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The Seismic Study of Frame Foundation for Rotary Machine

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Abstract—*The finite element modeling and dynamic analysis of heavy and frame foundation of rotary type machine is considered in this project. .The failure of foundation will result in to a huge loss. The work in this paper investigates the effect of earthquake on frame foundation and support condition for column at base on the response of foundation to dynamic machine load. Earthquake analysis is done by using SAP2000 software to check effect of seismic as per IS 1893-2002 (Part 1) on frequencies. Finally, the response of the machine foundation to seismic forces is evaluated. Seismic analysis is performed by three methods and compared the base shear values (1) Equivalent static methods as per IS 1893-2002 part 1 (2) Response spectrum analysis as per IS 1893-2002 (3) Time history analysis considering three earthquakes data.*

And dynamic analysis is done by considering unbalanced force as steady state of response. A detailed model of the steam turbine generation foundation considered as a rotary machine foundation and is constructed using as per clause number 9.1.1 from IS 2974 part 3. This model is used to perform response spectrum analysis. The influence of changes is those parameters on the foundation response is determined. The results are compared for with respect to frequency, amplitude and deflection. Analysis showed that the change in the seismic zones has almost no effect on the natural frequencies whereas deflection increases and Response Spectrum analysis showed that the change in the Support condition from fixed to pin

Index Terms*: Rotary Machine, Frame Foundation, Earthquake, Equivalent static method, Response spectrum.*

1. INTRODUCTION

The main constituents of a typical machine foundation system are machine, foundation and support medium. The machines are classified based on their type of motion as rotary, reciprocating, impact machines. A suitable foundation is selected, depending upon the type of machine. The types of machine foundation are block foundation, frame foundation, wall foundation etc. Soil is considered as very stiff rigid soil In this paper the seismic analysis is carried out on the rotary machine of frame foundation with and without machine weights.

The foundation is analysed by manual method and using software SAP2000. The different loads acting on foundation and the load combination that are useful in analysis of machine foundation are considered from IS2974 part3:1992.. The parametric study of natural frequencies has been done with machine load on the bearing locations and also earthquake analysis by equivalent static method and response method done and results of storey displacement compared and it is check for dangerous earthquake for safty design bytime history analysis has been done by considering the data from "IMPERIAL VALLEY EARTHQUAKE - EL CENTRO".

2. PROBLEM STATEMENT

For this study a problem of frame foundation for rotating type is taken from foundations for industrial machines" hand book for practicing engineers by Bhatia as detailed below. Fig. 2.1 shows the typical top view of TG foundation showing bearing locations, major notch and columns. Table 2.1 shows the loads acting at the bearing locations of machine. Fig. 2.2 shows the front elevation and side view of TG foundation

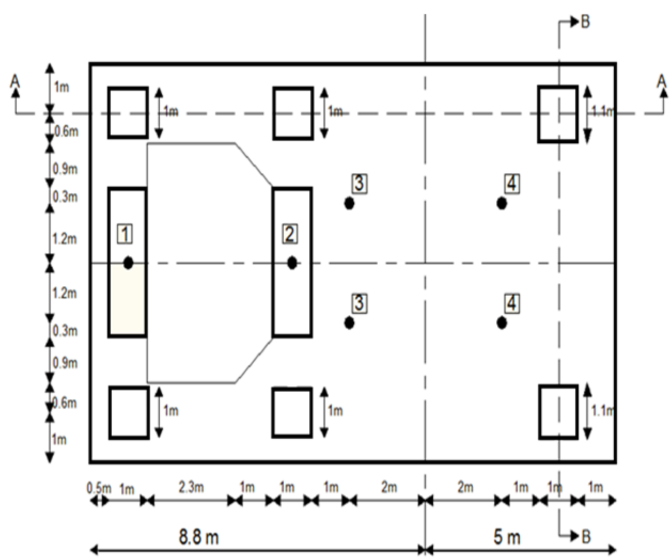


Fig. 2.1: Plan of the Turbo Generator Foundation showing the bearing locations of the Machine

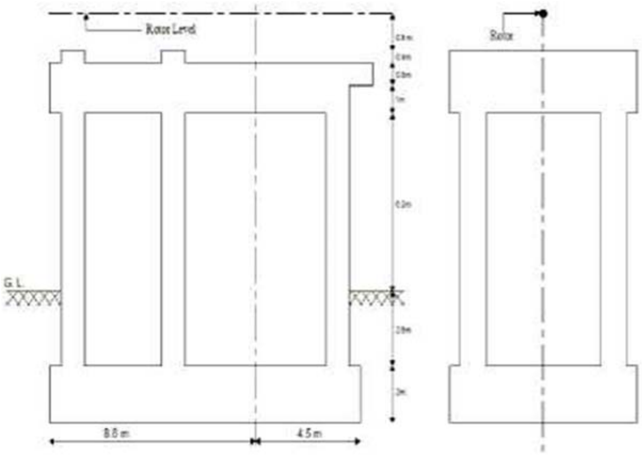


Fig. 1.2: Section A-A: - Elevation of the rotary machine Foundation and Section B-B: - Side View

Table 2.1 Machine Load Data

Bearing Points	1	2	3	4	Total (kN)
Total machine weight	400	360	200	200	1160
Rotor weight	25	35	70	70	200
Unbalance Force					
Lateral/Vertical	5	7	15	15	42
Longitudinal	2	3	6	6	17
Blade Loss force	3	11	-	-	14

Table 2.2 Foundation Data

Foundation material Properties	
Grade of Concrete	M:25
Mass density of concrete	p = 2500 kg/m^3
Modulus of elasticity	$E = 3 \times 10^7$ kN/m^2
Poisson's ratio	u = 0.15
Shear modulus	$G = 1.3 \times 10^7$ kN/m^2

Table 2.3: Soil Properties

Coefficient of uniform compression	C = 40000 kN/m^3
Coefficient of non-uniform compression	C_0 = 80000 kN/m^3
Coefficient of uniform shear	C_z= 20000 kN/m^3
Coefficient non-uniform shear	C_T = 30000 kN/m^3

3. ANALYSIS OF FRAME FOUNDATION

The analysis shall be done using a simulated mathematical model of linear-elastic properties. The modeling should take into account the basic characteristics of the system, that is, mass, stiffness and damping. Here rotary machine foundation modeled using SAP2000 software. And by the manual analysis also natural frequencies calculated. In manual analysis both static analysis and dynamic analysis are considered.

Manual Analysis

Manual analysis considers mainly static analysis and dynamic analysis.in static analysis the eccentricity check is considered and in dynamic analysis natural frequencies and total amplitude of vibration.

For the analysis purpose it is considered as three frames.

Centre of stiffness with respect to Frame I

Zkx =5.83 m

Zky =4 m

Centre of Gravity of the masses with respect to Frame I

Zmx =5.93 m

Zmy =4 m

Top deck Eccentricity along X direction

ex = Zmx-Zkx=0.1 m

Top deck Eccentricity along Y direction

ey = Zmy - Zky = 0 m

e = (0.1 / 13.8) X100

e = 0.72% (It is less than 1%)

Hence, Eccentricity is within permissible limit.

(Clause 8.6 from IS2974 Part3:1992)

Table 3.1: Dynamic Analysis –Natural Frequencies by manual method

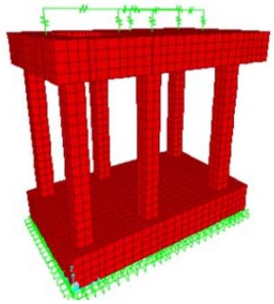
Mode		rad/sec	Hz
Translational Mode along X	P_x	16.74	2.65
1st Vertical Mode along Y	Py_1	140	22.041
2nd Vertical Mode along Y	Py_2	270	43
Overall Total Vertical Amplitude of Top Deck slab	16.88	microns	

Modelling for Frame Foundation-Software Analysis

The elements of the foundation system such as beam, column, deck slab and raft are modeled as solid elements.. In this model the boundary condition and make all the nodes at the bottom of the raft fixed in all six directions assuming the soil below the ground as very rigid. During modeling the small opening, notches, pockets, cut-outs, projections, etc. which unnecessarily increases the complexity of the problem without much influencing the results of the structure in the analysis are avoided. Only major openings and depressions are taken into consideration which is enough to represent the actual structure Turbine and generator masses are lumped at four bearing locations at the top deck.

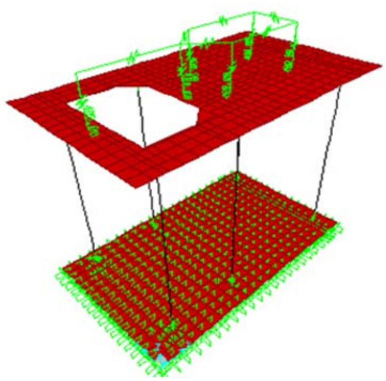
Solid Model with Fixed End

The elements like beam, column, deck slab and raft are modelled as solid elements and soil is modelled as six spring elements stiffness in all six directions.



Beam Shell Model with changes Column Sizes

Deck slab and Raft modelled using shell element and columns are modelled using frame elements and soil is modelled using springs in all six directions



Modal analysis has been done for two models and the difference in nature of natural frequencies presented below.

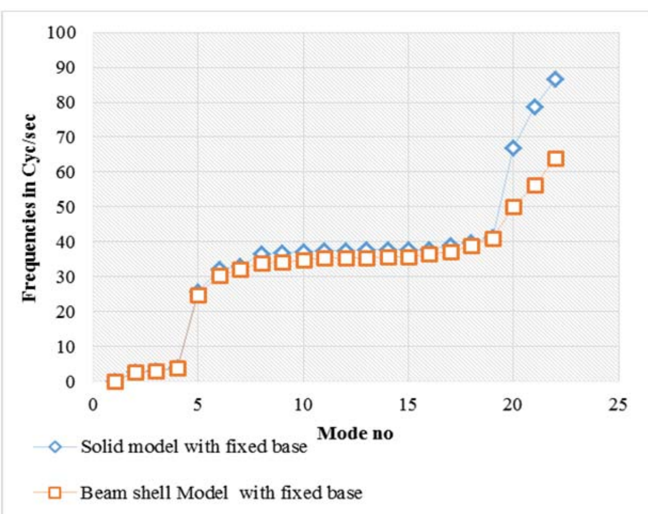


Fig. 3.1 comparison of Natural Frequencies

Table 3.1 Natural Frequencies For Different Modes

	Solid model with fixed base	**Beam shell Model with fixed base**	**Manual analysis results**
Mode No	**Natural Frequency (cyc/sec)**	**Natural Frequency (cyc/sec)**	**Natural frequency**
1	2.7908	2.692	
2	2.9303	2.9139	2.96 X
3	3.6907	3.7765	3.18 T
4	25.649	24.791	26.93 Y
5	32.206	30.399	
6	33.033	32.171	
7	36.513	33.875	
8	36.897	34.278	
9	37.207	34.642	
10	37.374	35.223	
11	37.456	35.352	
12	37.644	35.436	
13	37.667	35.569	
14	37.813	35.665	
15	37.834	36.444	
16	38.806	37.194	
17	39.874	38.855	
18	41.144	40.935	
19	66.842	65.95	
20	78.786	70.297	
21	86.56	72.95	

Observation:-

The operating frequency of the machine is 50Hz. So it is necessary to avoid frequency ranging from 40 Hz to 60 Hz .according to IS2974 part3:1992 the modal frequencies should not fall near to the operating frequency of the machine. For this the model is re defined its column sizes and this frequency range of resonance is avoided. In case2 the column sizes have been changed such that the required frequency range is obtained.

4. EARTHQUAKE QUAKE EFFECT ON FRAME FOUNDATION

In the absence of any specific code for earthquake-resistant design of machine-foundation systems, it is recommended to use the provisions of IS 1893 (Part 4) (BIS, 2005). The horizontal seismic coefficient *Ah* should be computed as per Clause 8.3 of these provisions. Unlike other structures, the author Bhatia [5] recommends that the vertical seismic coefficient be considered same as the horizontal seismic coefficient in the applications to machine-foundation systems.

For the calculation of time period the frame considered as RC frame and moment resisting frame structure without brick infill

Seismic weight of the building = 5452kN

Calculation of Fundamental Time Period of the Building (Ta) =0.4086sec

Zone Factor = 0.36

Soil Type= 1

Sa/g =2.43

Importance Factor= 1.5 Response Reduction = 5 No. stories= 1

Design Horizontal Acceleration Coefficient Ah= 0.131

Design Seismic Base Shear VB =714.15 KN

The seismic weight of the floor in Wi(kN) column

(machine weight +top deck+0.23%of columns wt) = 5452

Height of each floor in hi (m) column = 9.7

Table 4.1: Base shear of frame foundation for all zones

Zone	Storey	Wi (kN)	hi (m)	$Wihi^2 \times 10^{-3}$	Vi (kN)
5	1	5452	9.7	512979	714.15
4	1	5452	9.7	512979	476.00
3	1	5452	9.7	512979	317.00
2	1	5452	9.7	512979	198.00

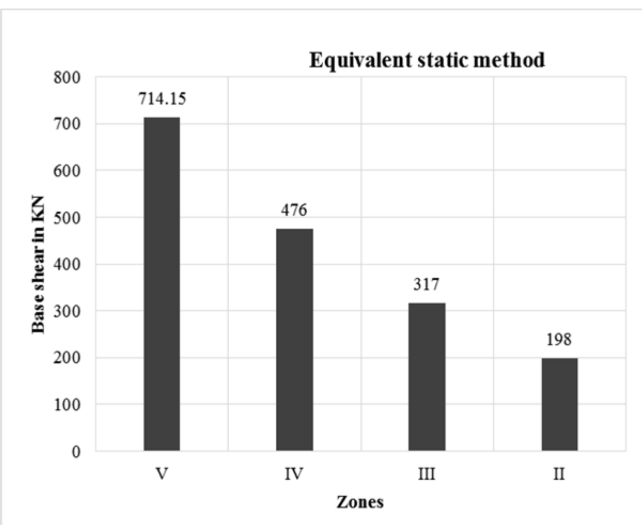


Fig. 4.2: Bar chart representation of base shears of different zones

Zones	II	III	IV	V	II	III	IV	V
Vertical amplitude of deck mm	0.19 6	0.31 4	0.47 1	0.70 6	0.20 3	0.32 5	0.48 7	0.73 1
Horizontal amplitude of deck mm	7.9	12.6 01	18.9	28.4 58	11.4 05	18.2 49	27.3 73	41.0 59
Overall horizontal deflection	7.9	12.6 53	18.9	28.4 8	11.4 05	18.2 49	27.3 73	41.0 59
Base shear	1237 .2	1979 .5	2969 .2	4453 .8	1142 .6	1828 .2	2742 .3	4113 .5

Observations and conclusion of equivalent static method

1. Because of the high bearing failure load acting in the transverse and vertical direction at the bearing location of the frame foundation, the seismic force of EQS should not be consider in the transverse direction
2. Seismic force of EQS method can be applied in longitudinal axis as bearing failure load is not acted in that direction
3. Base shear is decreasing from higher zone to lower zone
4. Bearing failure load i.e., five time the rotor weight = 5*200= 1000KN< bear shear 715 KN

Response spectrum analysis

Response spectrum analysis is done by using SAP2000 software to check Damping effect. This is followed by changing seismic zone factors as per IS 1893-2002 (Part 1) to check the effect on frequencies. Finally, the response of the machine foundation to seismic forces is evaluated for different type soils. Seismic analysis is performed by changing zone factors as per IS 1893-2002 part 1 .

Due to calculated time period of the frame foundation as per IS1893:2002 the effect of Sa/g is approximately getting same for all soils(2.5) so only SOIL TYPE-1(Very stiff soil) case is considered for the earthquake loads by response spectrum method

Ground Motion Records

Buildings are subjected to ground motions. The ground motion has dynamic characteristics, which are peak ground acceleration (PGA), peak ground velocity (PGV), peak ground displacement (PGD), frequency content, and duration. These dynamic characteristics play predominant rule in studying the behavior of Frame buildings under seismic loads. The structure stability depends on the structure slenderness, as well as the ground motion amplitude, frequency and duration. Based on the frequency content, which is the ratio of PGA/PGV the ground motion records are classified into three categories

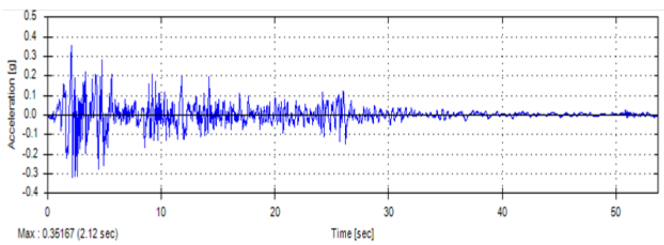
The ratio of peak ground acceleration in terms of acceleration of gravity (g) to peak ground velocity in unit of (m/s) is defined as the frequency content of the ground motion. [16]

Table 4.2: Earthquake characteristics of Earthquake applied on the RMF foundation of machine

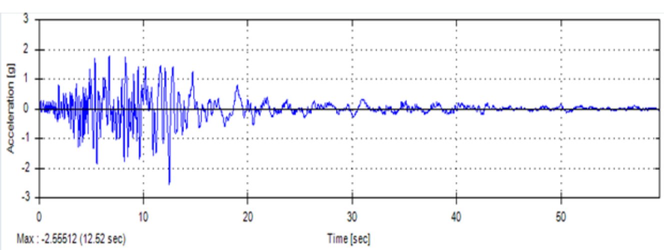
Records (Station)	Locatiin	Source	Magnitude	Duration (s)	Time step for response computation (s)	PGA (g)
1940 IMPERIAL VALLEY EARTHQUAKE	Elcentro	NISEE, U.C. Berkeley, California	7.1	53.46	0.02	0.352
1995MEXICO CITY EARTHQUAKE	Mexico	NISEE, U.C. Berkeley, California	-	59.5	0.02	0.107
1994 San Francisco	Pacoima Dam	NISEE, U.C. Berkeley, California GGP010	6.6	41.8	0.02	2.555

Fig. Error! No text of specified style in document.**.1 Ground motion characteristics and classification**

Elecentro Earthquake



SanFernando Earthquake



Mexicocity Earthquake

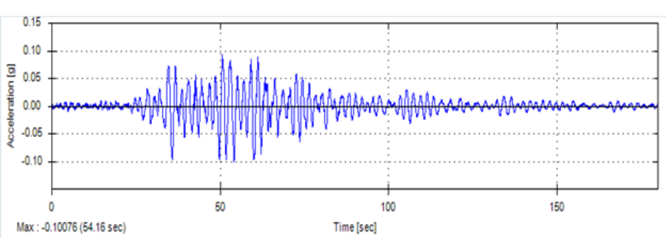
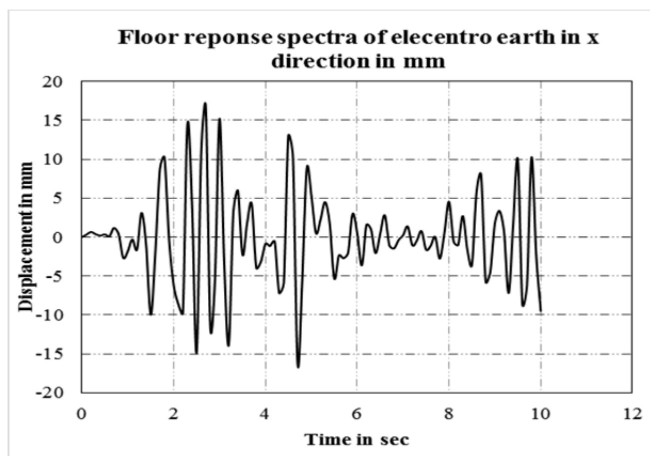


Table 4.3: Base Shear variation of the various earthquake Time histories

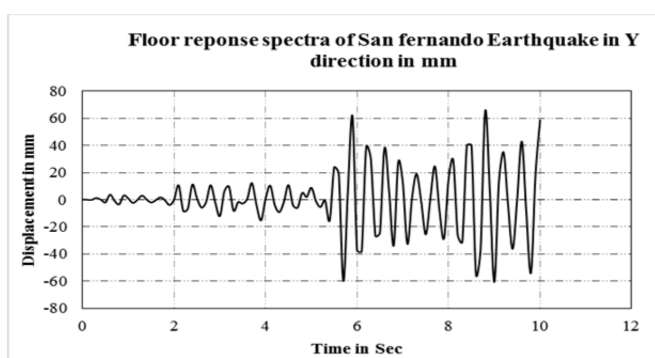
Earthquakes	Elecentro				Mexico city				San fernando			
	THAX		THAY		THAX		THAY		THAX		THAY	
Max/Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Storey displacement 9(mm)	15.681	4.951	25.21	0.51	30.23	9.263	4.72	0.08	60.56	10.23	58.326	8.736
Base Shear KN	2529	2554	2425	2576	47.83	58.10	56.484	72.8	25917	29929	32753	32753

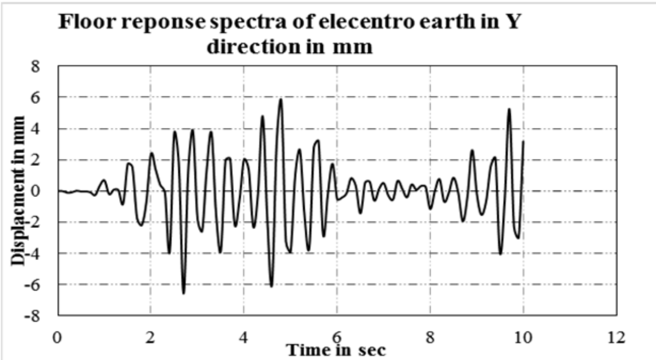
Floor response spectra

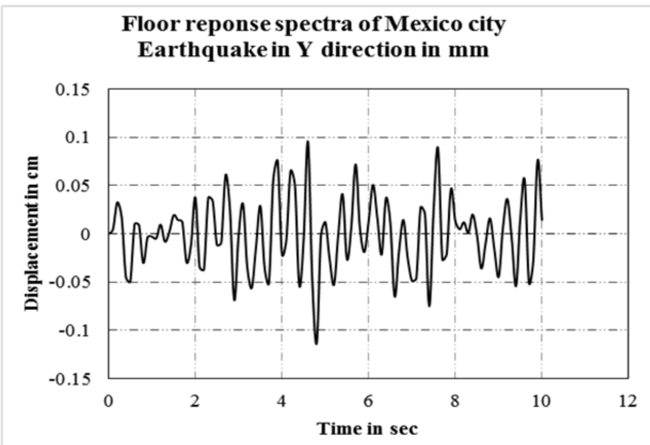
Floor response spectra is the response spectra for time history motion of a floor for appropriate material damping values subjected to a specified earthquake motion at the base of the structure. Linear Time History Analysis (THA) is performed on RMF foundation for three different earthquakes with varying PGA values and response spectrum of top deck slab is plotted in X and Y directions. Graph 4.1 shows the floor response spectra of a structure caused by the three chosen earthquakes in both X and Y directions.

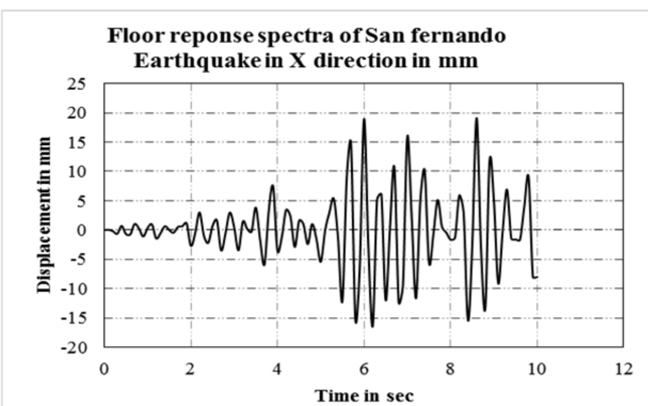


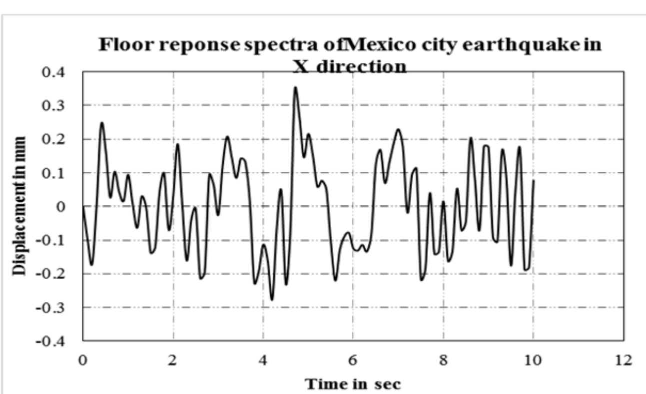
Graph 4: Floor response spectrum of three Earthquakes











Nodal Displacement at Floor Level

Table 4.5 shows the maximum displacement and base shear of top deck slab of TG foundation for three chosen earthquakes and without earthquake condition. As per IS 1893 [10], max storey drift should be less than or equal to 0.004 times the storey height of the structure.

The storey height = 10.7 m

Therefore, yield storey drift = 0.004 X 10.7 = 0.0428 m = 42.8 mm

1. It is observed that the maximum displacement of the RMF foundation increases with increase in PGA value of the earthquake.
2. It is noted that the maximum storey displacement under earthquake 1 and earthquake 2 lies well within the permissible storey drift both in X and Y direction. It means that the structure remains in elastic condition and safe.
3. The maximum storey displacement in X direction is 63.38 mm and in Y direction it is 58.3 mm under earthquake 3 loading.
4. Under earthquake 3 loading, storey displacement is exceeding the yield storey drift limitation by 32% in X direction and 27% in Y direction. It means that the RMF foundation is not safe and attends the inelastic condition and it will experience the severe damages.

Table 4.1: Maximum Displacement

Loading Condition (PGA)	Max. Storey Displacement	
	In X direction (mm)	In Y direction (mm)
Earthquake 1 (0.35 g)	19.35	25
Earthquake 2 (0.107 g)	38.86	41.34
Earthquake 3 (2.77 g)	63.38	58.3

Observations and Conclusions of Time history analysis

THA is very efficient method to determine the response spectra of floor, nodal displacement and member forces. The conclusions of this study are as fallows.

1. Floor response of RMF foundation is evaluated and shows that with increase in PGA value of earthquake ground motion the response also increases.
2. It is observed that the spectral response of structure is a function of the peak ground acceleration value and not on the magnitude of the earthquakes.
3. The nodal displacement of top deck slab under Imperial Valley earthquake and Mexico city earthquake lies well within the permissible nodal displacement and remains in elastic condition. Hence, the foundation is safe and sound under these two earthquake attacks.

4. However, under San Fernando earthquake, the nodal displacement of the RMF foundation exceeds the permissible nodal displacement in both X and Y direction. Hence, the RMF foundation under this attack is not safe and may experience severe damages.

5. It is concluded that the RMF foundation will be subjected to the higher seismic forces when exposed to higher PGA earthquakes and requires to be analysed for earthquake forces also.

5. CONCLUSION

1. Because of the high bearing failure load acting in the transverse and vertical direction at the bearing location of the frame foundation, the seismic force of EQS should not be consider in the transverse direction

2. Seismic force of EQS method can be applied in longitudinal axis as bearing failure load is not acted in that direction

3. Base shear is decreasing from higher zone to lower zone

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