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Non-Linear Dynamic Analysis of Multistoried Reinforced Concrete Building by Considering Soil-Structure Interaction (SSI)

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Abstract*: Structures susceptible to earthquake ground motions and damage them. Mostly the local soil properties ignored and carried out in fixed support conditions to make the seismic analysis simplifier. But, from the past results showed that the earthquake ground motion on different foundation soils influences the response of structures. This paper explores the investigation of earthquake ground motion on three dimensional ten storied reinforced concrete structure supported on different foundations by considering the soil-structure interaction in hard, medium and soft soils and without soil-structure interaction i.e., fixed condition. Structure was modeled and analyzed for linear time history analysis by using SAP-2000 which is finite element analysis procedure and the foundation was modeled by soil springs. The Koyna earthquake (1967) accelerogram selected for the purpose of analysis. The results of this paper shows that the behavior of structure in different foundations and the soil-structure interaction will effect the performance of the structure. There is need to analyze the structure for Time History Analysis to ensure safety against seismic forces.

Index Terms*: Koyna Earthquake, Non-Linear Dynamic Analysis, Sap 2000, Soil-Structure Interaction.

I. INTRODUCTION

Soil-structure interaction (SSI) analysis estimates the collective response of the structure, foundation and the foundation – soil to a specified free field ground motion and impact the structure response due to earthquake excitations [1]. The foundation is considered as part of the structure and the free-field ground motions are not affected by structural vibrations or the scattering of waves at, and around, the foundation. By considering rigid foundation on rigid soil SSI effects are absent. In this report results are accounted for the actual response of the structure on different foundations and the response of the structure on rigid base condition [2].

SSI affects are considered as inertial interaction effects, kinematic interaction effects and soil-foundation flexibility effects [3]. Inertial interaction effects are rooted in structural inertia, base shear, torsion and moments are developed during structure vibration. Displacements and rotations are generated due to inertia forces at the soil-foundation interface and related with foundation inertia and structure. They occurred due to flexibility in the soil-foundation system, which significantly contributes to overall structural flexibility and increases the structure period. Kinematic interaction vary from differences between foundation input and free-field ground motions, where rigid foundation elements are placed at or below the ground surface. The results obtained from forces and displacements by the building and the soil-medium influence the flexural, axial, and shear deformations of structural foundation elements depends on foundation flexibility.

Based on the effects discussed soil structure interaction was categorized as direct and substructure methods. The soil and structure are comprised in identical model and analyzed as a complete system and the soil, foundation and structural elements are represented as a finite elements in direct analysis as shown in Fig-1(a). In this approach estimation of site response by means of wave propagation analysis through the soil is important [4]. SSI was divided into different parts and they join to convey complete solution in substructure approach. Kinematic interaction is interesting as this needs variable input motions in all three dimensions but direct analysis report all soil-structure interaction effects as shown in Fig-1(b). If the system consists of geometrically complex and contains significant nonlinearities in the soil or structural materials, the solution for SSI becomes complex. Hence, it is rarely used in practice. The frequency dependent stiffness and damping characteristics of the soil-foundation interaction are characterized and represented by using relatively simple impedance function models or a series of distributed springs and dashpots [5]. Use of impedance function models for rigid foundations and series of springs and dashpots around foundation are illustrated in Fig-1(c-i), Fig-1(c-ii). If the foundation elements are non – rigid, or moments, shears and displacements are the essential outcomes of the analysis then distributed springs and dashpots is used. For the condition of base slab and the structure with no mass are applied to Foundation Input Motion (FIM). This motion involves both translational and rotational components which is generally differs from the free-field motion, and it represents the seismic demand applied to the structural and foundation system. The planned soil-foundation interface as also performed with the free-field motion, wave-propagation analyses to estimate the foundation input motion as shown in Fig-1(d). As a part of analysis equivalent linear properties for the soil shear modulus, material damping, etc. are to be evaluated.

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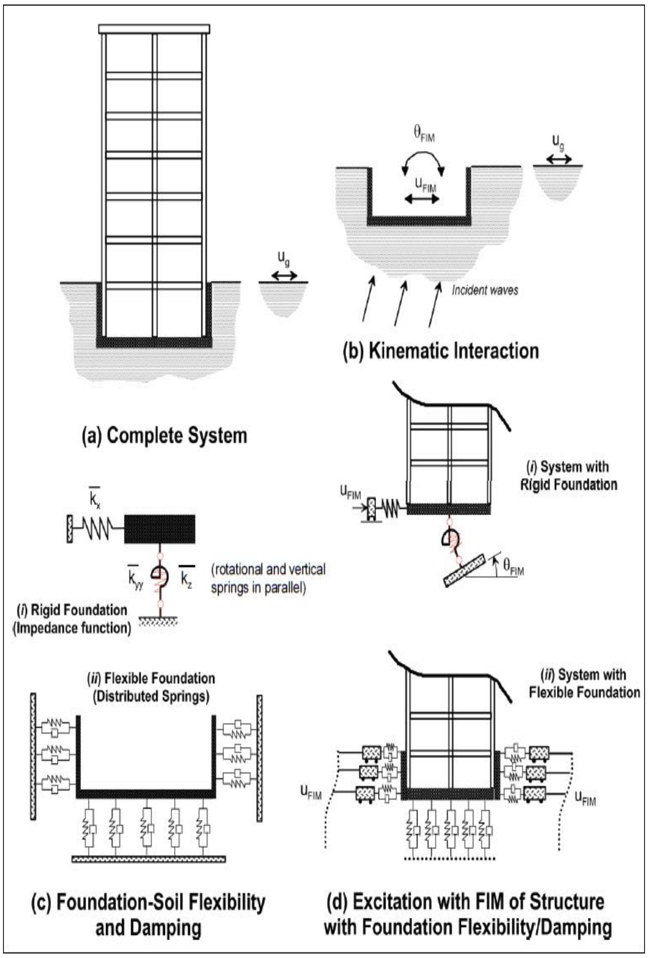

Fig-1: Soil-Structure Interaction System Assumptions from NEHRP 2012

SSI investigations for modeled soils and buildings are performed on the soil structure interface by considering the amplification of seismic waves [6]. Lateral boundary of foundation was modeled by utilizing spring system to integrate seismic waves as a viscous boundary to avoid reflection of the seismic through the soil medium and consideration of the infinite lateral boundary conditions. The spring coefficient and springs stiffness are calculated by taking Richart and Lysmer (1970) proposed technique. Different models are considered with and without SSI and subjected to natural ground motion record occurred in Koynanagar, Maharashtra on December 10, 1967 with the magnitude of 6.5 and Peak Ground Acceleration (PGA) of 0.489g as shown in Fig-2. The Koyna earthquake round motion was considered for performing Time History Analysis (THA) as it made many structures unusable and Koyna Dam suffered some structural damage and leaks were observed in the face of the dam. Waves were sensed strongly for many towns and cities in Western Maharashtra, including Mumbai and Pune.

II. MODELLING

A symmetrical plan of 18 m x 48.1 m of reinforced concrete 3D ten storey building was modeled and analyzed by SAP 2000 the finite element analysis software. The proposed plan and elevation of the structure was shown in the Fig-3. All the building parameters and the loads applied are shown in the Table-I.

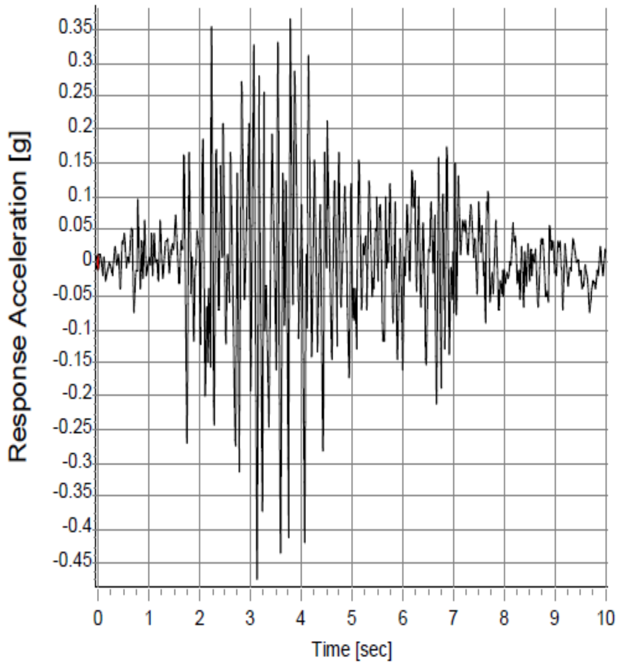

Fig-2: Koyna, 1967 Accelerogram

Table-I: Building Parameters

Parameter	Dimension/s
Height of the building	33.00m
Height of each storey	3.30m
Number of stories	10
Column size	0.3m x 0.6m
	0.45 x 0.6m
Longitudinal beams	0.6m x 0.30m
Transverse beams	0.6m x 0.45m
Plinth beams	0.3m x 0.45m
Slab thickness	0.15m
Parapet wall height	1m
Exterior wall thickness	0.23m
Interior wall thickness	0.115m
Grade of concrete	M25
Grade of steel	Fe 415
Unit weight of RCC	25 KN/ m^3
Unit weight of brick work	19 KN/ m^3
Live load (floor)	3.00 KN/ m^2
Live load (terrace)	1.50 KN/ m^2
Floor finish	1.0 KN/ m^2
Terrace finish	2.0 KN/m^2

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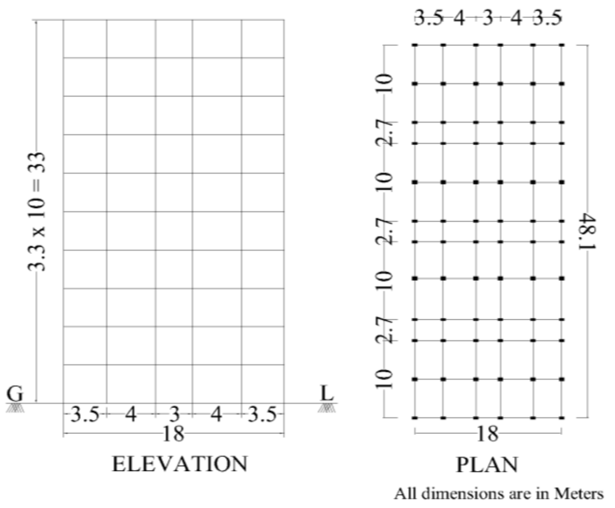

Fig-3: Plan and Elevation of Proposed Structure.

III. SOIL-STRUCTURE INTERACTION

The Seismic Wave generated from the fault hit the base of the foundation. Some amount of wave transmits and some wave was reflected back to the ground. The transmitted wave travels in upward direction which results vibration of structure, again they are reflected at top and travels back return down to the foundation where Soil-Structure Interaction occurs. The response of structure decreases when the reflected wave transmits into the ground completely, it happens when the foundation and soil interaction was better.

Isolated foundation of four types of footings has been modeled for hard soil. Raft foundation of 50 x 20 x 0.6m has been modeled using thick R.C. Shell elements and pile foundation by laying pile groups a total number of 242 piles, each pile of diameter 0.75m up to 25.5m below the ground, to facilitate simulation of Soil Structure Interaction effects for the hard, medium and soft soils. The properties of soil have adopted and calculated, are shown in Table-II. The spring stiffness values for vertical, horizontal, rocking and twisting motions are calculated as per Richart and Lysmer model [7] as shown in Table-III, in which, G = dynamic shear modulus of soil and is calculated by using ANFIS; υ = Poisson's ratio of the soil; K = equivalent spring stiffness of the soil; r = equivalent radius of a circular foundation; L = length of the foundation; and B = width of the foundation. The whole area is meshed with quad shell elements and soil springs are applied.

Table-II: Soil Properties

Parameters			Hard soil	Medium soil	Soft soil
SPT No	N		50	15	4
Dry Density (KN/m^3)	γ	By soil test	25	21	17
Moisture Content	w	By soil test	6	15	30
Shear modulus (KN/m^2)	G x 10^5	By ANFIS	240	33.9	7.08
Poisons ratio	ϑ	0.4-0.5	0.2	0.3	0.45
Safe Bearing Capacity(KN/m^2)	SBC	By soil reports	450	250	100

IV. TIME HISTORY ANALYSIS

To determine the accurate behavior of the structure during earthquake, nonlinear dynamic analysis or Time History Analysis (THA) is the finest possible method [8]. It is significant method for particularly when the estimated structural response is nonlinear and the structural seismic analysis [9]. To carry out this analysis, a particular earthquake time history motion data is required for a structure and the seismic response of the structure was determined [10].

Table-III: Soil Springs as per Richart and Lysmer (1970)

Direction	Spring values	Equivalent Radius
Vertical	$K_z = \frac{4Gr_z}{(1-\upsilon)}$	$r_z = \sqrt{\frac{LB}{\pi}}$
Horizontal	$K_x = \frac{32(1-\upsilon)Gr_x}{(7-8\upsilon)}$	$r_x = \sqrt{\frac{LB}{\pi}}$
	$K_y = \frac{32(1-\upsilon)Gr_y}{(7-8\upsilon)}$	$r_y = \sqrt{\frac{LB}{\pi}}$
Rocking	$K_{\phi x} = \frac{8Gr^3_{\phi x}}{3(1-\upsilon)}$	$r_{\phi x} = \sqrt[4]{\frac{LB^3}{3\pi}}$
	$K_{\phi y} = \frac{8Gr^3_{\phi y}}{3(1-\upsilon)}$	$r_{\phi y} = \sqrt[4]{\frac{BL^3}{3\pi}}$
Twisting	$K_{\phi z} = \frac{16Gr^3_{\phi z}}{3}$	$r_{\phi z} = \sqrt[4]{\frac{LB^3 + BL^3}{6\pi}}$

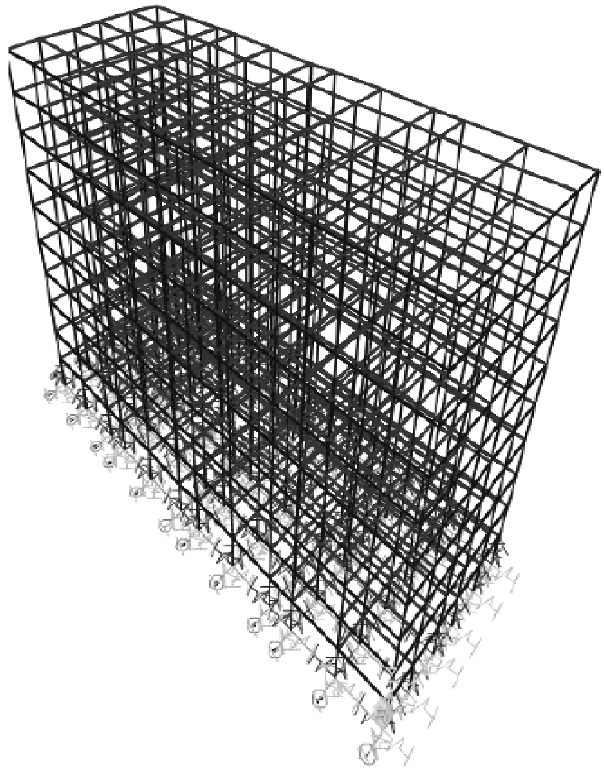

Fig-4a: Structure with Soil Springs

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THA is a step-by- step analysis of the dynamic response of a structure to a specified earthquake loading that may vary with each second. SAP 2000 is a finite element analysis based software which can perform multiple analysis on the structure [11]. The structure carried out by modelling the frame and then assigning the support conditions fixed for without soil-structure interaction and Joint Springs for the soil – structure interaction as shown in Figure-4a , 4b. Define the load cases and assign them to the members, earthquake was applied in X-direction only. Define the time history analysis load case and then adopt Koyna Earthquake (1967) accelerogram which has the duration of 10.1 sec [12]. Then analyze the structure for all load cases, total of four models were analyzed (i) Fixed base condition; (ii) Isolated foundation for Hard soil; (iii) Mat foundation for Medium soil; (iv) Pile foundation for Soft soil in accordance with the classification of the IS 1893(Part 1): 2002 [13].

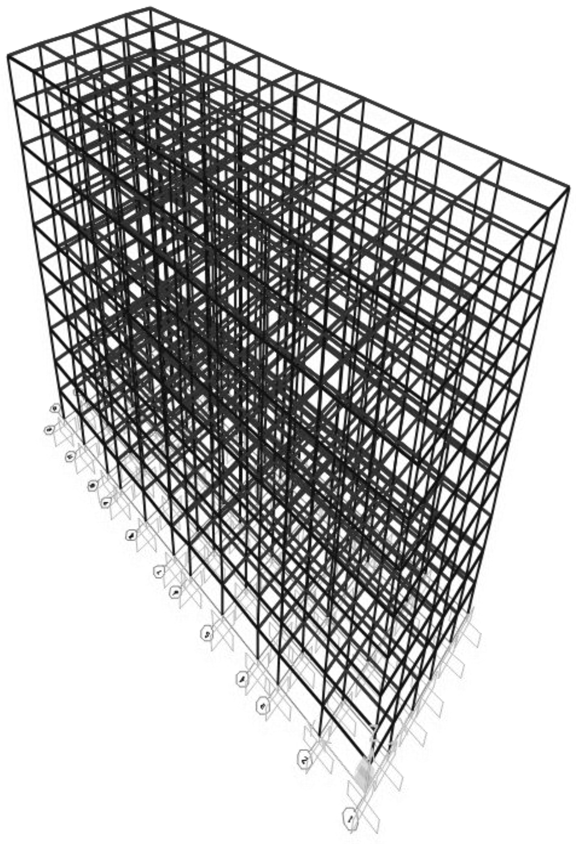

Fig-4b: Structure with Fixed Support

V. RESULTS AND DISCUSSION

The results found from the analysis are tabulated in Table-IV & V and the graphical representation of variations in results are shown in Fig-5 to 9. The graphs show the variations in seismic responses Base shear and Displacement for Fixed condition and the SSI consideration.

From the Time History Analysis the maximum displacement occurs at 10.01sec .i.e., the last second of the accelerogram in the fixed condition (No SSI) model. By considering SSI maximum displacement in hard soil model occurs at 10.01 Sec, Medium soil model occurs at 8.52 sec and for the soft soil it occurs at 6.71 Sec.

Table-IV: Base shear and Displacement

Foundations	Peak Displacement, mm	Base Shear, KN
Fixed	7.821	2917
Hard Soil	8.585	3277
Medium Soil	9.312	4620
Soft Soil	10.15	5629

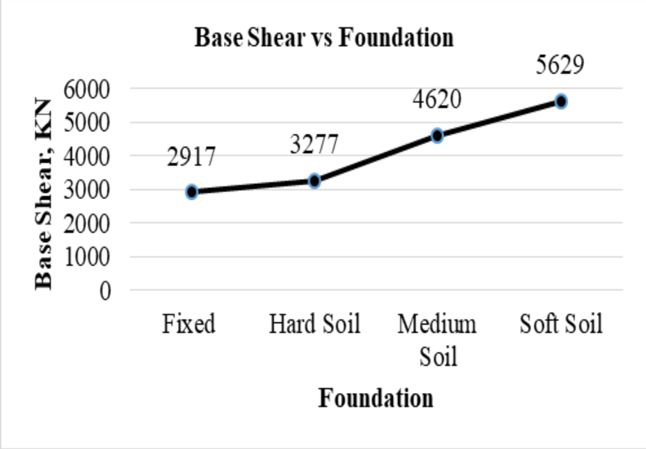

Fig-5: Foundations vs Base Shear

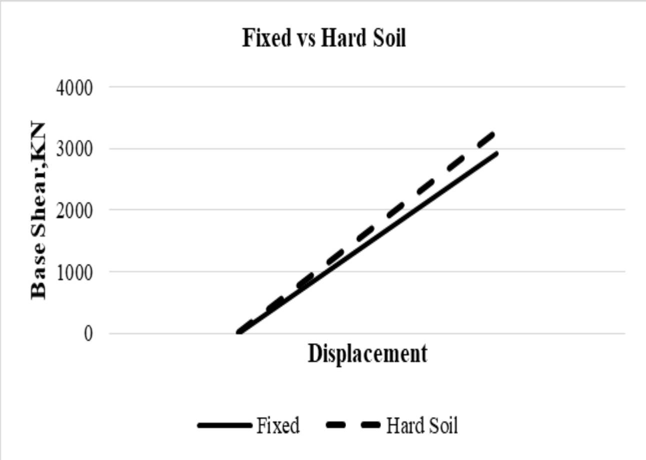

Fig-6: Base Shear between Fixed vs Hard Soil

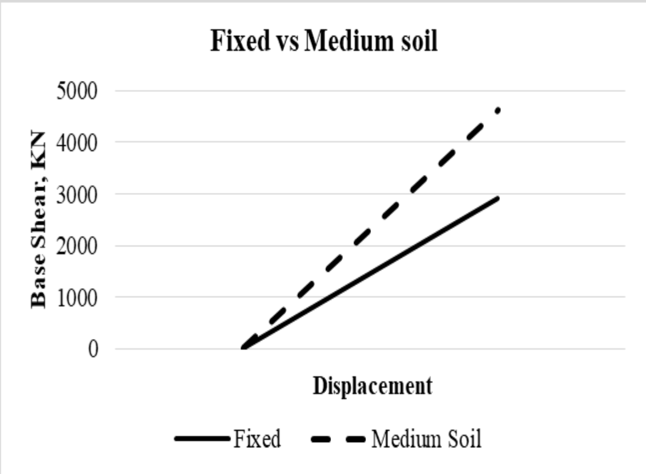

Fig-7: Base Shear between Fixed vs Medium Soil

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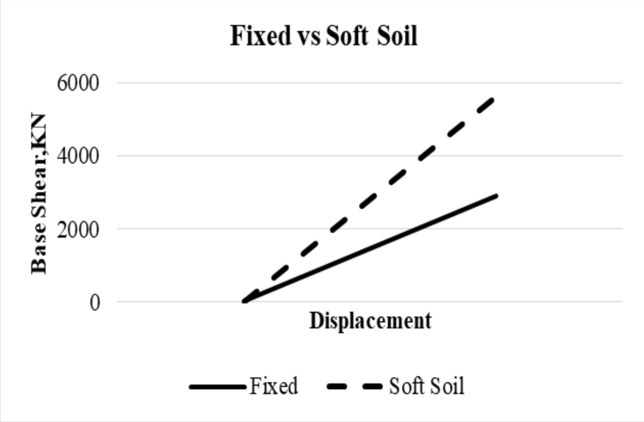

Fig-8: Base Shear between Fixed vs Soft Soil

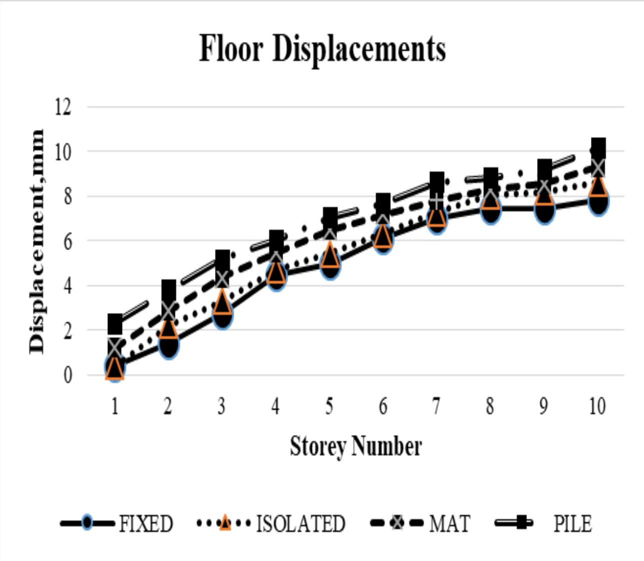

Fig-9: Storey level Displacements

Table-V: Displacement in floor level by THA

Storey No.	Displacements, mm			
	Fixed	Isolated	Mat	Pile
1	0.397	0.377	1.2	2.301
2	1.404	2.211	2.857	3.807
3	2.755	3.291	4.34	5.162
4	4.456	4.699	5.47	6.031
5	4.936	5.416	6.457	7.028
6	6.076	6.326	7.176	7.666
7	7	7.263	7.767	8.631
8	7.416	8.02	8.269	8.808
9	7.467	8.177	8.525	9.187
10	7.821	8.585	9.312	10.15

VI. CONCLUSION

- In the present study ten storied RC building was considered and analyzed by method specified by IS code: 1893- 2002. The non-linear dynamic analysis was carried out for December 10, 1967 Koyna earthquake by utilizing SAP 2000.
- The results showed that the structures founded on different foundations in different soils affect the seismic response by considering SSI.
- Base shear was increased at the rate of 11%, 37%, 48% with respect to the no SSI model to considering SSI in Hard, Medium, Soft soil models respectively.
- The results showed that base shear and displacements in SSI are increased for buildings founded on soft ground conditions and for firm ground conditions i.e., hard soil, they are decreased and can be neglected when compared to fixed condition.
- Time History Analysis is accurate method used for earthquake analysis as it produces better check for the safety of structures rested on loose soils.

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