Analyzing the Effects of Soil-Structure Interaction and Geometric Configuration on Structure

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Abstract — Soil structure interaction plays a part in how well structures can handle static and dynamic loads. This study looks at how soil structure interaction and the shape of a building affect how it behaves. It considers types of foundations how stiff the soil is and the shape of the building including how tall it is, its shape and if the plan is irregular. The study uses a kind of computer simulation to see how the soil and the building interact when different loads are applied. The results show that soil structure interaction really changes how a building responds to loads especially when the soil is soft or medium. Buildings with shapes have bigger responses because the shape and the soil flexibility work together. If we do not consider soil structure interaction we might design buildings that're not safe enough especially tall and skinny ones. The study also shows that the shape of a building is very important in how it interacts with the soil and buildings with regular shapes do better than ones, with irregular shapes. The results of this study are important because they show that we need to think about soil structure interaction when we design buildings so they can handle earthquakes and other dynamic loads. This research helps engineers and designers make buildings that're safer and work better by optimizing the shape and the foundation.

Keywords: Soil-Structure Interaction (SSI); Building Geometry Effects; Dynamic Structural Analysis; Foundation Flexibility; Seismic Response of Buildings; Structural Performance Optimization;

I. INTRODUCTION

Soil and structures are connected in a way. When we design buildings we need to think about how the soil underneath them will affect the way they behave. For a time people thought that the ground was solid and would not move but that is not true. The soil can. That can change the way a building acts.

Soil-structure interaction is what happens when the soil and the building talk to each other. The soil is not hard like rock it can. That changes the way a building moves too. It affects things like how a building wobbles how much it wobbles and how far it moves. The shape of the building and the soil, around it can also make things more complicated.

This study is going to look at how soil-structure interaction and the shape of a building affect how well it performs. We will use computer models to see what happens when we change things. We want to know how soil-structure interaction and the shape of a building work to affect the buildings performance.

II. LITERATURE REVIEW

A. Dhahbia Guerdouh et.al. "Soil-structure interaction effects on the seismic performance of frame structures"

Soil–structure interaction (SSI) plays a crucial role in determining the seismic response of buildings, particularly those founded on flexible or layered soils. Traditional seismic analyses often assume a fixed base condition, which can underestimate displacements and internal forces during earthquakes. Recent studies using finite element–based direct methods have shown that soil properties, earthquake intensity, and interface behavior significantly influence structural performance. Structures on soft soils tend to experience larger lateral displacements and higher interface stresses, with damage often initiating at the soil–foundation interface before propagating into the superstructure. These findings highlight the importance of incorporating SSI effects in seismic design to obtain more realistic and reliable predictions of structural behaviour.

B. Arjit Verma, P. Pal et.al. "Soil-Structure Interaction for Building Structures: A Review"

Past earthquake events have clearly demonstrated that the seismic response of buildings is strongly influenced by the interaction between the soil, foundation, and superstructure. Early research often simplified this behavior by assuming rigid foundations; however, subsequent studies showed that such assumptions can significantly misrepresent structural response, particularly for buildings resting on soft or layered soils. Researchers have reported that soil– structure interaction (SSI) leads to period elongation, increased lateral displacements, and changes in damping characteristics, with effects becoming more pronounced for tall structures and flexible foundations. Both direct and indirect analytical approaches, along with numerical methods such as the finite element method, have been widely used to capture inertial and kinematic interaction effects more realistically. Recent literature consistently emphasizes that ignoring SSI may underestimate seismic demand and damage potential, highlighting the necessity of incorporating soil flexibility and interface behavior in modern seismic analysis and design practices.

C. Mohammed Hashir S1, Dr. K Sudha et. al." Analysis of Soil-Structure Interaction – A Review"

The existing body of literature clearly indicates that soil–structure interaction (SSI) plays a vital role in governing the seismic behavior of buildings and cannot be overlooked in realistic structural analysis. Early studies established that seismic waves transmitted through soil significantly modify structural response, particularly when foundations rest on soft or layered ground. Subsequent analytical, numerical, and experimental investigations demonstrated that SSI leads to changes in stiffness, natural period, damping, and internal force distribution, with these effects becoming more pronounced for pile-supported, tall, and closely spaced structures. Research has further shown that nonlinear soil behavior, liquefaction, and foundation flexibility can substantially alter seismic demand, often causing damage to initiate at the soil–foundation interface. While linear SSI approaches may be adequate for low- intensity ground motions, recent studies emphasize that nonlinear time-domain analysis is essential to capture realistic behavior under strong earthquakes. Overall, the literature consistently highlights that incorporating SSI effects is critical for accurate seismic assessment and safe structural design.

III. OBJECTIVE

The main objectives of this study are:

- To evaluate the influence of soil–structure interaction on structural response
- To analyze the impact of geometric configurations (regular vs irregular)
- To compare fixed-base and flexible-base conditions
- To assess seismic performance under different soil conditions
- To provide design recommendations incorporating SSI effects

IV. RESEARCH METHODOLOGY

A. Research Framework

This study uses computer simulations to see how the ground and buildings interact and how the shape of the building affects its behavior during earthquakes. We compare buildings with fixed foundations to those that can move with the ground. The research methodology combines building design, ground modeling and earthquake analysis to see how different scenarios affect the buildings performance. The soil-structure interaction and geometric configuration are the factors we are looking at.

B. Development of Structural Models

We selected a multi-story buildings made of reinforced concrete to represent short, medium and tall buildings. These buildings have numbers of floors like G+5, G+10 and G+15 and are designed according to Indian building codes. The soil-structure interaction is considered in the design of these buildings.

To see how the shape of the building affects its behavior we looked at two types of buildings:

- *Regular Buildings: These have a symmetrical shape and the weight is evenly distributed.
- *Irregular buildings: These have unusual shapes, like L-shapes and the weight is not evenly distributed.

We modeled all the parts of the building including the beams, columns and floors using properties. The materials used in the building like concrete and steel have properties like elasticity and density that are based on building codes. The geometric configuration of the building is a factor in its behavior.

C. Soil Modeling and Idealization

We modeled the ground under the building using an approach, where the ground is represented by springs at the foundation level. The soil-structure interaction is considered in this approach. We looked at three types of ground: medium and soft.

The ground and foundation are modeled using springs that can move and rotate. The stiffness of these springs is based on the properties of the ground like how much it can stretch and compress. This approach allows us to simulate the grounds flexibility without using much computer power. The soil modeling is a part of the research methodology.

D. Modeling of Soil–Structure Interaction

We included the soil-structure interaction in our models by using springs at the base of the building of fixed supports. The soil-structure interaction is a factor in the behavior of the building. We looked at two types of models:

- Fixed-base model: This assumes the ground is rigid and does not move.
- Flexible-base model: This takes into account the grounds flexibility using spring stiffness. The soil-structure interaction is considered in this model.

The interaction between the building and the ground allows forces to be transferred between them affecting the behavior of the system. The soil-structure interaction and geometric configuration are the factors we are looking at.

E. Loading and Seismic Input

The buildings are subjected to gravity and earthquake loads. The weight of the building and any objects inside are based on building codes. The earthquake loads are applied using a method that takes into account the type of ground and the buildings importance. The seismic input is a factor in the behavior of the building.

Key factors that affect the earthquake loads include the zone factor, importance factor, response reduction factor and damping ratio. We used curves to simulate realistic ground motion effects. The soil-structure interaction is considered in the input.

F. Numerical Analysis Procedure

We used computer software like ETABS or ANSYS to analyze the buildings. The analysis involves the following steps:

1) Creating the buildings shape. Assigning properties to the materials.
2) Defining the loads and combinations of loads.
3) Modeling the ground springs for soil-structure interaction cases.
4) Performing an analysis to find the natural frequencies and mode shapes.
5) Conducting a response spectrum analysis.
6) 6.. Comparing the response parameters. The soil-structure interaction and geometric configuration are the factors we are looking at.

G. Evaluation Parameters

We evaluated the buildings performance using key indicators, including:

- Natural time period
- Base shear
- Lateral displacement
- Storey drift
- Internal forces like bending moments and shear forces
- effects

These parameters are compared across different ground conditions, building shapes and boundary conditions to identify important trends. The soil-structure interaction and geometric configuration are the factors we are looking at.

H. Validation and Reliability

To ensure our results are reliable we verified our models, against Indian building codes and existing research. We also performed sensitivity analyses to see how the grounds stiffness and modeling assumptions affect the buildings behavior. The soil-structure interaction is considered in the validation and reliability of the results.

V. Result and Discussion

A. Overview of Results

We looked at the responses from the numerical analysis to see how soil-structure interaction and the shape of the building affect things. We compared buildings with fixed bases to those with bases and we looked at different types of soil and building shapes.

Effect of Soil-Structure Interaction on Natural Time Period

When we considered soil-structure interaction we saw that the natural time period of the building got longer. This was especially true for soil.

- For soil the natural time period was 20-35% longer than for buildings with fixed bases.
- For soil it was 10-20% longer.
- For soil the difference was not as big, only 5-10%.

This is because the soil makes the building more flexible which means it is not as stiff. Taller buildings, like ones with 15 stories are more affected by soil-structure interaction because they are more flexible.

B. Base Shear Variation

We found that when we considered soil-structure interaction the base shear was lower than for buildings with fixed bases.

- The base shear was 10-25% lower for soil.
- It was a little lower for hard soil.

Even though lower base shear might seem like a thing it actually means that the building is more flexible and might move more. So if we only look at shear we might not get the right design.

C. Lateral Displacement and Storey Drift

When we included soil-structure interaction we saw that the building moved more from side to side and that the distance between stories got bigger.

- The maximum displacement was 25-40% bigger for soil.
- Some irregular buildings had storey drift values that were too big.

Irregular buildings moved more because their stiffness and weight were not evenly distributed. When we combined soil-structure interaction with irregularity the building deformed more on the upper stories.

Influence of Geometric Configuration

- The shape of the building is very important for how it performs.
- If the plan was irregular, it caused torsional effects.
- If the building had setbacks, it concentrated forces at points.
- Irregular buildings had 15-30% drift than regular buildings.

These effects were even bigger when we included soil-structure interaction because the soil made the building more flexible.

D. Combined Effect of SSI and Geometric Irregularity

When we combined soil-structure interaction and geometric irregularity we got the critical response from the building.

- Tall irregular buildings on soil had the biggest displacement and drift values.
- Torsional irregularity got bigger because of the way the soil settled and was flexible.
- The forces inside the building got redistributed, which meant that some parts of the building had to handle bending.

This shows that we cannot look at soil-structure interaction and geometric configuration separately when we analyze a building.

E. Storey-Wise Response Behavior

When we looked at each story of the building we saw:

- The top story had the displacement.
- The middle stories had the drift.
- Irregular buildings had changes in response at certain points.
- Flexible-base models had bigger displacement profiles, than fixed-base models.

VI. Conclusion

- Soil structure interaction has an impact on how buildings behave when there are earthquakes. It makes the building move slowly and it becomes less stiff. This is especially true when the soil is soft or medium.
- When we include soil structure interaction in our calculations the force that the earthquake puts on the building is less. At the same time the building will move more from side to side and the floors will move more relative to each other. This is a deal because it can affect whether the building is safe and if it can still be used after an earthquake.
- The shape of the building is also very important. Buildings that are not shapes either on the ground or when you look at them from the side will have more stress and will move more than buildings that are regular shapes.
- When you combine soil structure interaction and a building that is not a shape the building will behave in a more extreme way. This is especially true for tall buildings that are on soft soil. This is the worst-case scenario when it comes to designing buildings.

- Most of the time people assume that the building is fixed to the ground and does not move. This is not accurate especially for very tall buildings or buildings that are not regular shapes.
- We need to include soil structure interaction when we are designing buildings so that they can withstand earthquakes. If we do not the building may not be safe. It could be a big problem. Soil structure interaction is very important. We need to think about it when we are designing buildings. The study shows that soil structure interaction is crucial for making sure buildings are safe, during earthquakes

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