Effect of Soil-Structure Interaction on Seismic Response of Buildings

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Abstract— in the present study attempt have been made to study the effect of (SSI) soil-structure interaction on the performance of building frame resting on isolated footing. Since the seismic response of a structure is greatly influenced by (SSI) soil-structure interaction. For superstructure (G+3) common rectangular building is considered for seismic analysis. For SSI study cohesive type of soil (medium soft clay) has been considered. The total work is divided into two parts. In first part the analysis is done manually in which two methods of analysis are used for seismic demands assessment of the target moment-resistant frame buildings: equivalent static load, response spectrum method (dynamic analysis) as per given in IS: 1893-2002 (part-II) and in the second part the analysis is carried out using ABAQUS software. The additional priority has given on manual earthquake analysis.

Key words: Seismic Response, Soil-Structure Interaction, Isolated Footing, Seismic Coefficient Method, Response Spectrum Analysis, Elastic Continuum, Finite Element Method

I. INTRODUCTION

The framed structures are generally analyzed with their bases considered to be either completely hinged or rigid. Though, the foundation resting on deformable soil also undergoes deformation relying on the relative rigidities of the foundation, soil and superstructure. Therefore interactive analysis is compulsory for the accurate evaluation of the response of the superstructure. Many researchers have suggested different methods to assess the effect of soil-structure-interaction from time to time. Winkler's idealization (1867) has presented the soil medium as a system of identical but closely spaced, mutually independent, discrete, linearly elastic spring [1]. George Gazetas (1991) represents complete set of numerical formulas and dimensionless charts for quick computation of damping coefficient (c) and dynamic stiffness (K) of foundation harmonically oscillating in a consistent half-space [2]. Shekhar Chandra Datta (2002) has represented possible substitute models for the purpose of soil-structure-interaction analysis [3]. Bhattacharya et al (2004) concluded that the effect of SSI can cause substantial increase in the base shear of low-rise building frames specifically those with the isolated footing [4].

The application of finite element method has attained a sudden outburst to analyze the complex mutual behavior of structure. It is possible to model many complex conditions with high degree of authenticity including non-homogenous material condition, change in geometry, non-linear stress-strain behavior and change in material property and so on. B.R. Jayalaxmi et al (2009) investigated earthquake response of multistoried RC frame with SSI effects by modeling soil-structure-foundation system using Finite Element Method [5]. Considering buildings under seismic response of SSI exhibit variation based on stiffness of soil and frequency content of motion. Garg and Hora (2012) has analyzed the performance of soil-footing-frame system by considering layered soil mass, plane frame, infill frame and homogenous soil [6]. They concluded that shear force and bending moment in superstructure get considerably altered due to differential settlement of soil mass.

Fig. 1 depicts a conventional building frame showing its dimensions respectively, is to be considered in the present study.

The rest of the research work is organized as follows: section 2 discusses about the objective of the present analysis. In the section 3, structural idealization of the system and the idealization of soil continuing medium have been discussed in precise. We outline our proposed strategy briefly in section 4, namely the methodology section in two parts where first part converge mathematical formulation and the second part focuses on FEM formulation with modeling in ABAQUS 6.14-4 software. Thus in section 5, notation is given. Lastly, we summarize our paper work, conclude the paper and target some future work in section 6 and 7 respectively.

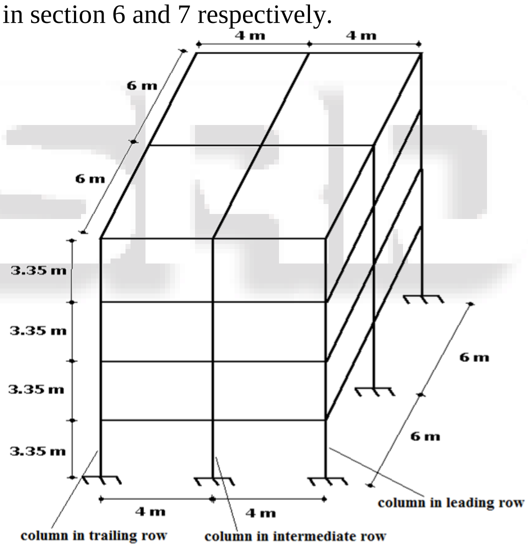

Fig. 1: Conventional building frame considered in the current study.

II. OBJECTIVE

The objective of the present analysis is to estimate the SSI effect on various static and dynamic properties of R.C. frame for instance Base Shear, Natural Time Period, etc. Firstly, the above study achieved manually by two recommended method according to the design criteria for multistoried buildings [IS code: 1893-1984], i.e.:

1) Equivalent static force analysis (seismic co-efficient method)
2) Dynamic analysis (response spectrum method) [7].

An effort is also made to interpret the effectiveness and serviceability of these models.

Secondly, the aim of this research work is to investigate the effect of SSI in the analysis of a residential building consisting of 4-storey and structured as RC frames using ABAQUS 6.14 software.

Special attention is paid to:

- The effect of (SSI) soil-structure-interaction in the dynamic behavior of the multistory building.
- The amplifications of the (SSI) soil-structure-interaction in the seismic design of the multistory building. The building is located in Gorakhpur, India (zone IV).

III. IDEALIZATION OF THE SYSTEM

A. Structural Idealization

A four storey (G+3) residential building located in zone 4 as per Indian code is considered. The building models having (2×2) bay of each bay is of 6m×4m in plan resting on isolated footing. The storey height of the residential building frame is 3.35m and depth of foundation is 1.0535m for all cases dimension of the column 230mm×230mm, dimension of beam 230mm×450mm, thickness of slab is 140mm and the thickness of brick masonry wall is 230mm only at periphery.

B. Idealization of Soil Continuing Medium

The response of soil-structure system mainly depends on the size of a structure, along with its dynamic characteristics and the soil profile as well as the nature of excitation. Soil Structure Interaction is also carried out by FEM (finite element method) by considering soil continuing medium as an elastic continuum below foundation. The finite soil mass is considered and based on convergence study, with boundary far beyond a domain where structural loading has got no effect. This is assumed to be modeled with finite boundary by providing the plan dimension of near-field finite element soil as 5 times the structure length [8]. Considering this, our soil mass block becomes (60mx40m) in plan and having 8m depth is used for the study.

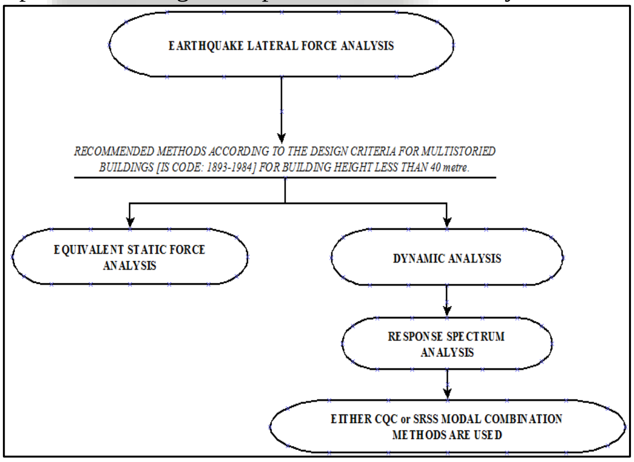

Fig. 2: Flow chart representing procedures for specifying seismic design lateral forces.

IV. METHODOLOGY

A. Part - 1

1) Mathematical Formulation (manually):

a) Calculation of design seismic force by static analysis using Equivalent static force method

Plan and elevation of a four-storey R.C. residential building is shown in fig. 1 as a building configuration.

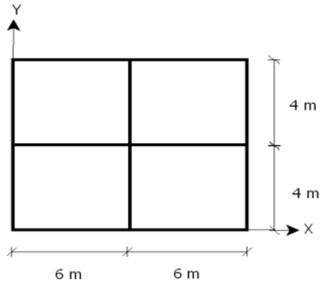

Fig. 2: Plan

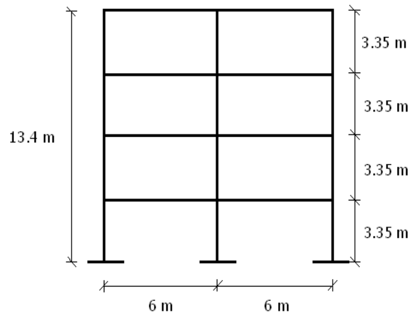

Fig. 3: Elevation

Now it is to determine the design seismic load and storey base-shear force distribution of the building as per code.

- Step 1: Design parameters- for seismic zone IV, the zone factor Z is 0.24 [table 2 of IS: 1893-2002 (part-1)]. Being a residential building, the Importance factor, I, is 1.0 [table of IS: 1893-2002 (part-1)] building is required to be provided with moment resisting frames particularized [as per IS: 13920-1993]. So, the response reduction factor, R is 3 OMRF [table 7 of IS: 1893-2002 (part-1)].
- Step 2: Seismic weights- the floor area is 12×8=96 m^2. Since the live load class is 3 kN/m^2, only 25% of the live load is lumped at the floors, and at roof no live load is to be lumped.

Columns = 230mm×230mm
Beams = 230mm×450mm
Thickness of slab = 140mm
Thickness of wall = 230mm only at periphery
Live load = 3 kN/m^2
Analysis considering stiffness of infill masonry.

Assuming unit weight of concrete as 25 kN/m^2 and 24 kN/m^2 for masonry.

- Slab: DL due to self-weight of slab = (12x8x0.14)x25 = 336 kN
- Beams: self-weight of beam per unit length = (0.23x0.45x25) = 2.5875 kN/m
- Total length = (6x6) + (4x6) = 60m
- DL due to self-weight of beams = (2.5875x60) = 155.25 kN
- Columns: self-weight of column per unit length = (0.23x0.23x25) = 1.3225 kN/m
- DL due to self-weight of columns = (9x1.3225x3.35) = 39.8734 kN
- Walls: self-weight of wall per unit length = (0.23x3.35x20) = 15.41 kN/m
- Total length = 180m
- DL due to self-weight of walls = (15.41x40) = 616.4 kN

- Live load [imposed load, IM (50%)] = {(0.5x3.35)x12x8} = 160.8 kN

2) Load on All Floors:

$W_1=W_2=W_3$= (336+155.25+39.8734+616.40+160.8)
= 1308.3234 kN

3) Load on the roof slab (live load on slab is zero)

W_4 = {336+155.25 + (39.8734/2)+(616.4/2)}
= 819.3867 kN

Total seismic weight, W= {(1308.3234x3)+819.3867)
= 4744.3569 kN

- Step 3: Fundamental period- lateral load resistance is provided by moment resisting frames in-filled with brick masonry panels. Hence, appropriate fundamental natural period. [Clause 7.6.2. of IS: 1893-2002 (part-1)]

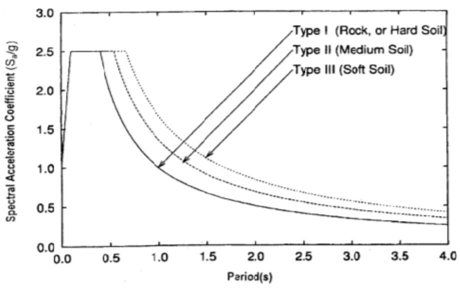

Fig. 4: Response spectra for rock and soil sites for 5% damping [7].

EL in X-direction:

$T_a = 0.09h/\sqrt{d}$
= (0.09x13.4)/√ (6+6)
= 0.348 sec

The building is located on type II (medium soil) from fig 3.

$S_a/g = 2.50\ (0.10 \le T_a \le 0.55)$

Zone factor: for zone IV, Z = 0.24 (seismic intensity severe)

I = 1.0

R = 3.0 (OMRF)

$A_h = (Z/2)(I/R)(S_a/g)$ = (0.24/2) (1.0/3) (2.50) = 0.1

$V_B = A_h W$ = (0.1x4744.3569) = 474.436 kN

Force distribution with building height:

The design base-shear is to be distributed with height as per clause 7.7.1. Table 1.1 provide the calculations. Fig. 4 shows the design seismic force in X-direction for the entire structure.

EL in Y-direction:

$T_a = 0.09h/\sqrt{d}$
= (0.09x13.4)/√ (4+4)
= 0.426385389
≈ 0.426 sec

$S_a/g = 2.50 \quad (0.10 \le T_a \le 0.55)$

Zone factor: for zone IV, Z = 0.24

I = 1.0

R = 3.0

$A_h = 0.1$

V_B = 474.436 kN

$Q_i = V_B [(W_i h_i^2)/\sum (W_i h_i^2)]$

Therefore, for this building the design seismic forces in Y-direction is as same as that in the X- direction. Fig. 4 shows the design seismic force on the building in the Y-direction.

Storey-Level	W_i (kN)	h_i (m)	$W_i h_i^2$ (kN-m)	$\frac{W_i h_i^2}{\sum W_i h_i^2}$	Q_i, Lateral force at i^{th} level for EL in direction (kN)	
					X	Y
4	819.39	13.4	147129.67	0.4172	198	198
3	1308.32	10.05	132143.59	0.3747	178	178
2	1308.32	6.7	58730.48	0.1665	79	79
1	1308.32	3.35	14682.62	0.0416	20	20
∑			352686.36	1	475	475

Table 1: Lateral Load Distribution with Height by the Equivalent Static Method

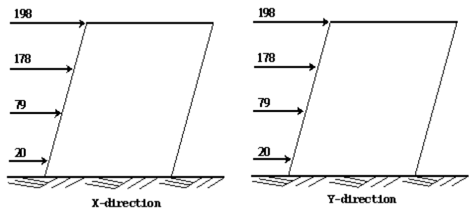

Fig. 5: Design seismic force on the building.

Storey shear forces are calculated as follows:

$V_4 = Q_4$ = 198 kN

$V_3 = V_4 + Q_3$ = (198+178) = 375 kN

$V_2 = V_3 + Q_2$ = (375+79) = 455 kN

$V_1 = V_2 + Q_1$ = (455+20) =475 kN = V_B

Lateral force and shear force distribution is shown in the following figure 5:

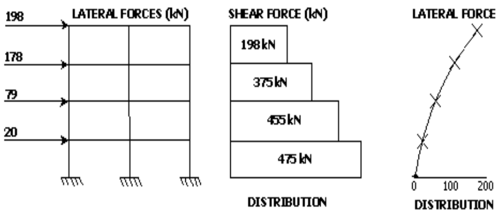

Fig. 6: Shear and lateral force direction along the height of structure.

B. Mathematical Formulation (Manually):

1) Calculation of design seismic force by dynamic analysis using Response-spectrum method

Response-spectrum method of analysis could be performed using the design spectrum stated in clause 6.4.2 or else by a site specific design; spectrum declared in clause 6.4.6 of IS: 1893-2002.

a) Step 1: Seismic weight-

$W_1=W_2=W_3$= (336+155.25+39.8734+616.40+160.8) = 1308.3234 kN

W_4= 336+155.25+ (39.8734/2) + (616.4/2) = 819.3867 kN

Seismic masses-

$M_1=M_2=M_3$= 133.41x10^3 kg

M_4= 83.55x10^3 kg

b) Step 2: Floor stiffness-

Column stiffness of storey, K = $(12 E_c I_c)/L^3$

Moment of Inertia of columns, $I_c = (0.23)^4/12$ = 2.332x10^ (-3) m^4

Young's modulus, $E_c = 5000\sqrt{f_{ck}}$ N/mm^2 = 5000√25 = 25000 N/mm^2

$K_1 = K_2 = K_3 = K_4 = 9 [(12 E_c I_c)/L^3]$ = 0.1675x10^9 N/m = 167.5x10^3 kN/m

c) Step 3: Natural frequencies & mode shapes-

Mass matrix=

$$\begin{bmatrix} M1 & 0 & 0 & 0 \\ 0 & M2 & 0 & 0 \\ 0 & 0 & M3 & 0 \\ 0 & 0 & 0 & M4 \end{bmatrix}$$

Stiffness matrix=

$$\begin{bmatrix} (K1+K2) & -K2 & 0 & 0 \\ -K2 & (K2+K3) & -K3 & 0 \\ 0 & -K3 & (K3+K4) & 0 \\ 0 & 0 & -K4 & K4 \end{bmatrix}$$

Solving the eigen equation, $|K\text{-}M\omega^2| = 0$, we will get eigen value and eigen vector respectively as;

$$\omega^2 = \begin{Bmatrix} 79.67 \\ 649.71 \\ 1196.42 \\ 1736.33 \end{Bmatrix}; \quad \omega = \begin{Bmatrix} 8.93 \\ 25.49 \\ 34.59 \\ 41.67 \end{Bmatrix} \text{rad/sec}$$

Φ_1	Φ_2	Φ_3	Φ_4
1.00	1.00	1.00	1.00
0.94	0.23	-0.82	-0.78
0.77	-0.54	-0.55	0.80
0.52	-0.72	1.01	-0.54

Table 2: Mode Shapes

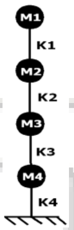

Fig. 7: Lumped mass model of the building.

Therefore, the natural periods are-

$T = 2\pi/\omega = [0.703, 0.246, 0.182, 0.151]$ seconds

Storey Level	Seismic weight (W_i), (kN)	MODE-1		
		Φ_{i1}	$W_i\,\Phi_{i1}$	$W_i\,\Phi_{i1}^2$
4	819.3867	1.00	819.39	819.39
3	1308.3234	0.94	1229.82	1156.03
2	1308.3234	0.77	1007.41	775.70
1	1308.3234	0.52	680.33	353.77
$\sum$	4744.3569		3736.95	3104.89
Modal mass, $M_1 = \frac{[\sum W_i \Phi_{i1}]^2}{g\sum W_i \Phi_{i1}^2}$		$\frac{(3736.95)^2}{3104.89\,g} = 4497.67$ kN/g		
% of total weight		$[M_1/\sum W_i] =$ 94.8%		
Modal participation factor, $P_1 = \frac{[\sum W_i \Phi_{i1}]}{\sum W_i \Phi_{i1}^2}$		= 1.204		

Table 3: Modal Participation Factor, Calculation

Storey Level	Seismic weight (W_i), (kN)	MODE-2		
		Φ_{i2}	$W_i\,\Phi_{i2}$	$W_i\,\Phi_{i2}^2$
4	819.3867	1.00	819.39	819.39
3	1308.3234	0.23	300.91	69.21
2	1308.3234	-0.54	-706.49	381.51
1	1308.3234	-0.72	-941.99	678.23
$\sum$	4744.3569		-528.18	1948.34
$M_2 = \frac{[\sum W_i \Phi_{i2}]^2}{g\sum W_i \Phi_{i2}^2}$		= 143.187 kN/g		
% of total weight		$[M_2/\sum W_i] = 3\%$		
Modal participation factor, $P_2 = \frac{[\sum W_i \Phi_{i2}]}{\sum W_i \Phi_{i2}^2}$		= -0.271		

Table 4: Modal Participation Factor, Calculation

Storey Level	Seismic weight (W_i),(kN)	MODE-3		
		Φ_{i3}	$W_i\,\Phi_{i3}$	$W_i\,\Phi_{i3}^2$
4	819.3867	1.00	819.39	819.39
3	1308.3234	-0.82	-1072.83	879.72
2	1308.3234	-0.55	-719.58	395.77
1	1308.3234	1.01	1321.41	1334.62
$\sum$	4744.3569		348.39	3429.49
Modal mass, $M_3 = \frac{[\sum W_i \Phi_{i3}]^2}{g\sum W_i \Phi_{i3}^2}$		= 35.391 kN/g		
% of total weight		$[M_3/\sum W_i] = 0.75$ %		
Modal participation factor, $P_3 = \frac{[\sum W_i \Phi_{i3}]}{\sum W_i \Phi_{i3}^2}$		= 0.102		

Table 5: Modal Participation Factor, Calculation

Storey Level	Seismic weight (W_i), (kN)	MODE-4		
		Φ_{i4}	$W_i\,\Phi_{i4}$	$W_i\,\Phi_{i4}^2$
4	819.3867	1.00	819.39	819.39
3	1308.3234	-0.78	-1020.49	795.98
2	1308.3234	0.80	1046.66	837.33
1	1308.3234	-0.54	-706.49	381.51
$\sum$	4744.3569		139.067	2834.21
Modal mass, $M_4 = \frac{[\sum W_i \Phi_{i4}]^2}{g\sum W_i \Phi_{i4}^2}$		= 6.824 kN/g		
% of total weight		$[M_4/\sum W_i] = 0.14$ %		
Modal participation factor, $P_4 = \frac{[\sum W_i \Phi_{i4}]}{\sum W_i \Phi_{i4}^2}$		= 0.049		

Table 6: Modal Participation Factor, Calculation

It is seen that the first mode excites 94.8% of the total mass. Consequently, in this case, the codal requirements on number of modes are to be considered such that at least 90% of the total mass is excited will be fulfilled by considering the first mode of vibration alone.

However, for illustration, solution to this paper work considers the first four modes of vibration.

The Q_{ik} lateral load acting in the k^{th} mode at the i^{th} floor is,

$Q_{ik} = A_{h(k)}\,\varphi_{ik}\,P_k\,W_i$ (Clause 7.8.4.5c of IS: 1893-2002 (Part-1). Where, $A_{h(k)}$ = Horizontal acceleration coefficient value as per clause 6.4.2.

1) Mode 1:

$T_1 = 0.703$ sec

$(S_a/g) = 1.36/T_1 = 1.93$ $(0.55 \leq T_a \leq 4.00)$ medium soil

$A_{h(1)} = (Z/2)(S_a/g)(I/R) = (0.24/2)(1.93)(1.0/3) = 0.0772$

$Q_{i1} = A_{h(1)}\varphi_{i1}P_1W_i = (0.0772\text{x}1.204\text{x}\varphi_{i1}\text{x}W_i) = (0.093\ \varphi_{i1}\,W_i)$

2) Mode 2:

$T_2 = 0.246$ sec

$(S_a/g) = 2.50$ $(0.10 \leq T_a \leq 0.55)$ medium soil

$A_{h(1)} = (Z/2)(S_a/g)(I/R) = (0.24/2)(2.50)(1.0/3) = 0.1$

$Q_{i2} = A_{h(2)}\,\varphi_{i2}\,P_2\,W_i = (0.1\text{x}\ \varphi_{i2}\text{x}0.741\text{x}W_i) = (0.0741\ \varphi_{i2}\,W_i)$

3) Mode 3:

$T_3 = 0.182$ sec

$(S_a / g) = 2.50\ (0.10 \le T_a \le 0.55)$ medium soil
$A_{h(3)} = (Z/2)\ (S_a / g)\ (I/R) = (0.24/2)\ (2.50)\ (1.0/3) = 0.1$
$Q_{i3} = A_{h(3)}\ \varphi_{i3}\ P_3\ W_i = (0.1x\ \varphi_{i3}x0.102xW_i) = (0.0102\ \varphi_{i3}\ W_i)$

4) Mode 4:

$T_4 = 0.151$ sec
$(S_a / g) = 2.50\ (0.10 \le T_a \le 0.55)$ medium soil
$A_{h(4)} = (Z/2)\ (S_a / g)\ (I/R) = (0.24/2)\ (2.50)\ (1.0/3) = 0.1$
$Q_{i4} = A_{h(4)}\ \varphi_{i4}\ P_4\ W_i = (0.1x\ \varphi_{i4}x0.049xW_i) = (0.0049\ \varphi_{i4}\ W_i)$

Table 7 summarizes the calculation of lateral load at different floors in each mode by modal analysis – SRSS method.

Storey Level	**Seismic weight (W_i),(kN)**	**Mode – 1**[Q_{i1}= (0.093 φ_{i1} W_i)]		
		φ_{i1}	Q_{i1}	V_{i1}
4	819.3867	1.00	76.20	76.20
3	1308.3234	0.94	114.37	190.57
2	1308.3234	0.77	93.69	284.26
1	1308.3234	0.52	63.27	347.53

Table 7(a): Calculation of Lateral Load at Different Floors

Storey Level	**Seismic weight (W_i),(kN)**	**Mode – 2** [Q_{i2}= (-0.0271 φ_{i2} W_i)]		
		φ_{i2}	Q_{i2}	V_{i2}
4	819.3867	1.00	-22.21	-22.21
3	1308.3234	0.23	-8.15	-30.36
2	1308.3234	-0.54	19.15	-11.21
1	1308.3234	-0.72	25.53	14.32

Table 7(b): Calculation of Lateral Load at Different Floors

Storey Level	**Seismic weight (W_i),(kN)**	**Mode – 3** [Q_{i3}= (0.0102 φ_{i3} W_i)]		
		φ_{i3}	Q_{i3}	V_{i3}
4	819.3867	1.00	8.36	8.36
3	1308.3234	-0.82	-10.94	-2.58
2	1308.3234	-0.55	-7.34	-9.92
1	1308.3234	1.01	13.48	3.56

Table 7(c): Calculation of Lateral Load at Different Floors

Storey Level	**Seismic weight (W_i),(kN)**	**Mode – 4** [Q_{i4}= (0.0049 φ_{i4} W_i)]		
		φ_{i4}	Q_{i4}	V_{i4}
4	819.3867	1.00	4.01	4.01
3	1308.3234	-0.78	-5.0	-0.99
2	1308.3234	0.80	5.11	4.12
1	1308.3234	-0.54	-3.46	0.66

Table 7(d): Calculation of Lateral Load at Different Floors

SRSS method (Clause no. 7.8.4.4 from IS:1893-2002):

The contribution of different modes are combined by (SRSS) Square Root of the Sum of the Squares using the following relationship,

$$V_i = \sqrt{(V_{i1}^2 + V_{i2}^2 + V_{i3}^2 + V_{i4}^2)}$$

Then, storey lateral forces are calculated by,

$$Q_i = (V_i - V_{i+1})$$

The results obtained are tabulated in the following table 8:

S. L.	V_{i1}	V_{i2}	V_{i3}	V_{i4}	**Combined shear force (SRSS) V_i (kN)**	**Combined lateral force (SRSS) Q_i (kN)**
4	76.20	-22.21	8.36	4.01	79.91	79.91
3	190.57	-30.36	-2.58	-0.99	192.99	113.08
2	284.26	-11.21	-9.92	4.12	284.68	91.69
1	347.53	14.32	3.56	0.66	347.84	63.16

Table 8: Calculations

Clause 7.8.2 requires that the base shear obtained by dynamic analysis (V_B = 347.84kN) be compared with that obtained from empirical fundamental period as per Clause 7.6. If V_B is less than that from empirical value, the response quantities are to be scaled up. We may interpret "base shear calculated using a fundamental period as per 7.6" in two ways:

– We calculate base shear as per Clause 7.5.3. This was done in the previous method 1(design seismic force by static analysis using Equivalent static force method) for the same building and we found the base shear as 475kN. Now, dynamic analysis gives us base shear of 347.84kN which is lower. Hence, all the response quantities are to be scaled up in the ratio (475/347.84 = 1.3655). Thus, the seismic forces obtained above by dynamic analysis should be scaled up as follows:
  Q_4 = 79.91x1.3655 = 109.12 kN
  Q_3 = 113.08x1.3655 = 154.41 kN
  Q_2 = 91.69x1.3655 = 125.20 kN
  Q_1 = 63.16x1.3655 = 86.24 kN
– We may also interpret this clause to mean that we redo the dynamic analysis but replace the fundamental time period value by T_a (= 0.348 sec) which is obtained from the previous method 1. In that case, for mode 1:

T_{a1} = 0.348 sec
$(S_a/g) = 1.93$
$A_{h1} = (Z/2)\ (I/R)\ (S_a/g) = 0.1$

Modal mass times A_{h1} becomes = (4497.67x0.1) = 449.767kN

Base shear in modes 2, 3 and 4 is as calculated earlier:

Now, base shear in 1st mode of vibration = 449.767 kN, 25.53 kN, 13.48 kN and -3.46 kN, respectively.

Total base shear by SRSS:
$=\sqrt{(449.767^2+14.32^2+3.56^2+0.66^2)}$
=450.01 kN

Notice that most of the base shear is contributed by first mode only. In this interpretation of Clause 7.8.2, we need to scale up the values of response quantities in the ratio (450.01/347.84 = 1.29). For instance, the external seismic forces at floor levels will now be:

Q_4 = 108.67x1.29 = 140.184 kN
Q_3 = 153.789x1.29 = 198.388 kN
Q_2 = 124.698x1.29 = 160.860 kN
Q_1 = 85.898x1.29 = 110.808 kN

Clearly, the first interpretation gives about 10% lower forces. We could make either interpretation. Herein we will proceed with the values from the first interpretation and compare the design values with those obtained in Method 1 as per design seismic force by static analysis using Equivalent static force method:

S. L.	**Static lateral force Q_i (kN)**	**Dynamic (scaled) lateral force Q_i (kN)**	**Static storey shear force V_i(kN)**	**Dynamic (scaled) storey shear force V_i (kN)**	**Static Storey Moment M (kNm)**	**Dynamic storey moment M (kNm)**

4	198	109.12	198	109.12	663.3	365.55
3	178	154.41	376	263.53	1259.6	882.83
2	79	125.20	455	388.73	1524.25	1302.25
1	20	86.24	475	474.97	1591.25	1591.15

Table 9: Summary of Results from Different Methods of Analysis

The storey lateral forces together with shear forces computed from equivalent static method as well as from response spectrum method (dynamic analysis) are distinguished in the above table.

C. Part – 2

Modeling in ABAQUS 6.14 software:

1) FEM Formulation

a) Soil Mass

The soil mass below the foundation is assumed to be elastic, linear and isotropic with input parameters namely; poison's ratio (γ), modulus of elasticity (E) and mass density of soil (p). The dynamic response of the structure (to a lesser extent) of the soil is to be calculated, seeing this radiation of energy of the waves generating into the soil region is not included in the model.

b) Frame Element

The (slab, beam, column) elements of the super structure are modeled using simplified modeling approach.

c) Foundation

The foundation material is assumed to be isotropic and elastic. The element is defined by thickness, and the material properties.

Three dimensional (3D) finite element modeling of the whole soil-structure-foundation system is generated using software ABAQUS 6.14.

2) Modeling in ABAQUS 6.14:

a) Preprocessing-

It includes all the respective steps to create the model with ABAQUS/CAE. Basic steps are as follows:

- Creating a part
- Defining the model geometry
- To define the material and section property
- Creating an assembly
- Configuration of the analysis
- Assigning the interaction property
- Applying boundary condition and loads
- Mesh designing
- Running and monitoring a job

b) Post Processing-

The 'visualization module' provides graphical display of (FEM) finite element models and results. It obtains model as well as result information from the output database; thus it controls what information is written to the output database by modifying the output request in the 'step module'.

Now, in the 'assembly module' instances are created for every individual parts already created and thus such instances can be increased in numbers and also can be positioned as per the requirement. Here some instances can also be joined to each other.

Instances are created for slab, beam, column, footing i.e. comprising of frame structure. By using linear part option, instances numbers are created. From the rotate instance option, angle of instances are changed. By using translate instance, position of instance can be shifted and every part of it, is positioned as required for the structure. After proper positioning, all instances are joined by using Cut/Merge instances. After Cut/Merge instances ABAQUS creates the final building. This final building is required to provide Stringers for each part. After the application of Stringers, building gets completed.

Now instance for soil is created. Soil instance is thus positioned in assembly.

3) Input Design Data for Building:

a) Geometric Properties

- Medium soft soil layer = 8m
- Slab thickness = 140 mm
- Size of the column = (230mm x 230mm)
- Size of the beam = (230mm x 450mm)

b) Material Properties

For medium-soft soil layer

- Density = 18 kN/m3
- Modulus of elasticity = 35000 kN/m2
- Poisson's ratio = 0.4
- Earthquake load: as per IS: 1893-2002 (part-1)
- Type of soil: type II, medium soil as per IS: 1893
- Typical storey height: 3.35m
- Depth of foundation below ground: 1.0535m
- Type of building: Residential

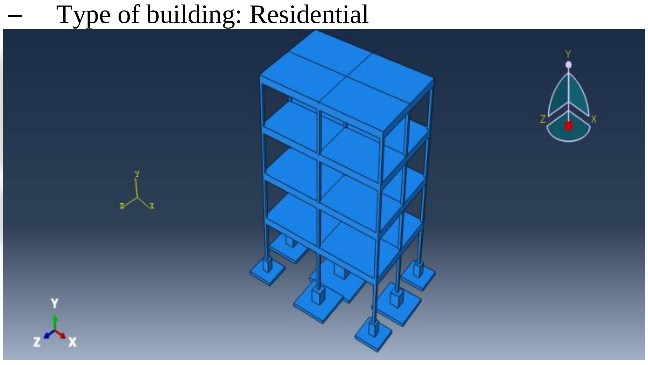

Fig. 7: Modeling of building without soil.

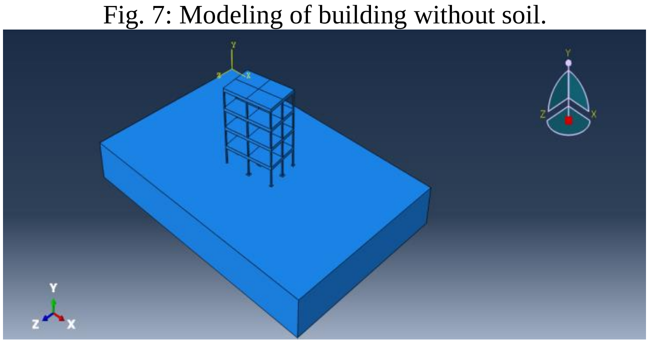

Fig. 8: Modeling of building with soil.

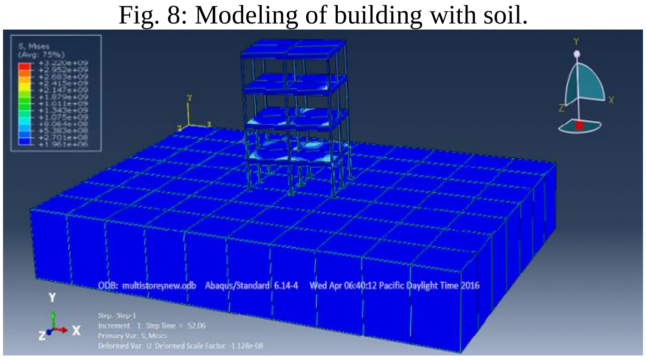

Fig. 9: Deformed building with soil.

Element	Maximum displacement without soil	Maximum displacement with soil
Whole model	-1.12m	-2.23 m

Table 10: Comparison of Displacement

V. NOTATION

SSI – Soil-Structure Interaction
I – Importance factor
R – Response reduction factor
DL – Dead load
IM – Imposed load
EL – Earthquake load
h – Height of building, in m
d – Base dimension of the structure at the plinth level, in m, along the certain direction of the lateral force.
S_a/g – Spectral acceleration
A_h – Horizontal acceleration coefficient
V_B – Base shear
W – Total seismic weight on floor
Q_i – Storey lateral forces
V_i – Storey shear forces
M_i – Seismic mass
ω – Natural frequency
K – Column stiffness
E_c – Elastic modulus (young's modulus)
I_c – Moment of Inertia of column
Φ_i – Mode shapes
T – Time period
M_i – Modal mass
P_k – Modal participation factor
F_i – Storey lateral forces
DOF – Degree of freedom
γ – Poison's ratio
ρ– Mass density of soil
G – Shear modulus of soil
E – Modulus of elasticity
RCC – Reinforced cement concrete

VI. CONCLUSION

1) Both static and dynamic loading is essential for accurate estimation of the response of structure under the effect of soil-structure interaction.
2) Mark that even though the base shear by the static and the dynamic analysis are comparable, there is considerable distinctness in the lateral load distribution with building height, and in there lies the interest of dynamic analysis. As in case of the storey moments are somewhat affected by change in distribution of load.
3) The realistic idealization of supporting soil is possible by FEM. It is possible to combine variation in the layered soil, boundary conditions and soil properties etc. Thus, this will produce precise data.
4) Taking overall soil behavior, it is found that the soil beneath the building and near the fixed-boundaries is analogously stable.
5) From the displacement data, it is observed that more displacement occurs in building with soil as compared to without soil.
6) FEM has proved to be a very useful method for studying the effect of SSI. It reduces the complexity for practical purpose.

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