correspondingly under both SSI and non-SSI conditions.

6.2 Percentage Increase in Maximum Raft Stress vs Percentage Increase in Load Case C5 to C9

Graph No. 5.13

Observation :

Under SSI conditions, the maximum raft stress increased from 18.6 MPa to 24.8 MPa. This corresponds to a percentage stress increase of approximately 33.3% due to increasing structural load.

16

6.3 Percentage Increase in Maximum Raft Stress vs Percentage Increase in Load Case C9 to C12

Graph No. 5.14

6.4 Percentage Increase in Minimum Raft Stress vs Percentage Increase in Load Case C1 to C4

Graph No. 5.15

Observation :

Under non-SSI conditions, the maximum raft stress increased from 24.0 MPa to 29.0 MPa. The percentage increase in stress was approximately 20.8%, indicating higher stress concentration within the raft.

6.5 Percentage Increase in Minimum Raft Stress vs Percentage Increase in Load Case C5 to C9

Graph No. 5.16

Observation :

The SSI model allowed redistribution of stresses through the supporting soil. Consequently, stress distribution became more realistic and localized stress concentrations were reduced.

6.6 Percentage Increase in Minimum Raft Stress vs Percentage Increase in Load Case C9 to C12

Observation 5:

The percentage-based comparison confirms that raft stress increases with increasing load. However, SSI analysis provides a more realistic representation of foundation behaviour than conventional fixed-support analysis.

7. Conclusion

7.1 Conclusion Without Consideration of SSI:

The analysis without considering Soil–Structure Interaction (SSI) assumed the raft foundation to be supported on rigid and fixed supports. As a result, the flexibility of the supporting soil was neglected, leading to higher stress concentrations within the raft foundation. The maximum stresses were observed beneath heavily loaded columns due to the absence of soil deformation effects. Therefore, the foundation system appeared more critical under non-SSI conditions.

The results showed that increasing raft size reduced stress concentration to some extent by distributing the load over a larger area. However, the stresses remained higher than those obtained from SSI analysis. The comparison indicated that fixed-support analysis tends to overestimate raft stresses and may lead to conservative designs. Hence, non-SSI analysis does not fully represent the actual behaviour of raft foundations on loose soils.

- The major conclusions obtained without considering SSI are summarized below:
- Maximum stress values were observed for Case C12.
- Fixed support conditions produced higher stress concentrations.
- Stress contours exhibited localized peak stresses beneath heavily loaded columns.
- Foundation behaviour appeared comparatively more critical under rigid support assumptions.
- Non-SSI analysis produced conservative stress estimates. 19
- Larger raft dimensions reduced stress concentration but could not eliminate unrealistic stress peaks.
- The percentage increase graphs showed that raft stresses increased consistently with increasing structural load under fixed support conditions.
- For Cases C1 to C4, a 60.1% increase in load resulted in approximately 20.8% increase in maximum raft stress without SSI, indicating significant stress concentration within the raft foundation.
- For Cases C5 to C8, the percentage increase in maximum raft stress reached approximately 25.0% when the structural load increased by 60%, demonstrating a direct relationship between load intensity and stress development.
- For Cases C9 to C12, the percentage increase in maximum raft stress increased up to approximately 28.1% for a 60% increase in load, representing the highest stress growth among the larger building cases.
- For Cases C1 to C4, the minimum raft stress increased by approximately 17.2% at the highest load level.
- For Cases C5 to C8, the minimum raft stress increased by approximately 15.5% at the maximum loading condition.
- For Cases C9 to C12, the minimum raft stress increased by approximately 17.8% for the highest load increment considered.
- The graphical results confirmed that fixed support assumptions tend to produce higher stress concentrations and less realistic stress distribution patterns compared to SSI analysis.
- The rate of stress increase under non-SSI conditions remained relatively higher because the supporting soil was assumed perfectly rigid and incapable of participating in load transfer.
- The percentage-based assessment demonstrated that conventional fixed support analysis may overestimate raft stresses and lead to conservative foundation designs.

7.2 Conclusion With Consideration of SSI:

The Soil–Structure Interaction (SSI) analysis provided a realistic representation of raft foundation behaviour by considering the flexibility of the supporting soil. The results showed lower raft stresses, improved stress redistribution, and gradual settlement patterns compared to fixed support conditions. Soil participation in load sharing reduced localized stress concentrations and enhanced overall foundation performance. Therefore, SSI analysis produced more reliable and practical results for loose soil conditions.

The study also indicated that increasing raft dimensions improved load distribution and reduced stress intensity within the raft and supporting soil. Comparative evaluation of all twelve cases confirmed that SSI significantly influences foundation response and stress behaviour. Furthermore, all calculated soil stresses remained below the assumed Safe Bearing Capacity of 150 KN/m², indicating safe foundation performance. Hence, SSI should be considered for accurate and economical design of raft foundations supporting multi-storey buildings.

- The major conclusions obtained from with SSI analysis are summarized below:
- Soil–Structure Interaction significantly influences foundation behaviour.
- Load redistribution occurred throughout the raft–soil system. 20
- All analysed cases satisfied the allowable soil bearing capacity requirements.
- Larger raft foundations demonstrated better load transfer behaviour.
- SSI analysis provided more reliable and realistic predictions of foundation response.
- Consideration of SSI is recommended for the analysis and design of raft foundations subjected to heavy structural loading.
- The percentage increase in raft stress did not increase linearly with the percentage increase in structural load, indicating the influence of foundation dimensions and soil flexibility on stress redistribution.
- For Cases C1 to C4, the maximum raft stress under SSI increased by approximately 33.3% for a 60.1% increase in load, whereas the increase without SSI was only about 20.8%, demonstrating different stress distribution mechanisms.
- In Cases C5 to C8, the percentage increase in maximum raft stress under SSI reached about 30.8% for a 60% increase in load, while the corresponding increase without SSI was approximately 25%, indicating effective load-sharing between soil and foundation.
- For Cases C9 to C12, the percentage increase in maximum raft stress under SSI was approximately 21.4%, whereas the increase without SSI reached 28.1%, showing that larger raft foundations benefited significantly from soil participation.
- The graphical comparison confirmed that SSI reduces the rate of stress increase for larger raft foundations and higher load levels.
- The percentage increase in minimum raft stresses remained lower under SSI conditions than under fixed-support conditions for most cases, indicating smoother stress distribution throughout the raft foundation.
- Peak percentage increases in minimum raft stress were observed near the intermediate loading cases, after which stress redistribution reduced the rate of increase.
- The graphs demonstrated that increasing raft size along with SSI consideration improved the overall structural response by reducing localized stress concentrations.

- The difference between SSI and non-SSI responses became more significant as building size and load increased, highlighting the importance of realistic soil modelling.
- Percentage-based evaluation provided clear evidence that Soil–Structure Interaction plays a major role in controlling stress development within raft foundations resting on loose soil.

7.3 Future Scope:

- The present study may be extended by considering nonlinear soil behaviour, layered soil profiles and different soil conditions.
- Dynamic loading effects such as earthquake and wind loading may also be incorporated to evaluate foundation performance under realistic field conditions.
- Advanced constitutive soil models and three-dimensional nonlinear contact formulations may further improve the accuracy of finite element predictions.
- Future investigations may also include comparative studies involving pile raft foundations, combined footing systems and ground improvement techniques.
- Future studies may investigate the relationship between percentage increase in structural load and percentage increase in raft stress using regression and statistical analysis.
- Parametric studies may be performed to establish empirical correlations between load increase, raft dimensions and stress variation under SSI conditions.
- Artificial Intelligence and Machine Learning techniques may be utilized to predict raft stresses and settlements based on load and soil parameters.
- Further investigations may compare percentage stress variation for different soil types such as loose sand, medium sand, dense sand and clayey soils.