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Seismic Evaluation of RC Building Considering Soil-Structure Interaction

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Abstract:
Soil-structure interaction (SSI) analysis is a special field of earthquake engineering. It is worth starting with definition. Common sense tells us that every seismic structural response is caused by soil-structure interaction forces impacting structure (by the definition of seismic excitation). Non-linear structural analysis is becoming most important in earthquake resistant design, which requires more information about the drifts, displacements and inelastic deformations of a structure than traditional design procedures. SAP2000 V14 is one of the most sophisticated and user-friendly software which performs the non-linear static (Push Over) analysis in a very simple way. In the present study 11 storey (2 basements + 9 upper floors) RC moment resisting frames are designed by the Limit state of design method. Then the frame is analysed by the nonlinear static analysis (Pushover Analysis) by considering soil structure interaction (SSI) effects using SAP2000 v14 software. To obtain the effect of soil structure interaction effects on RC frame structure, the default plastic hinges are to be assigned for moment resisting frames as per FEMA 356.

Keywords: *Soil structure Interaction, Storey drift, Pushover Analysis, Default plastic hinges, RC moment resisting frame.*

1. Introduction

A seismic soil-structure interaction analysis evaluates the collective response of the structure, the foundation, and the geologic media underlying and surrounding the foundation, to a specified free-field ground motion. The term free-field refers to motions that are not affected by structural vibrations or the scattering of waves at, and around, the foundation. SSI effects are absent for the theoretical condition of a rigid foundation supported on rigid soil. Accordingly, SSI accounts for the difference between the actual response of the structure and the response of the theoretical, rigid base condition. Methods that can be used to evaluate the above effects can be categorized as direct and substructure approaches. In a direct analysis, the soil and structure are included within the same model and analyzed as a complete system. In a substructure approach, the SSI problem is partitioned into distinct parts that are combined to formulate the complete solution.

2. Objectives of the Study

- To compare the roof displacement of RC Moment resisting frame for normal analysis and soil structure interaction analysis method.
- Observe the base shear variation of RC Moment resisting frame by normal analysis and soil structure interaction analysis method.
- To study the Natural time period and frequency of RC moment resisting frame by normal and SSI analysis method.
- To develop accurate performance criteria to assess seismic performance of RC moment resisting frames (SSI model and normal model) by carrying nonlinear static (pushover) analysis method.

3. Soil-Structure System Behavior

A rigid base refers to soil supports with infinite stiffness (i.e., without soil springs). A rigid foundation refers to foundation elements with infinite stiffness (i.e., not deformable). A fixed base refers to a combination of a rigid foundation elements on a rigid base. A flexible base analysis considers the compliance (i.e., deformability) of both the foundation elements and the soil. Consider a single degree-of-freedom structure with stiffness, k, and mass, m, resting on a fixed base, as depicted in Figure 1a. A static force, F, causes deflection:

$$\Delta = \frac{F}{K} \qquad (3.1)$$

From structural dynamics, the undamped natural vibration frequency,w, and period, T, of the structure are given by Clough and Penzien (1993) as:

$$\omega = \sqrt{\frac{K}{m}}, T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{K}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

By substituting Equation 3.1 into Equation 3.2, an expression for the square of period is obtained as:

$$T^2 = (2\pi)^2 \frac{m}{F/_{\Delta}} = (2\pi)^2 \frac{m\Delta}{F} \ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

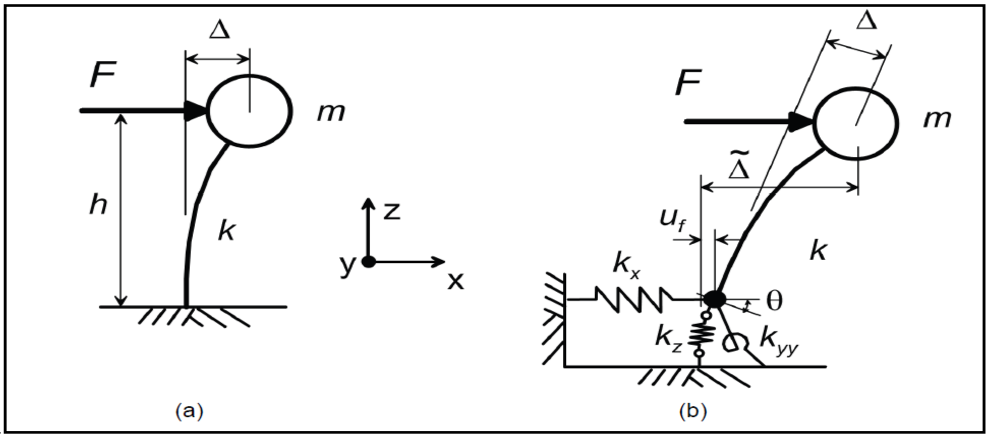

Figure 1: Schematic illustration of deflections caused by force applied to: (a) fixed-base structure; and (b) structure with vertical, horizontal, and rotational flexibility at its base.

4. Idealization of Soil

Flexibility of soil medium below foundation may appreciably alter the natural periods of any building. It usually causes to elongate time period of structure.

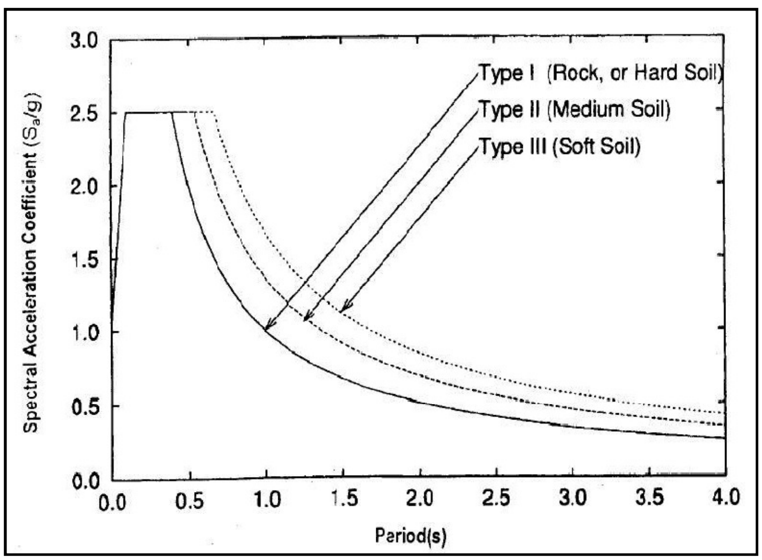

Figure 2: Response spectra for rock and soil sites for 5% damping (IS1893 Fig. 2)

The flexibility of soil is usually modelled by inserting springs between the foundation member and soil medium. While modelling, the number of degree of freedom should be selected carefully considering the objective of the analysis. During earthquake a rigid base may be subjected to a displacement in six degrees of freedom, and therefore resistance of soil can be expressed by the six corresponding resultant force components. Hence to make the analysis most general, translations of foundation in two mutually perpendicular principle horizontal directions and vertical direction as well as rotation of the same about these three directions are considered in this study. In this project, for isolated footing below each column, three translation springs along two horizontal and one vertical axis, together with three rotational springs about those mutually perpendicular axes, have been attached (as shown in Fig 4.5) to simulate the effect of soil flexibility.

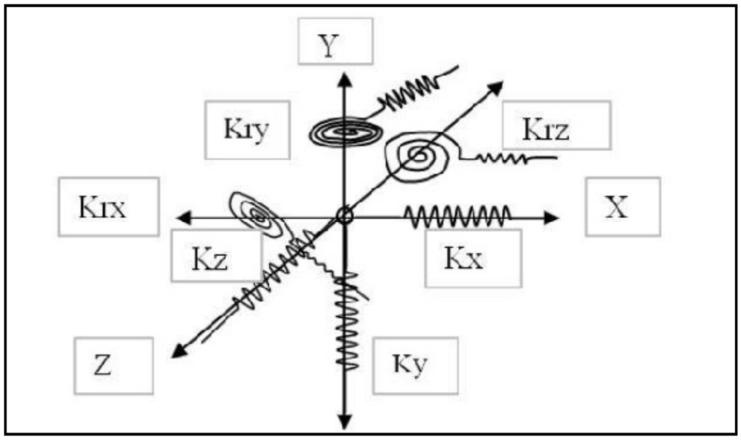

Figure 3: Idealization arrangement at a typical column square foundation strip and equivalent soil spring junction.

Degrees of freedom	Stiffness of equivalent soil spring
Horizontal (lateral direction) Kx	9Gb/(2-μ)
Horizontal (longitudinal direction) Kz	9Gb/(2-μ)
Vertical Ky	4.54Gb/ (1-μ)
Rocking (about longitudinal axis) Krx	0.45Gb3/(1-μ)
Rocking (about lateral axis) Krz	0.45Gb3/(1-μ)

Table 1: Spring stiffness for square footing along various degrees of freedom.

Where 'b' is the half width of square footing.
To obtain the values of spring stiffnesses of the springs for hard, medium and soft soil, value of shear modulus (G) of soil have been estimated using the following empirical relationship,

$G = Es/2(1 + \mu)$……………………………………… (4.6)

Where Es = Modulus Elasticity of soil.

μ = Poison's ratio of soil.

Soil	Modulus elasticity. MPa	Poison's ratio	Shear Modulus of soil (G) , KN/m^2
Hard soil	500	0.15	217391.30
Medium soil	150	0.25	60000.00
Soft soil	25	0.45	8620.68

Table 2: Types of soil and their parameters

5. Description of Frame

Frame type-	: RC moment resisting frame
Number of storey-	: 11
Number of bays in X-direction	: 4
Number of bays in Y-direction-	: 4
Spacing in X-direction-	: 7m
Spacing in Y-direction-	: 7m
Thickness of slab	: 175mm
Building Height	: 35m (8m + 27m)
Steel and Concrete	: Fe500 and M_{25}
Column size : 750x750mm (1st to 4thstorey) : 600x600mm (5th to 9th storey) : 450x450mm (10th to 11th storey)	
Beam size: 230x600mm	
Design loads	
Live load (LL)	: 4kN/m^2

Floor finish and Ceiling finish (FF) : 2kN/m^2	
Earthquake parameter	
Seismic zone- (Z= 0.24)	: IV
Importance factor- I	: 1
Response reduction factor-R	: 3
Type of soil-	: Hard, Medium, Soft.
Damping of structure-	: 5%
Codes Used: IS 456-2000, IS 1893-2002.	

Table 3: Description of frame.

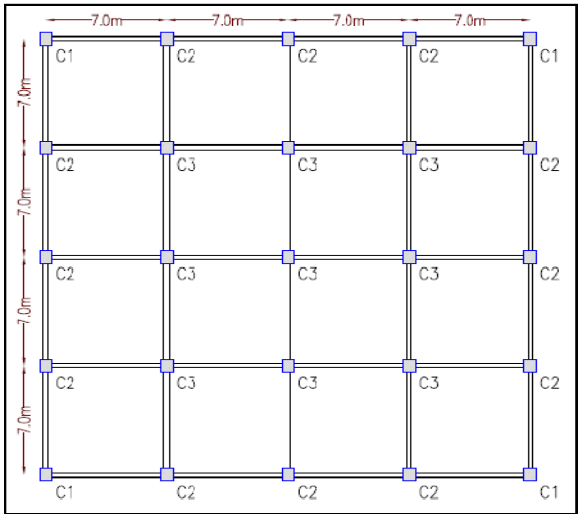

Figure 4: Plan of RC frame.

6. Spring Stiffness for Various Soil

COLUMN FOOTINGS	DEGREES OF FREEDOM		HARD SOIL STIFFNESS KN/m	MEDIUM SOIL STIFFNESS KN/m	SOFT SOIL STIFFNESS KN/m
C1	LATERAL	Kx	1321974.12	524571.42	100111.12
	LONGITUDINAL	Ky	1321974.12	524571.42	100111.12
	VERTICAL	Kz	2877237.79	617440	142319.58
	ROCKING LONGITUDINAL	Krx	224784.2	176868	56426.26
	ROCKING LATERAL	Kry	224784.2	176868	56426.26
	TORSIONAL	Krz	3524116.77	2446674	572413.152
C2	LATERAL	Kx	1692126.87	678857.142	132647.23
	LONGITUDINAL	Ky	1692126.87	678857.142	132647.23
	VERTICAL	Kz	185780.47	799040	188573.45
	ROCKING LONGITUDINAL	Krx	471406.64	383328	131258.9
	ROCKING LATERAL	Kry	471406.64	383328	131258.9
	TORSIONAL	Krz	7390608.54	5302704	1331549.26
C3	LATERAL	Kx	2273795.48	910285.74	172691.68
	LONGITUDINAL	Ky	2273795.48	910285.74	172691.68
	VERTICAL	Kz	2496419.38	1071440.57	245501.29
	ROCKING LONGITUDINAL	Krx	1143801.14	924205.5	289633.39
	ROCKING LATERAL	Kry	1143801.14	924205.5	289633.39
	TORSIONAL	Krz	17932260.22	12784842.75	2938169.87

Table 4: spring stiffness for various soil

7. Pushover Analysis of Structures

For pushover analysis, nonlinear behaviour is assumed to occur within frame elements at concentrated plastic hinges with default or user-defined hinge properties being assigned to each hinge. The default hinge properties are assigned to frame elements and SAP2000 V14 then creates, for each hinge, a different generated hinge property which is used in the pushover analysis. The generated hinge properties make use of the frame element section information and the user-defined hinge properties to fully defined plastic hinge properties. The default hinge properties are section-dependent and are typically based on the nonlinear modelling parameters given in Table 9-6 of the ATC- 40 documents.

8. Result

8.1. Roof Displacement

Storey height (m)	Soft Soil Displacement (m)		Medium Soil Displacement (m)		Hard Soil Displacement (m)	
	With spring	Without spring	With spring	Without spring	With spring	Without spring
35	0.432	0.302	0.323	0.262	0.285	0.221
32	0.385	0.270	0.285	0.259	0.27	0.212
29	0.358	0.253	0.256	0.231	0.25	0.191
26	0.306	0.239	0.23	0.216	0.23	0.184
23	0.275	0.212	0.213	0.192	0.20	0.165
20	0.23	0.184	0.182	0.165	0.17	0.144
17	0.191	0.156	0.156	0.136	0.14	0.115
14	0.153	0.123	0.124	0.114	0.11	0.091
11	0.17	0.094	0.092	0.088	0.08	0.07
8	0.082	0.062	0.068	0.056	0.045	0.04
4	0.032	0.02	0.023	0.020	0.02	0.015
0	0.005	0	0.004	0	0.002	0

Table 4: Roof Displacement.

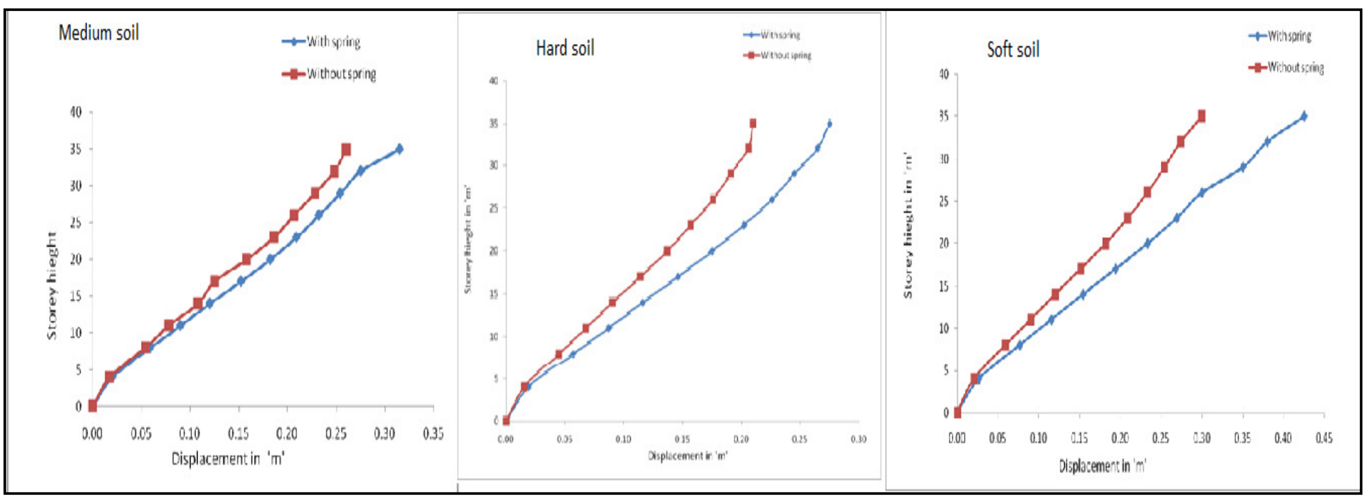

Figure 5: Plan of RC frame.

8.2. Time Period and Frequencies

	Soft soil		Medium soil		Soft soil	
	Time period (sec)	Frequencies (cyc/sec)	Time period (sec)	Frequencies (cyc/sec)	Time period (sec)	Frequencies (cyc/sec)
With SSI	0.72	1.32	0.7	1.439	0.65	1.439
	0.72	1.32	0.7	1.439	065	1.439
	0.75	1.182	0.732	1.271	0.68	1.271
Without SSI	0.648	1.544	0.64	1.494	0.60	1.494
	0.648	1.544	0.64	1.494	0.60	1.494
	0.67	1.476	0.668	1.471	0.62	1.471

Table 5: Roof Displacement

8.3. Base Shear

Soil type	Base shear in KN	
	Without SSI	With SSI
Softsoil	5511.15	4849.81
Medium soil	4488.72	4039.85
Hard soil	3298.85	3034.

Table 6: Time period and frequencies for soft soil.

8.4. Push over Curve for Soft Soil

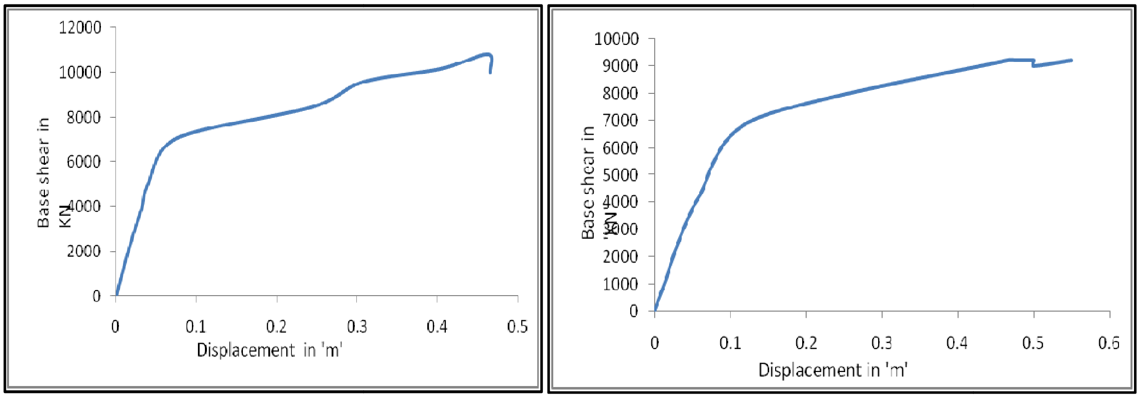

Figure 6: Pushover curve for non SSI model (left) and SSI model (right).

8.5. Performance Point for Soft Soil

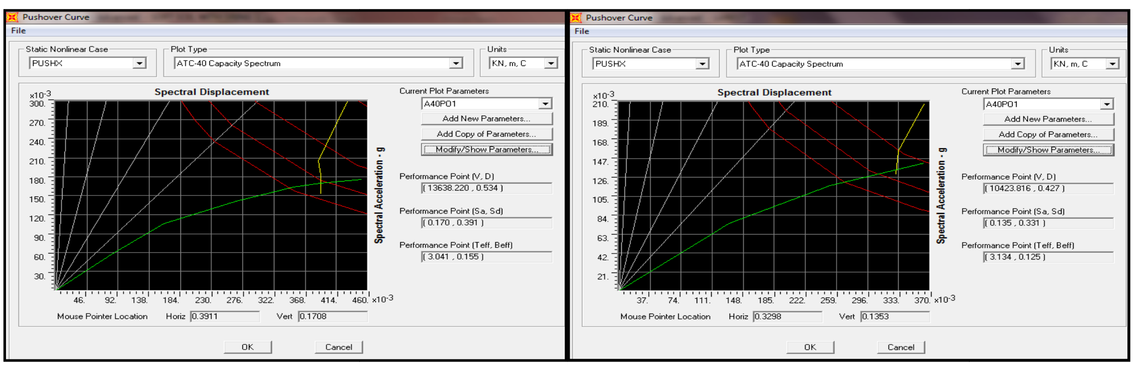

Figure 7: Performance point for SSI model (Left) and Non SSI model (Right).

9. Conclusion

- From the result of roof displacement soil structure interaction analysis gives more displacement than non-soil structure interaction analysis. So that foil flexibility effects allow the more displacement hence considering the SSI effects increase displacement in roof level.
- From the chapter 5.3 Natural time period of the structure is more in soil structure interaction analysis as compare to non-soil structure interaction analysis. Hence reduce the frequency of structure consideration of soil flexibility effects.
- From chapter 5.4 base shear of soft soil in normal analysis is 5511.15 KN. Base shear in SSI is 4849.81KN. Soil structure interaction effects influence in reduction of base shear of RC Structure.
- From push over curve we can conclude that soil structure interaction analysis gives more displacement. So it shows the more ductile nature of structure by its flexible base effects. Hence overturning moment is less for more displacement.
- From performance point, soil structure interaction analysis frame is more than non SSI analysis frame.

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