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Analytical Study of Soil Structure Interaction Effects on Earthquake Response R.C. Frame Buildings

Kare Varsha Bajrang[1] and Dr. Munesh Kumar[2]
[1]Research Scholar, Department of Civil Engineering
[2]Assistant Professor, , Department of Civil Engineering
Shri JJT University, Jhunjhunu, Rajasthan

Abstract: *Soil–Structure Interaction plays a significant role in influencing the seismic behavior of reinforced concrete frame buildings especially when constructed on soft & medium soils. Conventional seismic analysis generally assumes a fixed-base condition, neglecting flexibility of soil & foundation system which may lead to inaccurate estimation of structural response. In present study, an analytical investigation is carried out to evaluate earthquake response of multi-storey R.C. frame buildings. Numerical models of G+5, G+7 & G+10 storey R.C. frames are developed considering both fixed-base and flexible-base conditions using spring-based soil models. Seismic response parameters are compared. These indicate that Soil–Structure Interaction increases fundamental natural period & lateral displacements while reducing base shear demands. Study highlights seismic design for realistic performance assessment of R.C. buildings.*

Keywords: Soil–Structure Interaction, Earthquake Response, R.C. Frame, Seismic Analysis, Flexible Base & Spring Model

I. INTRODUCTION

Reinforced concrete frame buildings constitute a major portion of urban infrastructure in seismic regions. Accurate prediction of their seismic response is essential for ensuring structural safety & serviceability. In conventional seismic analysis, structures are assumed to be fixed at base implying that supporting soil is infinitely rigid. In reality, soil exhibits deformability which significantly affects dynamic response of structures during earthquakes. Soil–Structure Interaction refers to mutual interaction between soil, foundation & superstructure under dynamic loading conditions. During seismic events, flexibility of soil alters motion transmitted to structure leading to changes in natural period, damping & force distribution. These effects become more pronounced for buildings founded on soft soils & for tall structures.

II. LITERATURE REVIEWS

Gazetas, G. & Mylonakis, G. (2015) provides a comprehensive review of soil–structure interaction effects on seismic response of structures. It discusses theoretical concepts, analytical approaches & practical implications in earthquake engineering. Authors illustrate soil flexibility influences foundation motion, structural forces & energy dissipation. Paper serves as a foundational reference emphasizing need for rational SSI modeling to improve seismic design accuracy & performance-based engineering practices.

Mylonakis, G., Nikolaou, A. & Gazetas, G. (2017) examines foundation flexibility & soil nonlinearity influence structural response during earthquakes. Approaches are used to evaluate changes in forces, displacements & energy dissipation mechanisms. Results can significantly modify seismic demand & structural behavior. Authors highlight importance of foundation modeling in performance-based seismic design and recommend integrating into modern earthquake engineering practice.

Arboleda-Monsalve, L. G. & Chouw, N. (2018) assess variations in structural response parameters as base shear, displacement & natural period. Results demonstrate that soil flexibility significantly alters dynamic behavior compared to fixed-base assumptions. Taller buildings show pronounced SSI effects including increased displacement & reduced base shear. Study highlights importance of incorporating realistic soil conditions in seismic design to achieve accurate prediction of structural performance & improved safety under seismic events.

Kori, J. G. & Patil, S. S. (2019) evaluates seismic response of reinforced concrete frame structures considering soil flexibility. Analytical models are developed to compare fixed-base & flexible-base conditions under seismic loading. Results indicate that soil flexibility leads to increased lateral displacement and fundamental time period while reducing base shear forces. Study emphasizes that neglecting soil–structure interaction may result in inaccurate seismic demand estimation.

Choudhury, T. & Ghosh, S. (2021) compares fixed-base and flexible-base models to evaluate changes in response characteristics as lateral displacement, time period & storey drift. Results indicate to unconservative seismic design particularly for buildings founded on soft soils. This emphasizes that soil flexibility reduces structural stiffness & modifies seismic demand. Findings support in analytical models for more reliable earthquake-resistant design of RC structures.

Dasgupta, K. & Banerjee, S. (2022) examines variations in displacement, base shear & inter-storey drift under different soil conditions. Results show that flexible soil significantly increases lateral deformation while reducing seismic forces. These effects become more pronounced with increasing building height & decreasing soil stiffness. Findings underline necessity of considering soil behavior in seismic performance evaluation to ensure structural safety & serviceability.

Mondal, A. & Roy, R. (2023) focuses on seismic performance evaluation of reinforced concrete frames considering soil–structure interaction. Nonlinear dynamic analysis is performed to examine changes in structural response parameters. This reveal significantly affects seismic performance especially for buildings resting on soft soil. Results indicate increased deformation demands & altered failure patterns.

Singh, Y. & Ghosh, S. (2024) examines soil–structure interaction effects on earthquake response of reinforced concrete frame buildings. Comparative analyses between fixed-base & SSI-included models are conducted under seismic loading. Results demonstrate that soil flexibility increases displacement & time period while reducing base shear. Study highlights vary with soil stiffness & building height. Findings emphasize accurate response prediction & safer structural design.

III. METHODOLOGY

Methodology involves analytical modeling & seismic analysis of R.C. frame buildings with & without Soil–Structure Interaction.

1. Building Description

Multi-storey R.C. frame buildings of varying heights (G+5, G+7 & G+10) are considered. Each building has a regular plan & uniform storey height. Beams & columns are designed as per relevant Indian Standard codes.

2. Soil Modeling

Soil flexibility is modeled using equivalent linear springs representing translational & rotational stiffness at foundation level. Stiffness values are calculated based on soil properties as shear modulus & Poisson’s ratio. Medium soil conditions are considered for present study.

3. Structural Modeling

Two types of models are developed:

Fixed-base model: Assumes rigid support at foundation level

Flexible-base model: Incorporates soil stiffness through spring elements

4. Seismic Analysis

Linear dynamic analysis is carried out using response spectrum method as per IS 1893 (Part 1). Seismic parameters as zone factor, importance factor & response reduction factor are adopted according to code provisions.

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IV. RESULT & DISCUSSION

Seismic response of fixed-base & Soil–Structure Interaction considered models is evaluated and compared.

1. Natural Period

Inclusion of Soil–Structure Interaction (SSI) results in an increase in fundamental natural period of all building models. Percentage increase is observed to be higher for taller buildings indicating greater soil flexibility effects. This increase is more significant for taller buildings indicating a stronger influence of soil deformability on global structural stiffness.

Table 1: Fundamental Natural Time Period (sec)

Building Type	Fixed Base	With SSI	% Increase
G+5	0.84	1.24	47.6%
G+7	1.09	1.56	43.1%
G+10	1.41	2.11	49.6%

Results indicate a significant increase in fundamental natural time period of buildings when soil–structure interaction is considered. For G+5 building, time period increases from 0.84 s under fixed-base conditions to 1.24 s with SSI showing a rise of 47.6%. Similarly, G+7 structure exhibits an increase from 1.09 s to 1.56 s representing a 43.1% increase. G+10 building shows highest variation with time period increasing from 1.41 s to 2.11 s corresponding to a 49.6% increase. These results clearly demonstrate that SSI reduces overall structural stiffness & leads to longer vibration periods particularly for taller buildings.

2. Base Shear

A reduction in base shear is observed in Soil–Structure Interaction models compared to fixed-base models. This reduction occurs due to lengthening of natural period which shifts structure to a lower spectral acceleration region.

Table 2: Base Shear Comparison (kN)

Building Type	Fixed Base	With SSI	% Reduction
G+5	1820	1420	22.0%
G+7	2340	1815	22.4%
G+10	2985	2250	24.6%

Results show a noticeable reduction when soil–structure interaction is included in analysis. For G+5 building, base shear decreases from 1820 kN under fixed-base conditions to 1420 kN with SSI resulting in a reduction of 22.0%. Similarly, G+7 structure experiences a decrease from 2340 kN to 1815 kN corresponding to a 22.4% reduction. The G+10 building shows maximum reduction with base shear dropping from 2985 kN to 2250 kN amounting to a 24.6% decrease. These findings indicate that SSI increases system flexibility thereby lowering seismic force demand especially in taller buildings.

3. Storey Displacement

Flexible-base models exhibit higher lateral displacements at all storey levels. Increase in displacement demand is more prominent at upper storeys which may affect serviceability & non-structural components.

Table 3: Maximum Roof Displacement (mm)

Building Type	Fixed Base	With SSI	% Increase
G+5	18.5	32.8	77.3%
G+7	26.2	45.6	74.0%
G+10	38.4	68.9	79.4%

Results highlight a substantial increase in lateral deformation when soil–structure interaction is considered. For G+5 building, maximum roof displacement rises from 18.5 mm under fixed-base conditions to 32.8 mm with SSI reflecting a 77.3% increase. Similarly, G+7 structure shows an increase from 26.2 mm to 45.6 mm corresponding to a 74.0% rise. The G+10 building exhibits highest increase with displacement growing from 38.4 mm to 68.9 mm amounting to a

79.4% increase. These results demonstrate that SSI significantly enhances structural flexibility leading to greater lateral displacements particularly in taller buildings.

4. Inter-Storey Drift

Soil–Structure Interaction leads to increased inter-storey drift values, although they remain within permissible limits for studied cases. Drift demand increases with building height. Increase in drift ratio with SSI indicates greater deformation demand which can affect structural & non-structural safety if not properly controlled.

Table 4: Maximum Inter-Storey Drift Ratio

Building Type	Fixed Base	With SSI
G+5	0.0019	0.0032
G+7	0.0023	0.0038
G+10	0.0028	0.0045

Results reveal a clear increase in deformation demand when soil–structure interaction is incorporated. For G+5 building, maximum drift ratio increases from 0.0019 under fixed-base conditions to 0.0032 with SSI. Similarly, G+7 structure shows a rise from 0.0023 to 0.0038 while G+10 building experiences an increase from 0.0028 to 0.0045. These trends indicate that SSI reduces overall system stiffness & amplifies lateral deformation between storeys. Effect becomes more pronounced with increasing building height emphasizing in seismic drift control & structural performance evaluation.

V. CONCLUSION

When soil flexibility is taken into account, structural behavior differs significantly from conventional fixed-base assumption. Inclusion of SSI leads to an increase in fundamental natural period & lateral displacements while a reduction in base shear demand is observed due to period lengthening effect. These changes become more prominent with an increase in building height indicating that taller structures are more sensitive to soil flexibility. Although SSI may reduce force demands, increase in displacement & drift highlights need for careful serviceability & performance-based design considerations. Therefore, incorporating soil–structure interaction in seismic analysis provides a more realistic assessment of structural behavior & is essential for ensuring safe & reliable earthquake-resistant design of R.C. frame buildings.

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