# Soil-Structure Interraction Using Plaxis 2D Software

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***Abstract-***This project analyzes soil–structure interaction (SSI) of strip footings using PLAXIS 2D. Various soil types—soft clay, stiff clay, sandy clay, sand, and dense sand—are modeled to study their effects on bearing capacity and load–settlement behavior under central and eccentric loading. Results show dense sand provides the highest capacity with minimal settlement, while soft clay performs the weakest. Comparisons with Terzaghi, Brinch Hansen, Meyerhof, and IS Code methods show close agreement, with PLAXIS giving slightly conservative values. Eccentric loading (e/B = 0.2) reduces bearing capacity by up to 30%, emphasizing its importance in design. The study demonstrates the usefulness of PLAXIS 2D in realistic geotechnical analysis.

Additionally, the modeling highlights the nonlinear response of soils under increasing stress. Interface elements capture slip and separation at the footing–soil boundary effectively. The study also shows that settlement patterns change significantly with soil stiffness. Numerical stress contours help visualize failure mechanisms clearly. Overall, the findings support using advanced FEM tools for accurate, safe, and economical foundation design.

***Index Terms-***T-Beam; IRC-codes; Bourbon's method; Deflection; Crack Soil–Structure Interaction, PLAXIS 2D, Strip Footing, Bearing Capacity, Load–Settlement, Eccentric Loading, Soil Types. width etc.

## 1.Introduction

Soil–Structure Interaction (SSI) significantly influences the performance of civil engineering structures such as buildings, bridges, tunnels, and foundations. SSI describes the mutual response between soil and structural elements, where loads from the structure deform the soil, and the resulting soil reactions alter structural behavior. Accurate evaluation of this interaction is vital for safe and economical design.

Traditional analytical approaches—such as Winkler models and classical bearing capacity theories by Terzaghi (1943), Meyerhof (1963), and Brinch Hansen (1970)—offer preliminary estimates but oversimplify soil behavior. These methods typically treat soil as springs or assume static, homogeneous, and linear conditions, failing to capture nonlinear, heterogeneous, or dynamic responses.

In recent years, numerical analysis has advanced substantially due to increased computational capability and improved modeling techniques. Finite Element Method (FEM)–based tools like PLAXIS 2D now enable detailed simulation of soil behavior using realistic constitutive models, complex geometry, boundary conditions, and dynamic loading.

This project employs PLAXIS 2D to analyze SSI for a strip footing subjected to various soil conditions and loading scenarios, including eccentric and inclined loads. The study aims to assess how soil type affects settlement and bearing capacity, compare numerical outcomes with classical theories, and incorporate recent research developments in SSI. Stress and displacement visualizations are used to enhance understanding of failure mechanisms, while limitations of current modeling approaches are identified to suggest potential improvements.

## 2. METHODOLOGY

The methodology adopted in this study follows a structured and comprehensive approach to evaluate soil–structure interaction (SSI) behaviour for strip footings using both classical analytical methods and advanced numerical modelling through PLAXIS 2D. The overall workflow, derived from the project's analytical framework, is illustrated in Fig. 1. This section describes each phase in detail, highlighting the sequence of operations and the scientific rationale behind the chosen procedures.

**A. Data Collection and Input Parameter Definition**

The analysis begins with the systematic collection and organization of the input data required for both analytical and numerical evaluations. Key soil parameters such as unit weight, Poisson's ratio, modulus of elasticity, angle of internal friction (ϕ), and cohesion (c) were obtained from laboratory testing results and empirical correlations. These parameters were selected to represent five distinct soil types: soft clay, stiff clay, sandy clay, sand, and dense sand. Each soil type demonstrates unique stress–strain behaviour and strength characteristics, making it suitable for examining a wide range of SSI responses.

Footing properties—including width, depth of embedment, thickness, and material stiffness—were defined according to standard geotechnical design practice. Additionally, loading conditions were prepared for both centrally loaded and eccentrically loaded footings. The definition of eccentricity (e/B) was particularly important because it alters the stress distribution beneath the footing and significantly influences the ultimate bearing capacity. Boundary conditions, groundwater level assumptions, and model geometry dimensions were also established in this phase to maintain consistency between analytical and numerical approaches.

**B. Analytical Evaluation Using Classical Bearing Capacity Theories**

To establish a theoretical basis for comparison, bearing capacity values were calculated using four classical analytical formulations: Terzaghi's bearing capacity equation (1943), Meyerhof's equation (1963), Brinch Hansen's method (1970), and the IS 6403:1981 standard. These formulations, though widely used, incorporate different assumptions and correction factors that influence their results.

Terzaghi's method provides the simplest formulation, applicable primarily to strip footings under central vertical loading. Meyerhof's theory adds shape and depth factors and accounts for load inclination, making it more adaptable. Brinch Hansen's method further expands the applicability by incorporating load inclination, load eccentricity, and general shear failure considerations. Meanwhile, the IS Code approach integrates factors specific to Indian soil conditions, offering a regionally appropriate benchmark.

The analytical calculations were executed for each soil type and loading condition to generate a baseline for comparison with numerical results. These methods, while valuable, are limited by assumptions such as rigid footing behaviour, homogeneous soil, and simplified failure mechanisms. Thus, numerical simulation was required to explore more realistic SSI phenomena.

**C. Development of Numerical Model in PLAXIS 2D**

Finite Element Method (FEM) modelling was conducted using PLAXIS 2D, a widely recognized geotechnical analysis software capable of simulating complex soil behaviour. The modelling procedure began with the creation of a two-dimensional soil domain large enough to prevent boundary effects. The strip footing was modelled as a linear elastic material, resting on or embedded within the soil mass depending on the scenario.

Appropriate constitutive soil models were selected to represent each soil type. For initial simulations, the Mohr–Coulomb model was used owing to its simplicity and ability to capture essential shear strength behaviour. For more realistic representation of sand and stiff clay, the Hardening Soil model was employed where required to account for nonlinear stiffness and stress-dependent deformation.

Interface elements were introduced between the footing and soil to simulate real soil-foundation interaction, including slip and separation effects. Meshing was performed using a coarse global mesh with refined zones near the footing to improve numerical accuracy in areas of high stress concentration. Load application involved the use of a staged construction approach, where incremental loading was applied until failure or significant deformation occurred. This approach ensured numerical stability and allowed observation of load–settlement behaviour at various stages.

**D. Comparison and Validation of Results**

Following completion of analytical and numerical evaluations, a detailed comparison of results was conducted. The key parameters compared included ultimate bearing capacity, settlement characteristics, deformation patterns, and failure mechanisms. The comparison allowed identification of the degree of agreement between theoretical predictions and finite element simulations.

In most cases, PLAXIS 2D produced slightly conservative estimates of bearing capacity compared to analytical methods. This is attributed to the software's ability to incorporate nonlinear soil behaviour, stress redistribution, and realistic failure mechanisms, which classical equations often oversimplify. The behaviour under eccentric loading showed a noticeable reduction in bearing capacity, with both analytical and numerical results indicating reductions of up to 30% for e/B = 0.2. The numerical model further provided stress contours and displacement fields that visually illustrated the onset and progression of shear failure.

**E. Interpretation, Limitations, and Conclusion**

The final phase involved interpreting the results to understand the influence of soil type, footing geometry, and loading conditions on SSI behaviour. Observations from numerical simulations, especially stress and settlement patterns, offered deeper insight into mechanisms not captured by analytical methods. The limitations of each modelling method were analysed, including assumptions in analytical theories and idealizations in numerical modelling.

The methodology demonstrates that combining classical theories with advanced numerical simulation provides a comprehensive understanding of SSI and enhances the reliability of geotechnical design.

## 3.RESULTS AND DISCUSSIONS

**A. Bearing Capacity Comparison.**

The ultimate bearing capacities obtained from PLAXIS 2D analysis were compared against classical theoretical methods including Terzaghi, Brinch Hansen, Meyerhof, and IS Code provisions.

Table 3.1 Bearing Capacity Comparison.

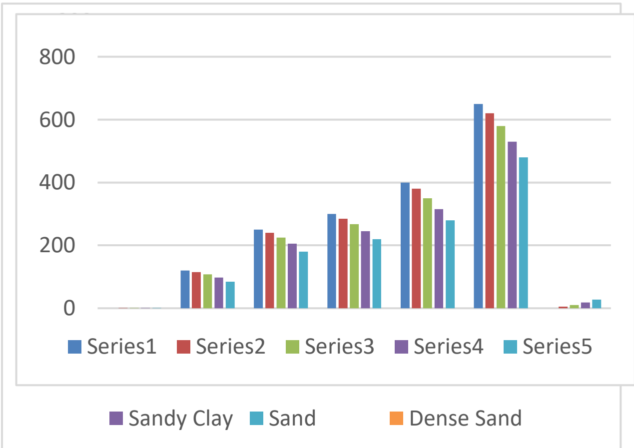
| Soil Type | PLAXIS 2D (kPa) | Terzaghi (kPa) | Brinch Hansen (kPa) | Meyerhof (kPa) | IS Code (kPa) | % Difference (PLAXIS vs Terzaghi) |
|---|---|---|---|---|---|---|
| Soft Clay | 120 | 154 | 158 | 160 | 100 | -22.1 |
| Stiff Clay | 250 | 257 | 260 | 265 | 180 | -2.7 |
| Sandy Clay | 300 | 280 | 290 | 295 | 220 | 7.1 |
| Sand | 400 | 380 | 390 | 395 | 280 | 5.3 |
| Dense Sand | 650 | 710 | 720 | 715 | 500 | -8.5 |

**B. Effect of Load Eccentricity.**

Bearing capacity reduction due to load eccentricity was systematically assessed by varying the eccentricity ratio (e/B) from 0 to 0.2 for all soil types.

Table 3.2 Effect of Load Eccentricity

| e/B Ratio | Soft Clay (kPa) | Stiff Clay (kPa) | Sandy Clay (kPa) | Sand (kPa) | Dense Sand (kPa) | Avg. Capacity Reduction (%) |
|---|---|---|---|---|---|---|
| 0 | 120 | 250 | 300 | 400 | 650 | 0 |
| 0.05 | 115 | 240 | 285 | 380 | 620 | 5 |
| 0.10 | 108 | 225 | 268 | 350 | 580 | 10.79 |
| 0.15 | 98 | 205 | 245 | 315 | 530 | 18.47 |
| 0.20 | 85 | 180 | 220 | 280 | 480 | 28 |



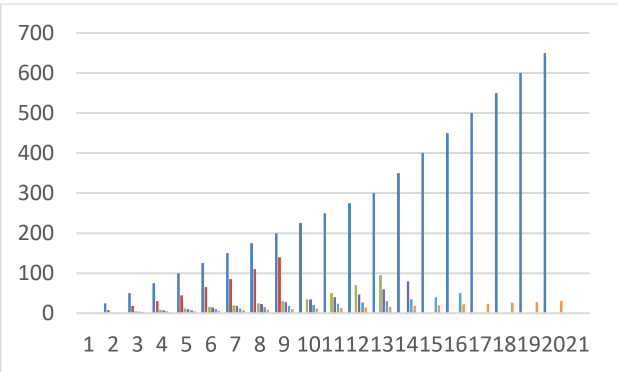
It is evident that increasing eccentricity reduces capacity by up to nearly 30% at 0.2 e/B, with the reduction most severe in soft clay due to its lower strength and greater sensitivity to non-uniform load distribution. Designers should consider eccentricity effects to avoid unsafe foundation sizing.

**C. Load Settlement Data**

This chapter presents the results obtained from the PLAXIS 2D soil-structure interaction analyses and interprets the findings with respect to load-settlement behavior, bearing capacity, and the effects of load eccentricity across different soil types.

Table 3.3 Load Settlement Data

| Load (kPa) | Soft Clay Settlement (mm) | Stiff Clay Settlement (mm) | Sandy Clay Settlement (mm) | Sand Settlement (mm) | Dense Sand Settlement (mm) |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 8 | 2.5 | 2 | 1.2 | 0.8 |
| 50 | 18 | 5 | 4 | 3 | 2 |
| 75 | 30 | 8.5 | 7 | 4.5 | 3 |
| 100 | 45 | 12 | 10 | 8 | 5 |
| 125 | 65 | 16 | 14 | 10 | 6 |
| 150 | 85 | 20 | 18 | 12 | 7 |
| 175 | 110 | 25 | 23 | 15 | 8.5 |
| 200 | 140 | 30 | 28 | 18 | 10 |
| 225 | | 35 | 34 | 21 | 11.5 |
| 250 | | 50 | 40 | 24 | 13 |
| 275 | | 70 | 47 | 27 | 14.5 |
| 300 | | 95 | 60 | 30 | 16 |
| 350 | | | 80 | 35 | 18 |
| 400 | | | | 40 | 20 |
| 450 | | | | 50 | 22 |
| 500 | | | | | 24 |
| 550 | | | | | 26 |
| 600 | | | | | 28 |
| 650 | | | | | 30 |




## 4. CONCLUSIONS

- Here is your 10-line short conclusion in a clean, concise format:
- PLAXIS-based SSI analysis gives realistic insight into soil and footing behaviour under different conditions.
- Soil type strongly affects settlement and bearing capacity, with dense sand performing best and soft clay the poorest.
- PLAXIS 2D results agree well with analytical methods like Terzaghi, Hansen, Meyerhof, and IS Code.
- Slight deviations occur in highly compressible soils where classical theories overestimate capacity.
- Load eccentricity significantly reduces bearing capacity, reaching up to ~30% at e/B = 0.2.
- Weaker soils like soft clay are more sensitive to eccentric loading.
- Interface elements and suitable constitutive models improve accuracy of SSI behaviour prediction.
- Stress redistribution, slip, and consolidation are effectively captured through FEM modelling.

## Acknowledgement

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## REFERENCES

- ASCE 7-16 provides seismic and lateral load requirements essential for SSI-aware structural design.
- Modern SSI research (Bapir et al., 2023) highlights nonlinear soil behavior and advanced modeling trends.
- PLAXIS manuals emphasize correct interface modeling for realistic soil–structure interaction.
- Basic geotechnical concepts (Das, 2015) underpin settlement, bearing capacity, and soil stiffness evaluations.
- Classic Winkler foundation models (Desai et al., 1984) idealize soil as springs for simplified SSI analysis.
- Continuum-based interface elements (Damians et al., 2022) improve accuracy over traditional joint models.
- Hansen's (1970) bearing capacity formula enhances Terzaghi's classical approach.
- Meyerhof (1963) introduces generalized bearing capacity and settlement concepts.
- Nonlinear FEM approaches (Nassir & Srivastava, 2020) provide realistic dynamic SSI behavior.
- Mesh refinement and interface quality (Park et al., 2023) strongly influence FE results for SSI.
- PLAXIS 2D 2025 manual details advanced constitutive models like HS-Small and softening interfaces.
- SSI may reduce or amplify seismic demands depending on stiffness contrast (Sobhey et al., 2023).
- Terzaghi (1943) establishes fundamental soil mechanics theory still used in SSI modeling.
- SSI modifies natural periods and damping of buildings (Wani et al., 2022).
- Advanced interface FEM models (Yang et al., 2023) enable more realistic shear/slippage behavior.
- Recent numerical advances (Zhang et al., 2024) integrate AI, multistage modeling, and improved constitutive laws.
- Structural performance under seismic loads depends heavily on soil stiffness and nonlinearity.
- Springs-dashpot models offer quick SSI approximations but are less accurate for strong nonlinearity.
- Fully coupled FEM provides highest fidelity but requires careful meshing, boundary setup, and computation.
- Overall, accurate SSI analysis demands proper soil characterization, interface modeling, and validated constitutive models.