STUDY OF PUSHOVER ANALYSIS ON RC FRAMED STRUCTURE WITH UNDERGROUND STRUCTURE CONSIDERING THE EFFECTS OF SOIL STRUCTURE INTERACTION

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Abstract

This study states that the effects of soil structure interaction on the Reinforced Concrete (RC) framed structures is directly influenced by the soil properties of the site. Here, one preexisting structure is taken for the study. The building is a hospital building with two underground basements. Taking into account the actual soil condition of building site, this study provides idea on the soil structure interaction on the structure The properties of springs are calculated from different standard penetration test (SPT) values, Poisson’s ratio and elasticity of soil along the depth of the soil. Entire soil-foundation-structure system is modelled and analyzed using spring approach. Static analysis, response spectrum analysis and pushover analysis (PA) are done in order to find the variations in natural periods, base shears and deflections of the structures by incorporating soil flexibility as compared to structures with conventional fixed base. Pushover analysis is done to evaluate the performance of the structure when modelled in fixed base and spring base system.

Keywords: Soil structure interaction (SSI), Pushover analysis (PA), Soil stiffness, Performance points, Spring modelling.

1. Introduction

Earthquake produces strong ground motions. These effects of ground motion on the building depends on the base condition taken in the analysis. In the normal design practice, we will consider building frame as a fixed base but in actual case the flexible nature of soil allows the foundation for movement. Soil structure interaction (SSI) plays an important role in earthquake resistant design of structure. SSI effects are needed to be considered for the tall buildings and buildings resting over soft soils. Assumption of a fixed base condition adopted by practitioners is not always conservative or cost-effective, especially for rigid buildings over soft soils (Gerardo, 2017).

Moreover, recent studies show that the effects of soil structure interaction may be decrimental to the seismic response of structure and neglecting SSI in analysis may lead to an un-conservative design (Raheem, Ahmed, & Alazrak, 2015). This research focuses to know the effect of SSI on the response of multi storey building with underground structure on its soil condition subjected to earthquake ground motion acceleration. Taking into account the soil condition of building site, this study provides idea on the soil structure interaction. Substructure spring approach is used to incorporate soil structure interaction in the analysis. Springs stiffness are calculated and they are assigned for footings and retaining walls. The top 30 m of surface soil stratum is considered key influence on the structure and its respectively ground motions (Kiku*et al.*, 2001). Lithological formations are guiding the SPT values. In sub structure modelling, spring stiffness is used to account for frequency dependency of interaction. Gazetas is referred for development of spring stiffness solutions that are applicable to any solid

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basemat shape (FEMA 356). For determination of seismic responses, it is necessary to carry out seismic analysis of the structure using different available methods (Duggal, 2010). Suhas K S and D. S. Prakash (2017) showed that there can be increase in base shear when SSI is considered. Taking SSI into account, there is more deflection of structures and hence structures undergo more in tension (Dongol *et al.*, 2019).

Results are deduced from the following parameters i.e. fundamental time period, base shear etc. Static analysis, response analysis and pushover analysis are done in order to find the variation in natural period, bending moments and deflections of structure by incorporating soil flexibility as compared to structures with conventional fixed base. Here, pushover analysis is done to check the seismic response of RC building frame in terms of performance point. The main objective of this study is to observe the performance of a building designed as per IS 456:2000, IS 1893: (Part1) 2002 and ATC-40. The pushover analysis of the building is carried out by using structural analysis and design software SAP 2000.

2. Description of Building

Building taken for the study is a hospital building with two basements located at Kavre, Nepal. Location of the building is shown in Fig.1. The building taken for the study is horizontally and vertically irregular in shape. Plan of the building is shown in Fig. 2.

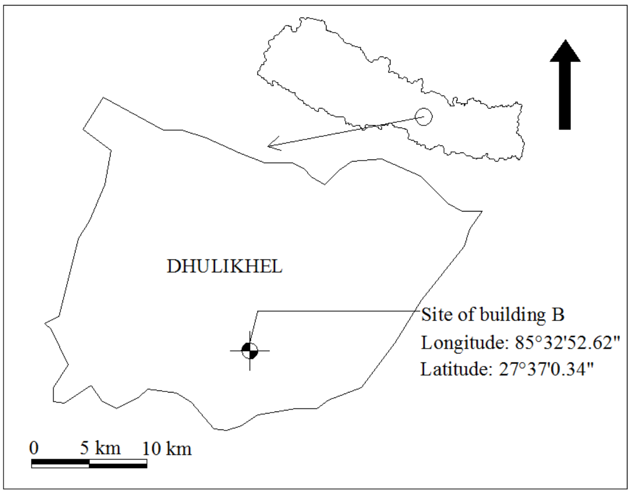

Fig. 1 Location of the site

Some of the major features of the structure are given below:

- Beam: 350 mm x 600 mm
- Column: 750 mm x 750 mm (Maximum size)
- Depth of slab:125 mm
- Thickness of Lift wall: 200 mm
- Thickness of retaining wall: 200 mm
- Thickness of Shear wall: 350 mm
- No. of storey: 9
- Total height of building: 32.4 m
- Height of storey: 3.6 m
- Live Load: 4kN/m^2
- Floor Finish: 1.5 kN/m^2
- Terrace Load: 3kN/m^2
- Unit wt. of concrete: 24kN/m^3
- Unit wt. of bricks: 19kN/m^3
- No. of Lifts: 3
- Type of Staircase: Dog-legged
- No. of Storeys: 8
- No. of Basements: 2
- Thickness of internal walls: 110 mm
- Thickness of external walls: 230 mm
- Plinth area of the building: 1161.48 sqm
- Type of foundation: Raft Footing
- Depth of raft foundation: 700 mm
- Location of Foundation from GL: 7.2 m
- Importance factor (I):1.5
- Zone factor (Z): 0.36
- Response reduction factor (R): 5
- Concrete Strength: M25 (beam, slab, shear wall and lift wall) and M30 (column)
- Rebar Strength: Fe500

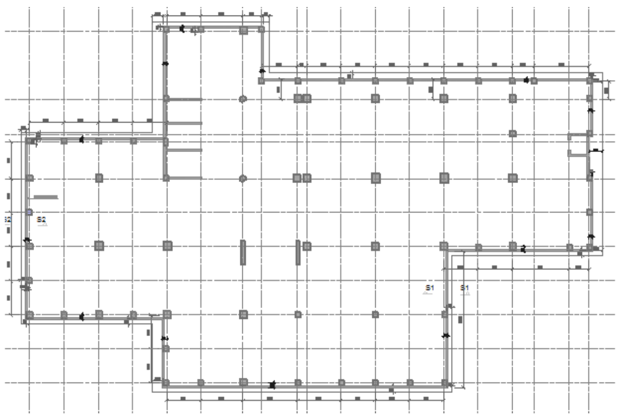

Fig. 2 Plan of the building for the study

3. Methodology

Table 1: Soil condition parameters of the building site obtained from Kiku*et al.*

Depth (m)	N-value	Vs (m/s)	G (MPa)	E (MPa)
3	18	158.84	29.03	81.56
6	13	144.44	33.19	93.24
>9	15	150.60	34.90	98.06

Table 2: Surface Stiffness according to Gazetas

Description	Surface Stiffness
Translation Stiffness, Kxsur	$\frac{2GL}{(1-\nu)}[2+2.5x^{0.85}]-\left[\frac{0.2}{(0.75-\nu)}\right]GL\left(1-\frac{L}{B}\right)$
Rocking Stiffness, Krxsur	$\frac{G}{(1-\nu)}Ix^{0\cdot75}\left(\frac{L}{B}\right)0\cdot25\left(2.4+0.5\left(\frac{B}{L}\right)\right)$
Translation Stiffness, Kysur	$\frac{2GL}{(1-\nu)}[2+2.5x^{0.85}]$
Rocking Stiffness, Krysur	$\frac{3G}{(1-\nu)}Iy^{0\cdot75}\left(\frac{L}{B}\right)0\cdot1$
Translation Stiffness, Kzsur	$\frac{2GL}{(1-\nu)}[0.73$
Rocking Stiffness, Krzsur	$GJb^{0\cdot75}\left[4+11\left(1-\frac{B}{L}\right)10\right]$

Soil investigation report of the building site was used in order to model spring base system for the properties of soil. Kiku*et al.* was used to convert the value of N of soil to the soil properties required for the study as shown in Table 1. Springs are introduced in the modelling of the building in SAP 2000 version 18 using the soil parameters using formula of Gazetas. The properties of soil varying with the depth is also taken into account for the study. Spring properties are different at different depth of the structure. Gazetas (1991) formula for the spring is incorporated to calculated the stiffness of soil which is taken from FEMA356. Tables 3 and 4 show formulas for surface stiffness and embedment stiffness of soil respectively. Here surface and embedded stiffness are calculated separately for the soil stiffness at certain depth of the soil condition and at ground surface condition. Surface stiffness denotes the stiffness at the top level whereas the embedment stiffness denotes the Stiffness of soil at the foundation level considering soil properties. Properties of soil is the key factor for the analysis and the study of SSI in this study.

Using the formula given in Tables 2 and 3, stiffness for the spring is calculated that is used in spring modelling of building for the analysis in SAP 2000 software as shown in Fig 3.

Table 3: Embedment Stiffness according to Gazetas

Description	Embedment Stiffness
Translation Stiffness, Kxemb	$Kx,sur\left[1+0.15\sqrt{\frac{D}{B}}\right]x\left[1+0.52\left(\frac{h}{B}\frac{Aw}{L^2}\right)^{0.4}\right]$
Rocking Stiffness, KRxemb	$Krx,sur\left[1+1.26\frac{d}{B}\left[1+\frac{d}{B}\left(\frac{d}{D}\right)^{-0.2}\sqrt{\frac{B}{L}}\right]\right]$
Translation Stiffness ,Kyemb	$Ky,sur\left[1+0.15\sqrt{\frac{D}{B}}\right]\left[1+0.52\left(\frac{h}{B}\frac{Aw}{L^2}\right)^{0.4}\right]$
Rocking Stiffness, KRyemb	$Kry,sur\left[1+0.92\left(\frac{d}{L}\right)^{0.5}\left[1.5+\left(\frac{d}{L}\right)^{1.9}\left(\frac{d}{D}\right)^{-0.6}\right]\right]$
Translation Stiffness, Kzemb	$Kz,sur\left[1+\frac{1}{21}\frac{D}{B}(1+1.3x)\right]\left[1+0.2\left(\frac{Aw}{Ab}\right)^{2/3}\right]$
Rocking Stiffness, KRzemb	$Krz,sur\left[1+1.4\left(1+\frac{B}{L}\right)\left(\frac{d}{B}\right)^{0.9}\right]$

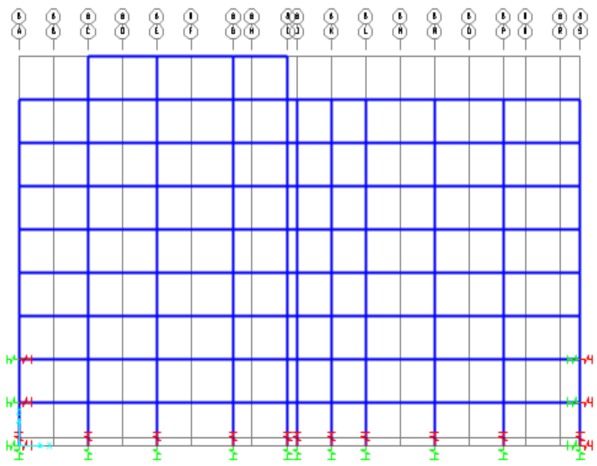

Fig. 3 Spring modelling of the building in SAP2000 software

4. Results and Discussions

Building taken for the study carries heavier load and it is further more penetrated in its soil condition as there are two basement system in the building. The analysis is carried out in fixed base and spring base modelling. Results are computed from static, dynamic and pushover analysis.

Table 4: Time period of the building

Base Condition		X	Y
Fixed Base	(sec)	0.893	0.682
Spring Base	(sec)	0.871	0.657
Difference	(%)	2.464	3.665

Table 5: Base Reaction of the building

Base Condition		X	Y
Fixed Base	(kN)	6315.587	8266.365
Spring Base	(kN)	6555.452	8691.798
Difference	(%)	3.798	5.147

Table 4 shows that time period decreases while considering SSI in spring system by 2.464% and 3.665% in x and y direction respectively. Generally, it is assumed time period value is more if SSI is considered. However, different soil conditions at different depth eventually affects the time period to decrease. There is increase in base reaction by 3.798% to 5.147% along x and y direction respectively as shown in Table 5.This increase in base reaction is due to nonuniformity of soil properties along the depth of underground structure.

Table 6: Roof displacement of the building

Base Condition	Static		Dynamic	
	X	Y	X	Y
Fixed base (mm)	46	70	50	77
Spring base (mm)	50	77	55	79
Difference (%)	8.695	10	10	2.597

Table 6 shows that there is increase in roof displacement by 8.695% and 10% respectively in static analysis shown by Figs. 4 and 5 for x and y direction respectively. The value of displacement increases further more in case of dynamic analysis as shown in Figs. 6 and 7 for x and y direction respectively. This clearly shows that considering the effects have visibly more deflection in the structure along each storey than the structure that is considered fixed at the base.

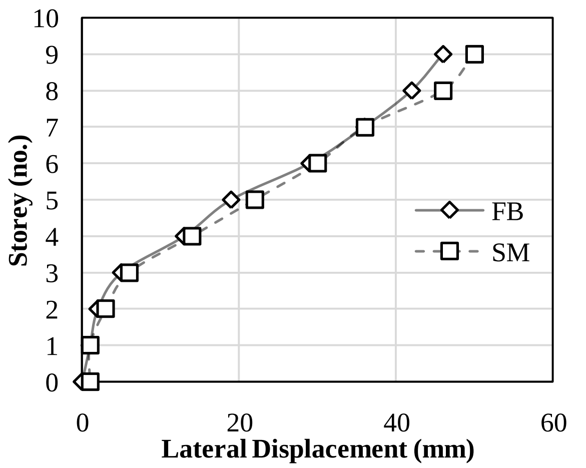

Fig. 4 Storey displacement for static analysis along x-direction

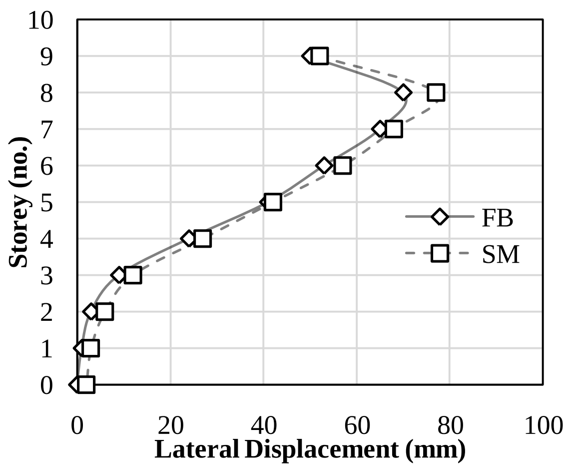

Fig. 5 Storey displacement for static analysis along y-direction

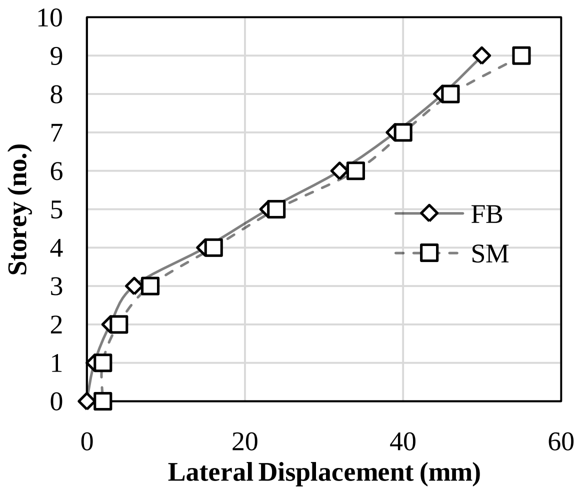

Fig. 6 Storey displacement for dynamic analysis along x-direction

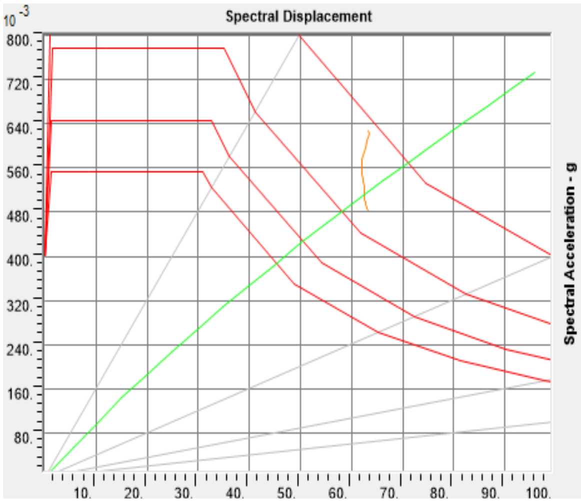

Fig. 9 Capacity and demand curves for fixed base condition along y-direction

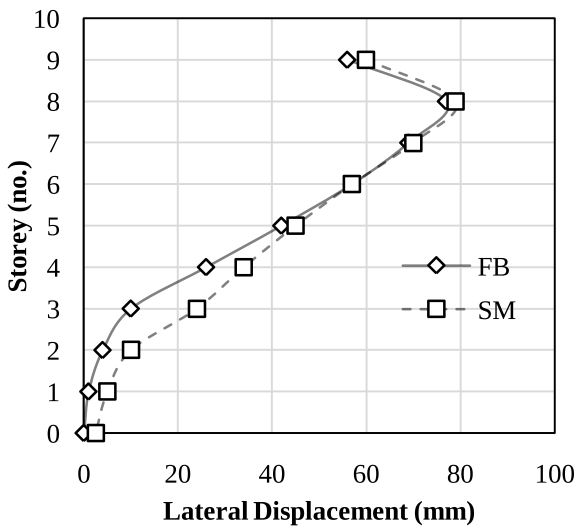

Fig. 7 Storey displacement for dynamic analysis along y-direction

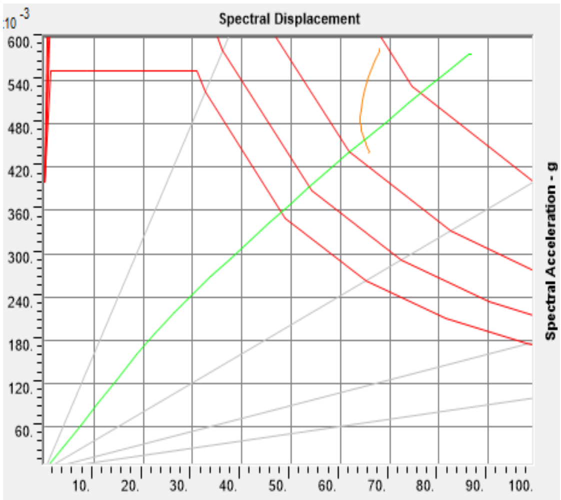

Fig. 10 Capacity and demand curves for spring base condition along x-direction

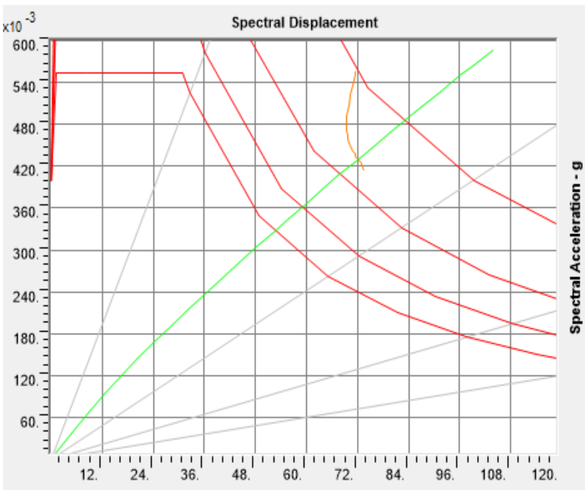

Fig. 8 Capacity and demand curves for fixed base condition along x-direction

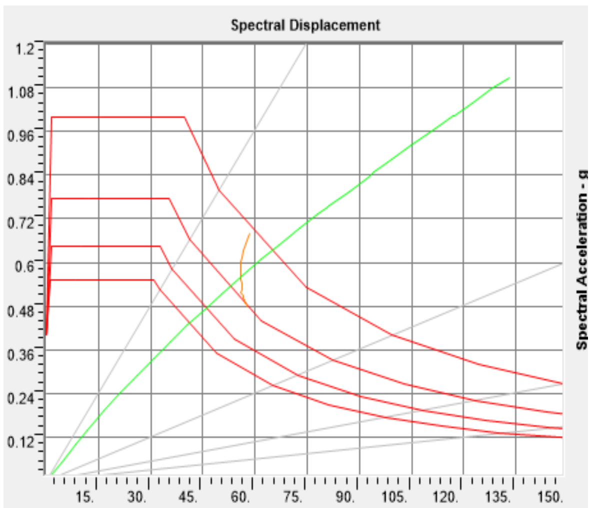

Fig. 11 Capacity and demand curves for spring base condition along y-direction

Table 7: Performance point in terms of Base shear

Base Condition	X	Y
Fixed Base Condition (kN)	29770.207	32102.591
Spring Base Condition (kN)	30543.030	32312.693
Difference (%)	2.530%	0.654%

Table 8: Performance point in terms of deflection

Base Condition	X	Y
Fixed Base Condition (mm)	103.281	67.069
Spring Base Condition (mm)	90.176	61.673
Difference (%)	-12.688%	-8.045%

Performance points calculated from pushover analysis in SAP2000 software are in terms of base shear and deflection. The performance point is obtained as per ATC 40 capacity spectrum method. Capacity and demand curves for pushover analysis on fixed base modelling are shown in Figs 8 and 9 along x and y direction respectively. While capacity and demand curve in spring base modelling are shown in Figs 10 and 11 for x and y direction respectively. Tables 7 and 8gives the brief description of the results of pushover analysis in tabular form. Table 7 shows that there is increase in base shear by 2.530% along x-direction and 0.654% along y-direction in spring base condition while compared with fixed base condition. Table 8 shows that there is decrease in deflection by 12.688% along x-direction and 8.045% along y-direction in spring base condition while compared with fixed base condition. This clearly shows that the value of base shear increases in the consideration of spring base system which represents that SSI condition on the structure. Therefore, there is more chance for the building to act more vigorously when SSI is considered.

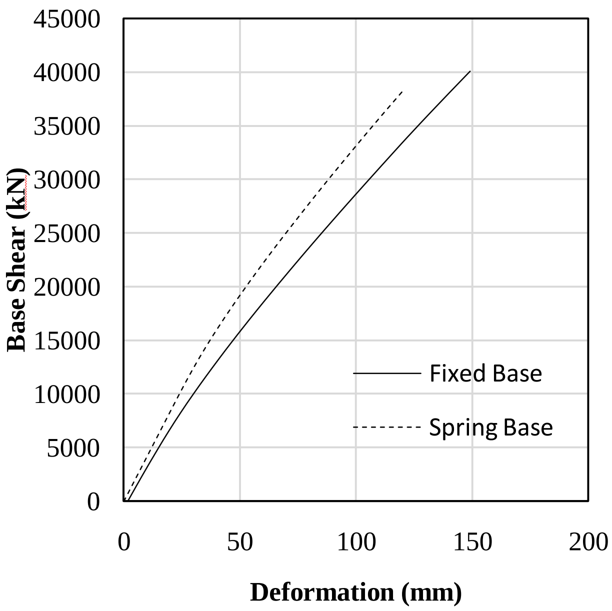

Fig. 4 Capacity curve along x-direction

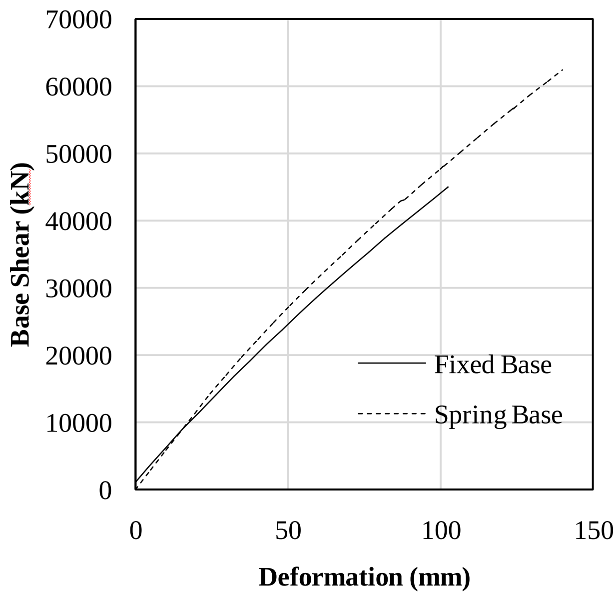

Fig. 5 Capacity curve along y-direction

Capacity curves are obtained to compare the behavior when modelled in fixed base and spring base as shown in Figs 12 and 13 along x and y direction respectively. The behavior of curves shows that spring base modelling has greater base shear than that at fixed base modelling for any specific deflection. This is due to nonuniformity of soil properties along the depth of underground structure. Different soil condition acts on the structure at different depths. This shows the effects of soil conditions on the structure. Joy et al. (2016) obtained capacity curve for different types of buildings and results obtained showed that base reaction considering SSI is dependent on soil condition. Similar results can be seen in this study of RC framed structure under the influence of SSI. Fig 12 shows that the value of base shear causing have deflection is more in spring base system whereas the value is lesser for the fixed base condition. This is directly influenced by the stiffness of soil which represents is soil condition of the site. Same results are seen in Fig 13.

5. Conclusions

This study focused on the effects of soil structure interaction on the building having basement considering soil properties as per given in soil investigation report. It illustrated that the behaviour of the base condition greatly affects the performance of the building. Soil condition plays an important role in the overall response of the structure. For heavier building like the case study taken, which penetrates on soil with two basements, the time period and base shear are affected by the penetration of the structure in the soil and results are directly affected by the soil conditions. The properties of soil varied with the depth. Hence the influence in the structure is varying along the underground basement. The difference in the stiffness of soil contributes to formulation of different springs. Here, storey deflects less and time period is slightly decreased while considering SSI even though structure is larger in comparison to the consideration of fixed base. The role of soil condition is quite vivid in pushover analysis. Pushover curves for building shows that performance of building is hugely influenced by their soil condition along with the depth of penetration. Hence, presence of underground structure has a huge impact on SSI. Change in building height, its use, its plinth area, load carried by it, soil condition varying with depth and presence of underground structures changes various parameters of the building such as time period, roof displacement and base shear that means soil structure interaction is necessary. As SSI deals with the soil related factors, its stiffness and inflence on the structure, the response of the structure can be understood in more detail.

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