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Seismic Analysis Of Multi-Storied RCC Buildings On Sloping Ground Along With Soil-Structure Interaction

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Abstract:
With the population increase necessitates the construction of multi-storey buildings on sloping terrain. Due to the lack of plain land in hilly regions, most of the structures are built on the slopes of hills with irregular structural layouts and varying foundation levels. Because of their unbalanced vertical and horizontal layouts, structures in mountainous regions are more susceptible to earthquake loads. In most situations, when analyzing and designing structures, the response of soil-structure interaction (SSI) is neglected.
in present work the seismic analysis of a multi-storey G+5 residential building located in seismic Zone-V according to IS 1893-2016 on sloping terrain with ground inclinations of 0°, 5°, 10°, 15°, and 20° on medium soil with and without soil-structure interaction (SSI) is the focus of the current dissertation. In the current study the seismic analysis of all building models is done using the response spectrum method, which uses the complete quadratic combination (CQC) in accordance with IS 1893-2016. Additionally, the resulting storey displacement, shear force, base shear, bending moment, are examined and contrasted with the building models that do not take SSI into account.
Finally, it is concluded that increment of slope angle increases the seismic response values as compared to buildings on plain ground. Also, buildings without SSI consideration were found to underestimate response values like displacement and drift and overestimate force values like base shear, shear force, bending moment.
Key Word: *Soil-structure interaction, complete quadratic combination, ground inclination, seismic analysis.*

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I. Introduction

Real estate development in hilly areas has accelerated due to economic expansion and growing urbanization. As a result, the hilly region's population density has significantly expanded. Because of this, there is a strong and growing need for the development of multi-storey buildings in and around cities on hill slopes. Buildings in hills are particularly sensitive to seismic forces because of their irregular vertical and horizontal layout. In India north-eastern part are more vulnerable to seismic activities. Historical earthquakes, that struck Kangra in 1905, Bihar, Nepal in 1934, 1980 and 2014, Assam in 1950, Uttarkashi, India in 1991, Assam in 1897, Jammu & Kashmir in 2005, had demonstrated that structures situated in close proximity to hills or sloping terrain had experienced significant damages. Usually, while constructing buildings, the soil beneath footings is generally assumed to be stiff, but in reality, soil behaves differently. In order to obtain accurate results, it is necessary to take into account soil structure interaction (SSI). The majority of the time, the response of SSI is ignored while analyzing and designing the buildings on a sloping surface with varying sloping angles for seismic responses.

Initially, Gazetas et al. (1985), Gazetas (1991), Wolf (1998) and Stewart et al. (1999) analyze the effects of inertial SSI on system. Birajdar and Nalawade (2004) carried out the seismic assessments of twenty-four RC buildings in three different configurations: step-back building, step-back set-back building and set-back building. Menglin et al. (2011) presented the dynamic interaction between structure and soil. A brief description of the development and current state of the field of studying the dynamic interaction between structures, soil and other structures that takes into account nearby structures was suggested as a guide for researchers based on a number of references. Singh and Gade (2011) presented several observations regarding the seismic behaviour of hill buildings during the September 18 2011, earthquake in Sikkim. Furthermore, an analytical research was also done to examine the unusual seismic behavior of hill buildings. Khadiranaikar and Masali (2014) presented a summary of research on the behavior of structures on sloping terrain during earthquakes. Girgin (2016) suggested a simple method for the soil-structure interaction of rigid spread footings, mainly when exposed to high eccentric loads. Anand and Kumar (2018) examined earlier studies on SSI and its affects structural response. Mercado et al. (2020) presented numerical simulations that model the soil's damping and flexibility utilizing dashpots and springs. Falborski (2020) studied the seismic response of high-rise irregular reinforced-concrete residential buildings by considering soil structure interaction. Dangol and Motra (2021) examined the behaviour of step-back and step-back-set-back buildings on a 34° slope with varying storey ranging from 7 to 9, and compared their responses to those of plain area buildings and SSI was considered. Adhikari et al. (2022) studied the Kathmandu Valley's three-storey low-rise residential RC-framed building seismic ability while considering infill walls and the effects of soil-structure interaction.

Ghosh and Debbarma (2019), Kassem et al. (2023) and Chougule and Deshpande (2023) studied the buildings situated on different slope angles and compared with the same building situated on plain level ground. Bapir et al. (2023) discussed a summary of the relevant research and findings on the primary methodologies for assessing seismic soil-structure interaction issues using widely-used modeling and computational tools. Reddy and Badry (2023) compared step back building with inverted V bracings on different soil types and inclinations with fixed base buildings.

In the present work, seismic analysis of a multi-storey G+5 residential building located in seismic Zone-V according to IS 1893-2016 on sloping terrain with ground inclinations of 0°, 5°, 10°, 15°, and 20° on medium soil with and without soil-structure interaction (SSI) is carried out. The soil is modeled using spring-dashpot model proposed by Gazetas (1991). The resulting storey displacement, shear force, base shear, bending moment are examined and contrasted with the building models that do not take SSI into account.

II. Material And Methods

The multi-storied RCC G+5 residential building on plain and sloping grounds with following data is considered for the present study:
Height of building: 18 m, Plan - 15 m × 15 m
Storey Height: 3 m
Frame Type: Special moment resisting frame (SMRF)
Beam Size and cross-section: 300×500 mm (Rectangular Section)
Column Size and cross-section: 500×500 mm (Square Section)
Slab thickness: 150 mm
Wall thickness: 150 mm
Grade of concrete: M30
Grade of steel: Fe 415
Masonry: brick masonry
Unit weight of concrete: 25 kN/m^3
Unit weight of brick masonry: 20 kN/m^3
Live load: 3 kN/m^2 at all floors level
Live load: 1.5 kN/m^2 at roof level

For Seismic loading,
Zone V
Soil Type = Medium (II)
Zone factor (Z) = 0.36
Importance factor (I) = 1
Response reduction factor (R) = 5
Damping ratio = 5 %

Following SSI data has been taken:
Length of footing (L) = 1.52 m
Width of footing (B) = 1.52 m
Depth of footing (D) = 1.5 m
Area of footing (base area) (A_b) = 2.3104 m^2
Mass density of soil = 13500 kg/ m^3
Shear wave velocity (Vs) = 100 m/s
Lysmer's Analog wave velocity (VL_a) = 64.9475 m/s
Poisson's ratio (υ) = 0.4
Modulus of rigidity (G) = 13500 kN/m2

The sub structure method of analysis for SSI is considered as spring and dashpot model as given by Gazetas (1991) to calculated static stiffness and dashpot coefficient for spring and dashpot model as shown in Figure 1 (neglecting rocking mode in spring and dashpot model) are as follows:

a) Static stiffness (k)

i) Horizontal direction (longitudinal direction) (x) in kN/m

$$k_x = k_y - [0.2/(0.75 - \upsilon)]GL[1 - (B/L)] \quad (1)$$

ii) Horizontal direction (lateral direction) (y) in kN/m

$k_y = [2GL/(2-\upsilon)](2+2.50X^{0.85})$ (2)
iii) Vertical (z) in kN/m
$k_z = [2GL/(1-\upsilon)](0.73+1.54X^{0.75})$ (3)
where, $X = A_b/4L^2$
b) Dashpot coefficient (c)
i) Horizontal direction (longitudinal direction) (x) in kN.sec
$c_x = \rho V_s A_b$ (4)
ii) Horizontal direction (lateral direction) (y) in kN.sec
$c_y = (\rho V_s A_b)\tilde{c}_y$ (5)
where, $c_y = \tilde{c}_{y;}(L/B; a_0)$ as given by Gazetas (1991)
iii) Vertical (z) in kN.sec
$c_z = \rho V_{La} A_b$ (6)
where, $c_z = \tilde{c}_z(L/B); a_0$ as given by Gazetas (1991)

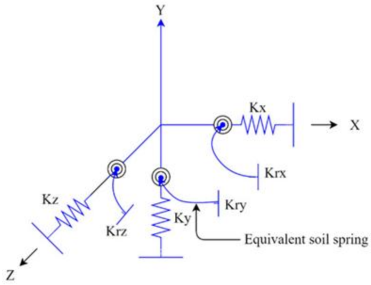


Figure 1 Equivalent soil spring model with six degrees of freedom Gazetas (1991), Adhikari et al. (2022)

Figure 2 shows the model of building situated on sloping ground having an angle of inclination 0°, 5°, 10°, 15°, and 20° respectively considering soil-structure interaction.

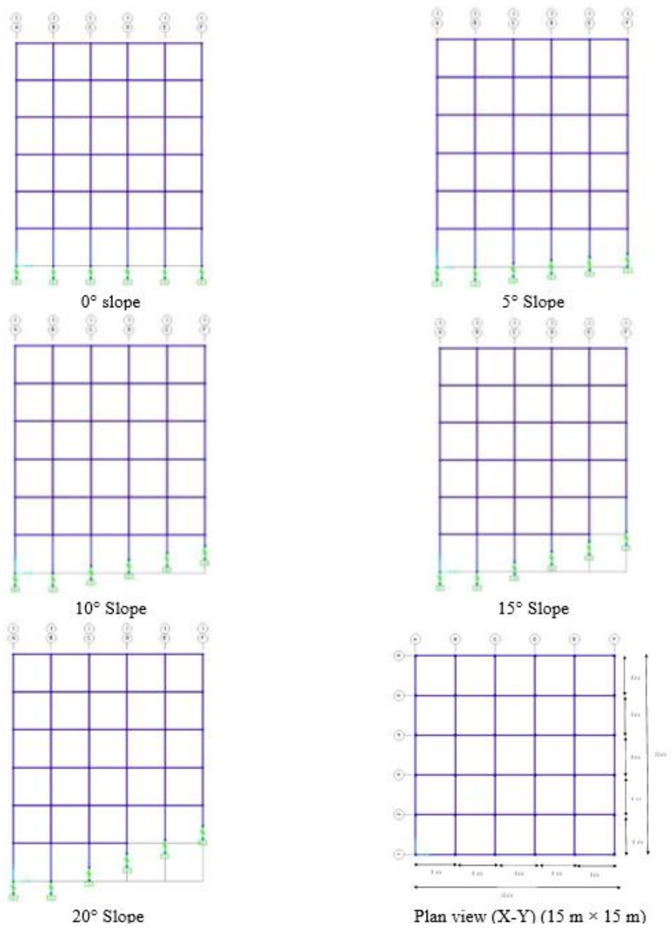


Figure 2 Elevation (X-Z) of RCC building resting on different slopes with SSI and plan view (X-Y)

III. Results And Discussions

RCC multi-storey buildings seismic analysis for different ground inclinations (0°, 5°, 10°, 15°, 20°) without and with soil-structure interaction. The response spectrum method using complete quadratic combination (CQC) as per IS 1893-2016 is used for the seismic analysis of all the building models

Figure 3 and Table 1 shows base shear values at various sloping ground inclinations (0°, 5°, 10°, 15°, 20°) without and with soil-structure interaction. Without considering the interaction between the soil and the structure, it has been found that base shear reduces as building inclination increases. It is clearly visible that, when soil-structure interaction is not considered, base shear is lowest at a 20° inclination and largest at 0° on plain level ground. Based on soil-structure interaction, base shear is shown to be lowest at 0° on plain level ground and largest at 15° inclination. It has also observed that base shear decreases, if analysis is done by taking SSI into account at every given inclination of building.

Table no 1: Base shear (kN) without and with SSI

Ground inclinations									
0 degree		5 degrees		10 degrees		15 degrees		20 degrees	
w/o SSI	with SSI	w/o SSI	with SSI	w/o SSI	with SSI	w/o SSI	with SSI	w/o SSI	with SSI
4007.4	1963.6	4002.95	2232.5	3998.4	2651.58	3861	2661.02	3723.3	2578.7

Horizontal storey displacement has been found to rise with each building storey along the building's height, both with and without soil-structure interaction considerations as shown in Figure 4. Both with and without soil-structure interaction considerations, the top storey of the building experiences the greatest amount of storey displacement. Furthermore, it has been noted that the storey displacement is greater when SSI is present than when it is not.

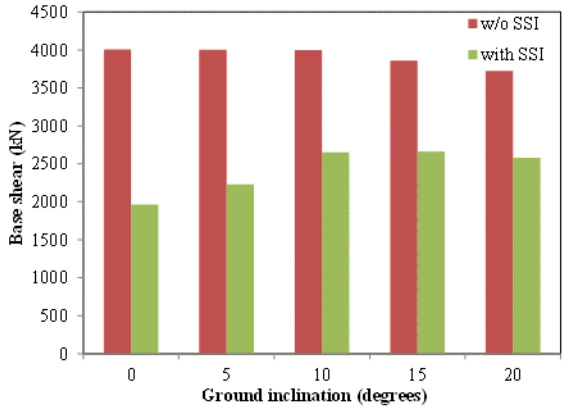


Figure 3 Base shear values without and with SSI

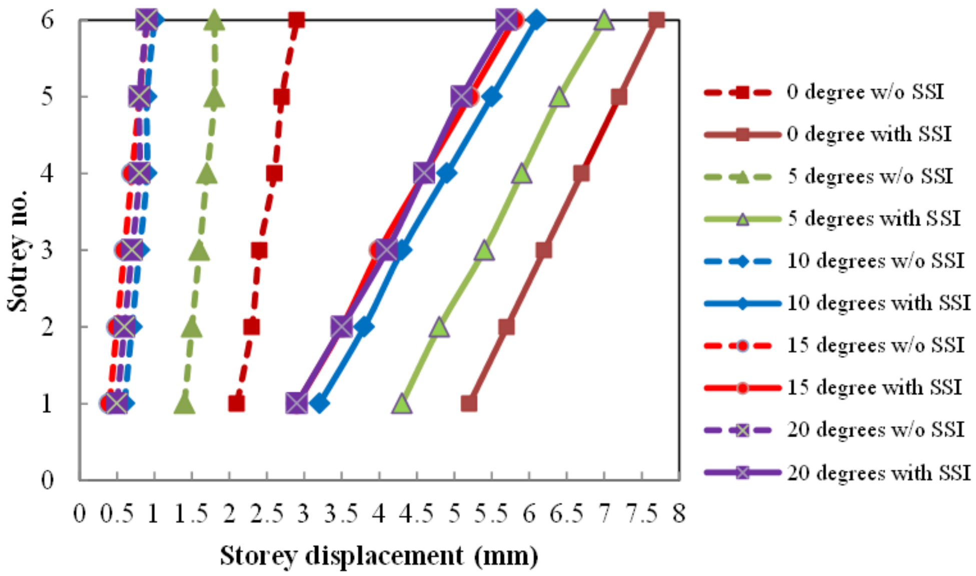
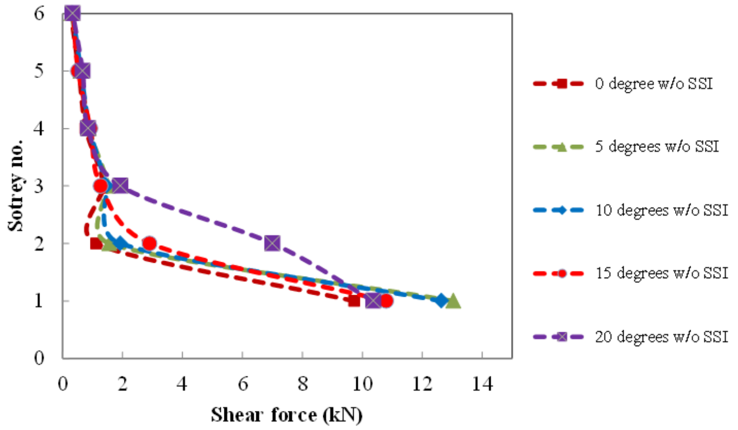
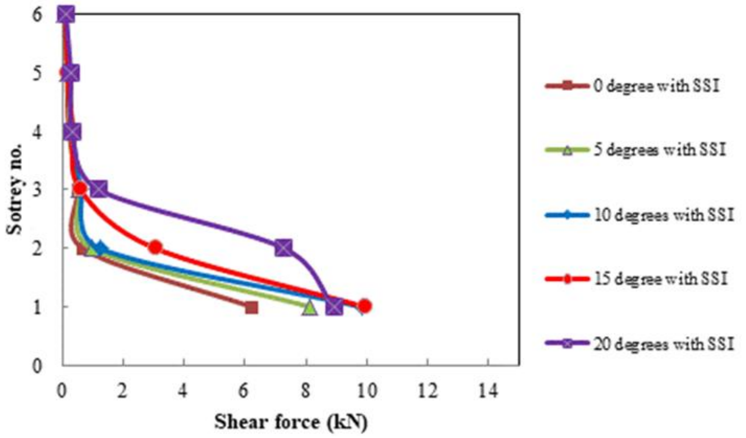


Figure 4 Storey displacement (mm) without and with SSI

Figure 5 shows the maximum shear force values at various sloping ground inclinations (0°, 5°, 10°, 15°, 20°) without and with soil structure interaction. Shear force starts reducing with each building storey, both with and without soil structure contact. Without and with soil-structure interaction, it is clear that shear force rises with ground inclination. Additionally, it has been noticed that when SSI is taken into consideration during analysis, shear force values go down.



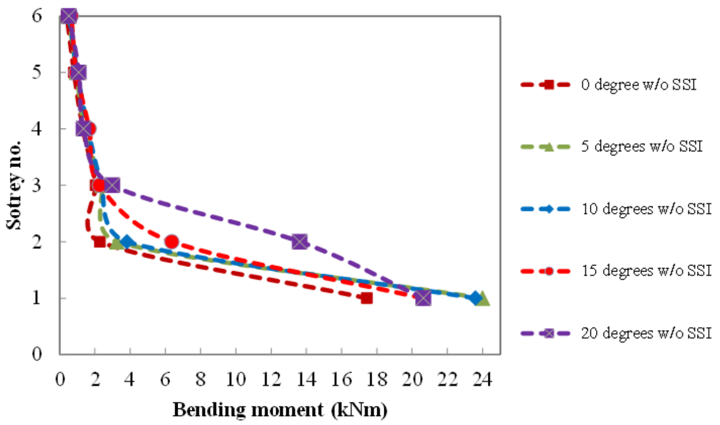
(a) without SSI



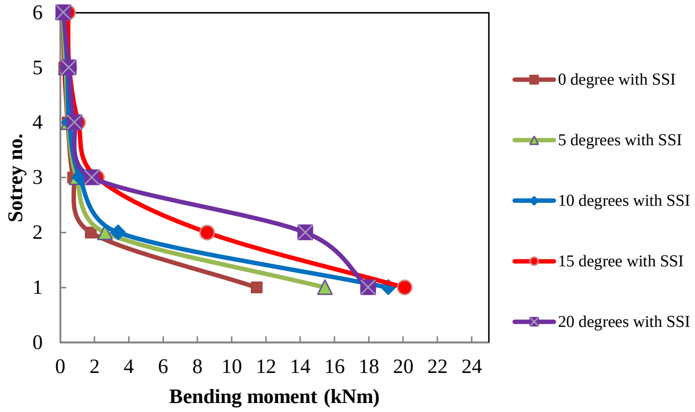
(b) with SSI

Figure 5 Shear force (kN) without and with SSI

Figure 6 shows maximum bending moment values at various sloping ground inclinations (0°, 5°, 10°, 15°, 20°) without and with soil-structure interaction. Bending moment has been seen to decrease with each building storey, both with and without soil-structure interaction. It is obvious that bending moment increases with ground inclination both with and without soil structure interaction, demanding further reinforcement. It has also observed that bending moment values decreases if analysis is done by taking SSI into account.



without SSI



(b) with SSI

Figure 6 Bending moment (kNm) without and with SSI

IV. Conclusions

In this work, all building models are subjected to seismic analysis using the response spectrum approach, which uses the complete quadratic combination (CQC) in accordance with IS 1893-2016. The resulting storey displacement, storey drift, shear force, base shear, bending moment, torsional moment and other data are then studied and compared with the building models that do not take SSI into account. The following conclusions are drawn from the present study:

1. When inclination increases without SSI, base shear reduces, and when inclination increases with SSI, base shear increases. It has been found that base shear reaches its maximum at 15° with SSI and 20° without taking soil structure interaction into account. Base shear decreases if analysis is done by taking SSI into account.
2. Storey displacement increases in every storey with increase in inclination without SSI and it increases in every storey with increase in inclination with SSI. It is observed that storey displacement is maximum at top storeys of building with or without SSI. Storey Displacement increases if analysis is done by taking SSI into account.
3. Shear force decreases at every storey of building with or without soil structure interaction. It can be observed that shear force increases as inclination of ground increases with or without soil structure interaction. Additionally, it has been noted that when SSI is taken into consideration during analysis, shear force values go down.
4. With or without soil structure interaction, the bending moment reduces with each building storey. More reinforcing is necessary because it is clear that bending moment rises with ground inclination, without and with soil structure interaction. Additionally, it has been noted that bending moment values drop, when SSI is taken into consideration during analysis.

Finally, it is concluded that increment of slope angle increases the seismic response values as compared to buildings on plain ground. Also, it was observed that the force values as base shear, shear force, bending moment are overestimated and response values as displacement and drift are underestimated when SSI is not considered. So, while planning a construction project on sloping ground, the influence of soil-structure interaction needs to be considered.

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