Dynamic Behaviour of Raft Foundation for Tall building with Variable Subsoil

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Abstract: Structures are often constructed on layers of soil unless bedrock is very close to the ground surface. When the ground is stiff enough, the dynamic response of the structure will not be influenced significantly by the soil properties during the earthquake, and the structure can be analysed under the fixed base condition. When the structure is resting on a flexible medium, the dynamic response of the complete structure will be different from the fixed base condition, where the interaction between the soil and the structure has to be incorporate. This behavioural difference because of the phenomenon commonly referred to as Soil-Structure Interaction (SSI), which if not considered in analysis and design properly; the accuracy in assessing the structural safety, response for earthquake excitation could not be reliable solution. Hence evaluation of the site, specific effect of soil stiffness on structure becomes important to understand behaviour of structure. Flexibility of soil increases natural period of structure, which basically turn changes the seismic response of structure. The interaction among structure, their foundation and soil media below foundation alter the actual behaviour of structure. Here G+25 storey building is modelled and analysed, employing Finite Element Method adopting Commercial code SAP2000 V19 under fixed base (no soil-structure interaction) and flexible base considering soil-structure interaction). An attempt has been made to evaluate the effect of soil structure interaction of super structure by considering the systematic parameters like time period, lateral displacement, storey drift, bending moment in dual global structural axis i.e., X-X and Y-Y direction.

Keywords: Raft foundation, soil-structure interaction, Winkler model, Seismic Response, time period, bending moment, lateral displacement, storey drift, SAP2000 V19

I. INTRODUCTION

The problem of soil-structure interaction in the seismic analysis and design of structures has become increasingly important, as it may be inevitable to build structures at locations with less favourable and compatible geotechnical conditions in seismically active regions. The 28 December 1989 Newcastle (Australia) earthquake killed and injured over 150 people and damage bill was about $4 billion. Recently, a similar disaster hit Haiti on 12 January 2010 causing over 200,000 deaths, and leaving over 3 million people homeless. The similarity of these two earthquakes is that both are intra-plate earthquakes occurring in the interior of a tectonic plate. In both cases, many mid-rise buildings (approximately 5-15 stories) were severely damaged [1]. The scarcity of land insists engineers to construct major structures over soft deposits. Therefore, there is a need to design structures safely, but not costly against natural disasters such as earthquakes. Effects of dynamic soil-structure interaction under extreme loads due to strong earthquakes are significant for many classes of structures and it must be included seriously precisely in the design procedure. Soil-structure interaction (SSI) includes a set of mechanisms accounting for the flexibility of the foundation beneath a given structure which resulting in modifying the ground motion near the foundation compared to the free-field. It determines the actual loading experienced by the soil-structure system resulting from the free-field seismic ground motions [2]. The seismic excitation experienced by structures is a function of the earthquake characteristics, travel path effects, local site effects, and soil-structure interaction effects respectively. The result of the first three of these factors can be summarized as free-field ground motion. Structural response to the free-field motion is influenced by SSI. Accelerations within the structure are affected by the flexibility of the foundation support and the difference between foundation support and free-field motions. Consequently, an accurate assessment of the inertial forces and displacements in structures requires a rational treatment of SSI effects[3],[7]. For determining the seismic response of building structures, it is a common practice to assume the structure is fixed at the base. However, this is a gross assumption, since flexibility of the foundation could be overlooked and underestimated in this case. This assumption is realistic only, when the structure is founded on solid rock[4]. The main concept of site response analysis is that the free field motion is dependent on the properties of the soil profile including stiffness of soil layers. The stiffness of the soil deposit can change the frequency content and amplitude of the ground motion. Likewise, on the path to the structure, wave properties might be changed due to the stiffness of the foundation. In general, the subsoil foundation response subjected to seismic ground motion has been dictated by the soil attributes, the soil conditions, and the characteristics of the earthquake. So, here this study is to propose a simplified but practical design procedure which enables structural engineers to consider detrimental effects of soil structure interaction in seismic design of building frames to ensure the design safety and reliability. The paper comprises study of the behaviour of tall structure resting on different types of subsoil with Raft foundation during seismic excitation and understanding an effect of subsoil on the behaviour of tall building by Time History Analysis.

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II. MODELLING

Soil structure interaction effect on tall building with raft foundation under seismic load is investigated.

The time history analysis of tall building has been done by subjecting the whole system to earth quack ground motion (Bhuj EQ data) using SAP 2000 V19 software. The details of the tall building and data of three different soil for this study is shown in Fig. 1.
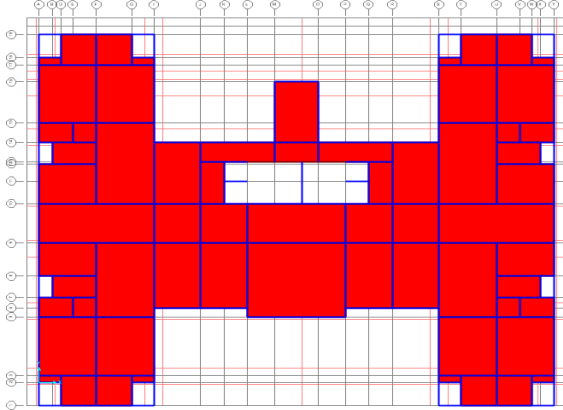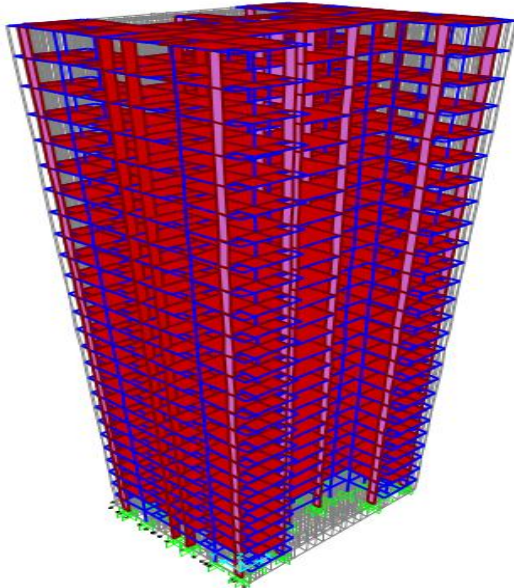

Fig. 1. Plan

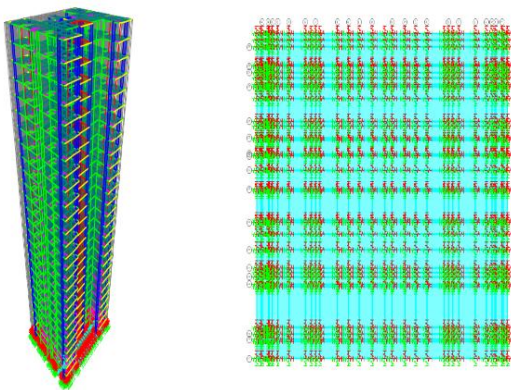**Fig. 2. 3-D view with Fixed Base**

Fig. 3. 3-D view with Raft Foundation

III. PROBLEM STATEMENT

Total three numbers of (G+25) RCC tall building structure models with rigid base and Raft Foundation resting on three varying types of soil ranging from soft to stiff has been carried out. Complete building is subjected to acceleration time history of BHUJ earthquake ground motion. Here, soil is idealized as a Winkler model and prescribed ground motion is used for global soil structure interaction analysis. The necessary deta is given below in Table I.

Table – I: Parameters

Location	Surat (Seismic Zone III)
Type of structure	RC Framed structure
No. of Storey	G + 25
Height of building	81.500 m
Storey Height	3.2 m
Floor Thickness	130, 150, 250 mm
Thickness of Shear Wall	250, 300 mm (IS 13920: 2002)
Material	
Unit Weight of Concrete	25 kN/m^3
Unit Weight of Masonry	20 kN/m^3
Grade of Material	M25, M30, M40, HYSD415 and HYSD500
Load	
Floor Finish Load	1.5 kN /m^2
Outer Wall Load	14 kN /m (230 mm Thick)
Inner Wall Load	7 kN/m (115 mm Thick)
Live Load	3 kN /m^2 (IS 875 Part II Table I)
Earthquake Load	As Per IS 1893
Seismic Zone	III (Z=0.16)
Importance Factor	1.2 (IS 1893(Part - I): 2016 Table 8)
Response Reduction Factor	5 (Special Moment Resisting Frame, IS 1893(Part - I): 2016 (Table 9)
% IL to Be Considered	50% (IS 1893(Part - I): 2016 Table 10)
Load Combination	As Per IS 1893(Part - I): 2016 Clause 6.3.2.2
Foundation data (Raft Foundation)	
Thickness of Raft	800 mm
Area of Raft	683.3983 m^2
Modulus of Sub Grade Reaction of Soil (Laboratory)	K_1=26576.0215 kN/m^3
	K_2=39618.866 kN/m^3
	K_3 =56486.304 kN/m^3

IV. RESULTS AND DISCUSSIONS

A variation in time period due to soil flexibility is depicted in Fig.4 which also highlights the comparison between fixed and flexible base with two methods, i.e., equivalent static and time history analysis[6],[8].Fig. 5 showsZ displacement of Raft foundation in both EquivalentStatic Analysis and Time History Analysis respectively [9].
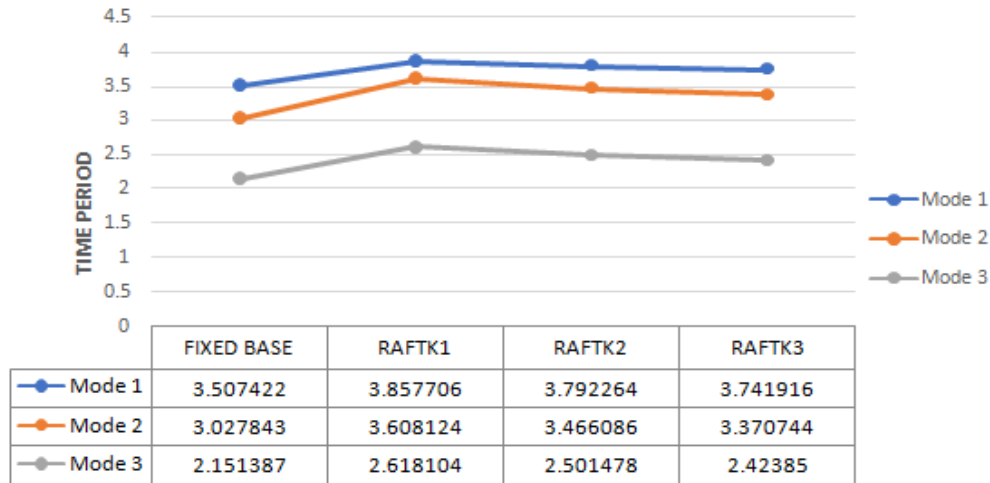

	FIXED BASE	RAFTK1	RAFTK2	RAFTK3
Mode 1	3.507422	3.857706	3.792264	3.741916
Mode 2	3.027843	3.608124	3.466086	3.370744
Mode 3	2.151387	2.618104	2.501478	2.42385

Fig. 4. Variation of time period v/s foundation types

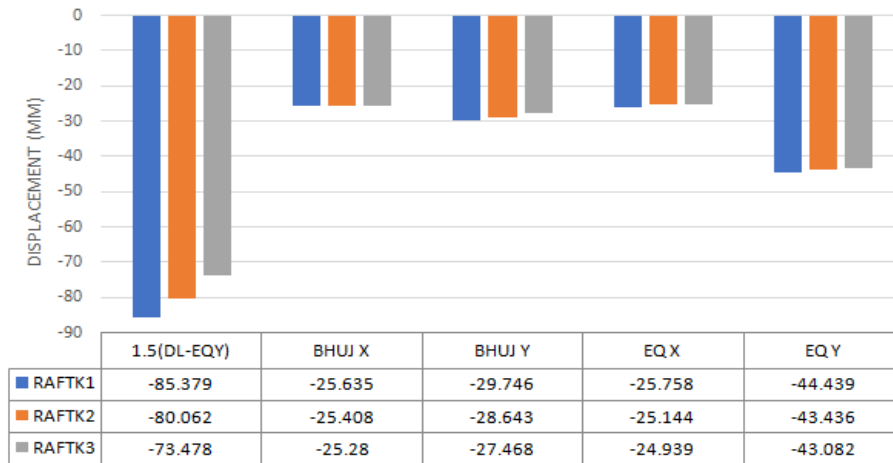|	1.5(DL-EQY)	BHUJ X	BHUJ Y	EQ X	EQ Y
RAFTK1	-85.379	-25.635	-29.746	-25.758	-44.439
RAFTK2	-80.062	-25.408	-28.643	-25.144	-43.436
RAFTK3	-73.478	-25.28	-27.468	-24.939	-43.082

Fig. 5. Maximum displacement of Raft Foundation in Z-Direction

Lateral displacement of tall building in both X - Direction and Y - Direction is depicted in Fig.6, 7, 8 and 9 respectively for both Fixed base and Raft foundation with various type of soil conditions for Static Equivalent Analysis and Time History Analysis.
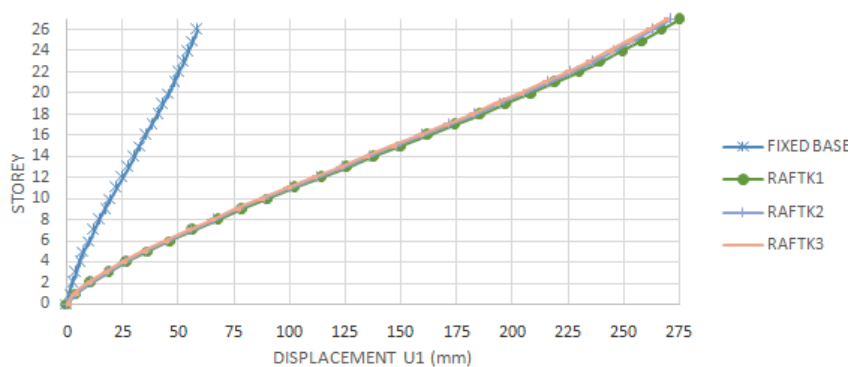

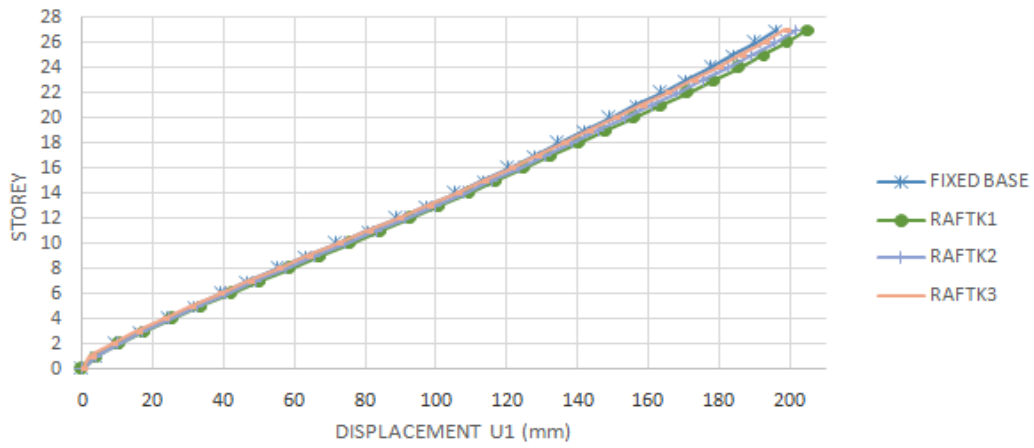**Fig. 6. Maximum Lateral displacement in X-Direction for EQ X**

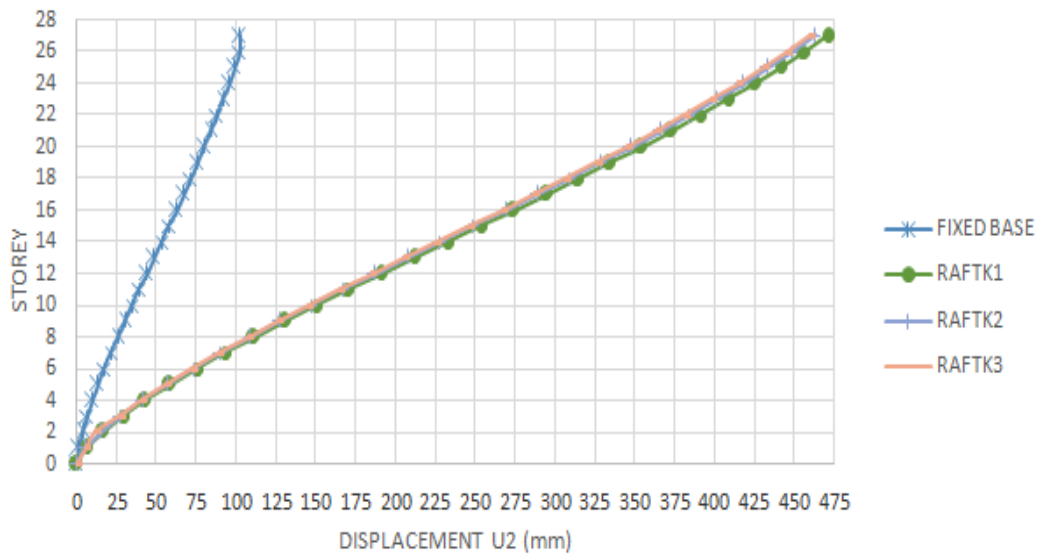**Fig.7. Maximum Lateral displacement in X-Direction for BHUJ X**

Fig.8. Maximum Lateral displacement in Y-Direction for EQ Y
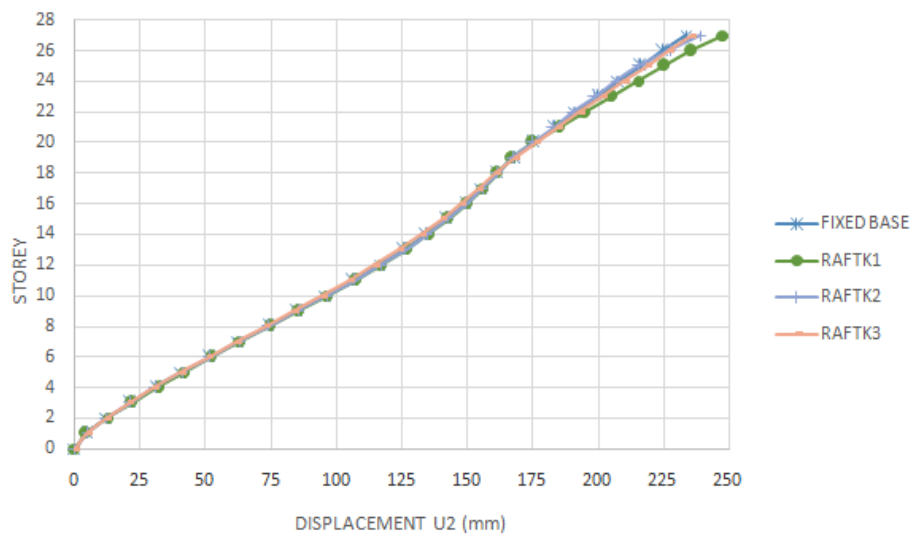

Fig. 9. Maximum Lateral displacement in Y-Direction for BHUJ Y

Fig.10 and Fig.11 shows Maximum Bending Moment (M11 and M22) of raft foundation of tall building along both X - Direction and Y - Direction by using Static Equivalent Analysis and Time History Analysis, while Fig.12. shows torsional moment (M12) for raft foundations about Z axis by using same methodological approach.
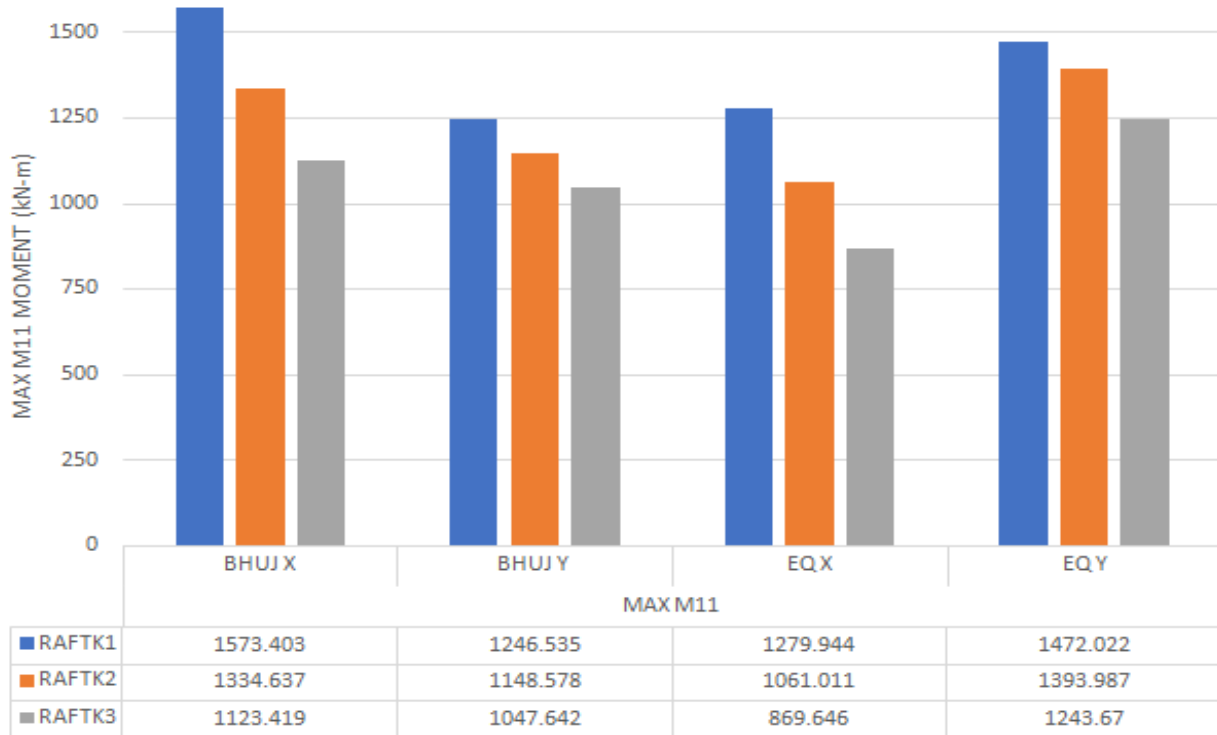

	BHUJ X	BHUJ Y	EQ X	EQ Y
■ RAFTK1	1573.403	1246.535	1279.944	1472.022
■ RAFTK2	1334.637	1148.578	1061.011	1393.987
■ RAFTK3	1123.419	1047.642	869.646	1243.67

Fig.10. Maximum Bending Moment (M11) along X-Direction

	BHUJ X	BHUJ Y	EQ X	EQ Y
■ RAFTK1	1190.394	1046.123	1135.374	1119.176
■ RAFTK2	974.797	997.584	984.855	1104.133
■ RAFTK3	820.231	910.817	796.579	964.496
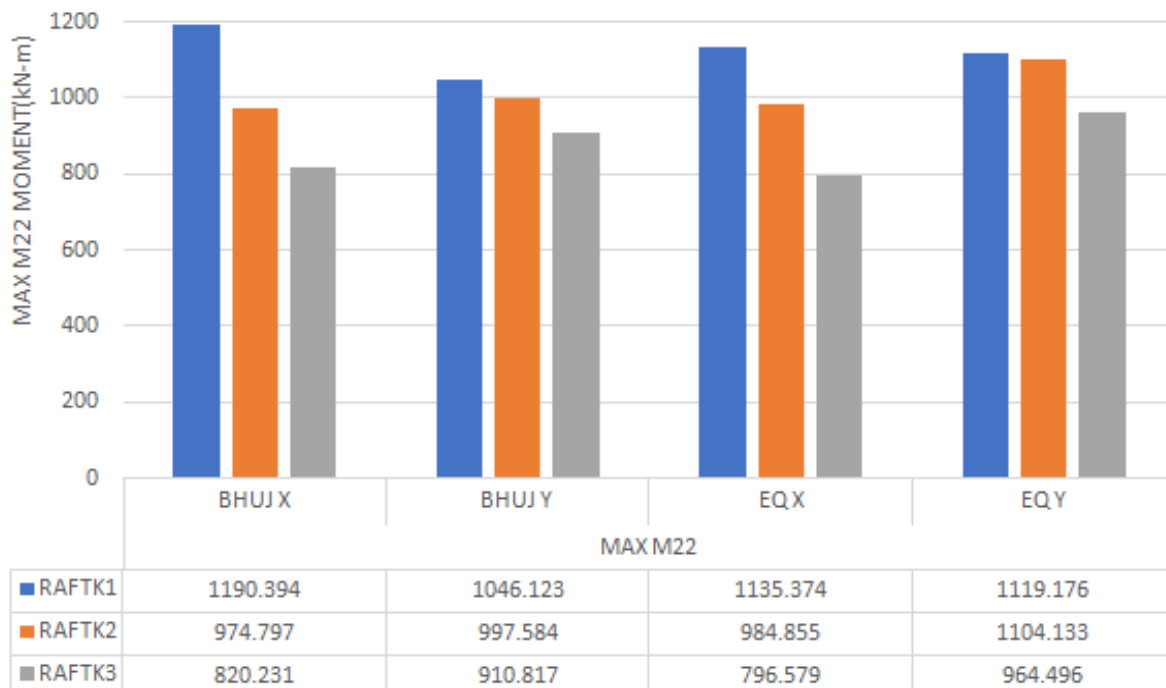
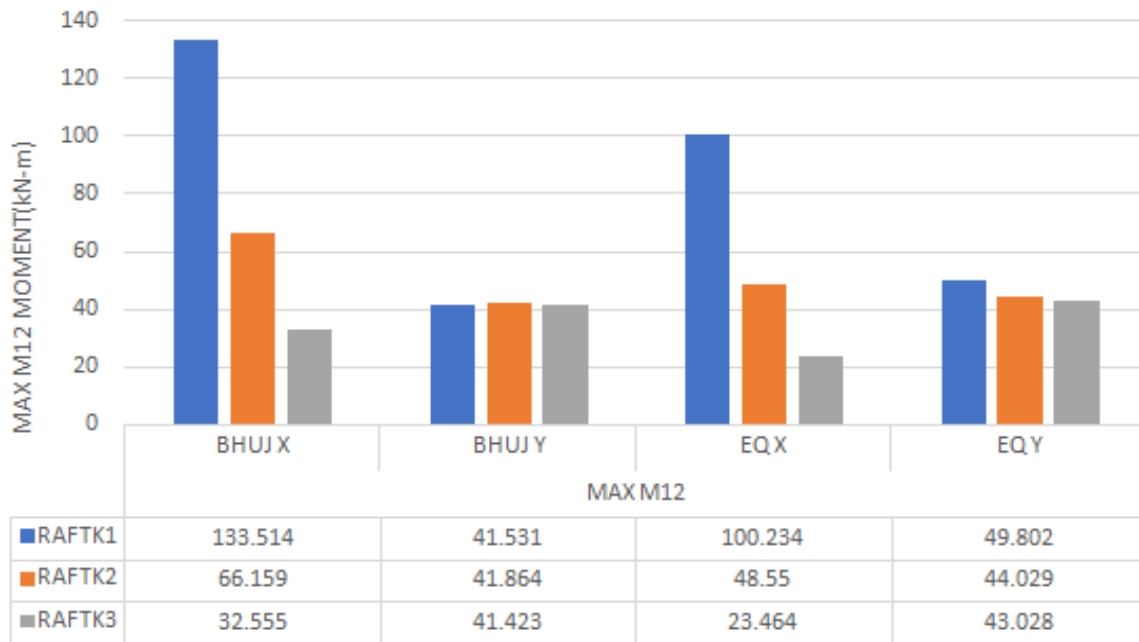**Fig.11. Maximum Bending Moment (M22) along Y-Direction**

Fig. 12. Maximum Torsional Moment (M12) along Z - Direction

V. CONCLUSION

Research attempts to study the effect of soil-structure interaction on Tall Building with raft foundation which provides complete idea of change in various seismic response quantities due to consideration of flexibility of soil below the foundation.

1. The time period of the tall building on the different soils with raft foundation is increased as compared with the fixed conditions. The increasing trend of time period was due to flexibility of soil medium below the foundation.

2. The displacement of Raft foundation in Z- Direction increases in both Static Equivalent Analysis and Time History Analysis as Soil flexibility increases.

3. Maximum Lateral displacement of tall building in X - Direction and Y – Direction increases in both Static Equivalent Analysis and Time History Analysis cases.

4. Maximum Bending Moment (M11 and M22) of Raft Foundation of tall building along both X - Direction and Y - Direction increases in both Static Equivalent Analysis and Time History Analysis.

5. Due to variation in subgrade reactions Maximum Torsional Moment (M12) of Raft Foundation of tall building increases in both Static Equivalent Analysis and Time History Analysis.

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