

Dynamics Analysis of Structures – Investigation Into Analysis of Raft Foundation

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ABSTRACT

A raft foundation supports numerous columns distributed evenly through a thick reinforced concrete raft. It is used when heavy loads exist relative to soil capacity. Raft foundations, however, are suited to seismic regions due to their continuity and inherent rigidity. When a structure is subjected to earthquake forces, column loads and base moments get affected causing increase in column load, on one side, and corresponding decrease, on the other. This causes a large eccentricity of loads with respect to the C.G. of the raft. This behavior induces differential settlement causing additional moments in the raft. Hence, it is necessary to investigate the effect of earthquake loading for the design of the raft. In the present study the effect of two dynamic analysis methods namely seismic coefficient and response spectrum are compared for a building.

In case of response spectrum analysis, the signs of the forces are lost due to SRSS combination, however, in analysis of raft, it is necessary to apply the forces with proper sign i.e. up and down. Pressure distribution under the raft for Response spectrum method is rectangular with no signs attached to it unlike other cases. Seismic coefficient method mostly gives results, which are conservative as compared with response spectrum method. Time History Analysis results can be assumed as exact but involves very laborious calculations and are time consuming and are not suitable without powerful analysis software packages, hence its use, for normal structures is not feasible. In this paper, emphasis is given on the pressure distribution under the raft for the first two methods and a modified response spectrum analysis is suggested for the analysis and design for the raft foundation. As the signs of forces in response spectrum method are lost, as an alternative the signs of seismic coefficient method are attached to the response spectrum forces while applying on the raft model and the analysis is performed.

INTRODUCTION

The purpose of a foundation under static conditions is to transfer vertical loads from the superstructure into ground. Under seismic conditions however, the strength demand of the foundation becomes more complicated. The movement of the ground during an earthquake becomes the source of dynamic loading. Suddenly the foundation must transmit seismic inertia forces in the structure caused by the ground motion back into the ground. Thus horizontal base shear, overturning moment, and axial force develop in the structure that must be resisted to effectively avert serious seismic damage.

A raft foundation is a large concrete slab, which transmits the loading from several columns in a building or the entire building loads to the ground. A raft is often used when the soil is of poor quality, or the column loads are so large, that more than 50% of the building-plan area is covered by footings. Rafts are also used beneath silo clusters, nuclear reactors, storage tanks, chimneys and other structures where a single foundation element beneath all parts of the structure is required.

RCC rafts are complex structures having intricate reinforcement details and their interaction with soil, which is generally with varying properties, makes the analysis very difficult. The analysis of RCC plated structures is a complex problem because of heterogeneous nature of concrete, uncertain material laws, variation in reinforcement in different parts etc. apart from these, in rafts the interaction with soil also becomes important.

Also with ease in availability of high power software, it is possible to perform nonlinear analysis of the raft structures for economy and to access proper results for important structures. In such cases, it is necessary to perform analysis with all possible load combination acting on the raft, where forces are combined with proper sign.

For the Seismic analysis of multistoried structure having raft foundation, various methods such as Seismic Coefficient Analysis, Response Spectrum Analysis and Time-History Analysis can be used for evaluation of earthquake forces. All the above stated methods have different approach for seismic analysis to get the structural deformations and member forces. In case of a raft foundation for a structure when analyzed for seismic forces with different methods, forces having different signs are induced depending upon the method of analysis used.

The Figure-1 a shows how the forces are induced in the structure basically foundation if seismic coefficient analysis is performed. The force application in seismic coefficient method for a raft of typical multistoried building structure results in compressive forces (on one side) and tensile forces (on other side) in the columns. These forces in term induce variation of pressure distribution on the raft.

In response spectrum method mode shapes and frequencies are calculated by considering the structure as multi-degree freedom system with lumped masses. The force application to the structure results in forces having no sign attached to them, thus the nature of reactions in not exactly known for the analysis of structure. (Figure 1b)

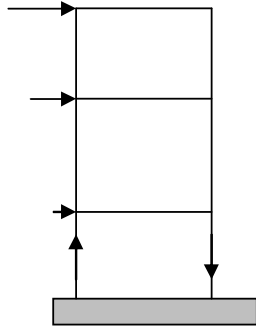


Figure 1a Vertical force distribution for Codal Coefficient method

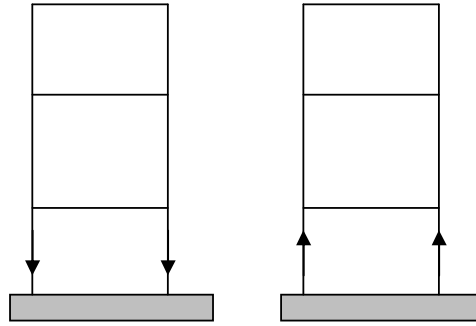


Figure 1b Vertical force distribution Response Spectrum method

In time history analysis from the time history graphs of the response, force amplitude with sign gives most exact results. But the method is very tedious compared with the other two. Here the comparison of these methods is carried out and emphasis is given to arrive at a more rational dynamics analysis procedure for design of rafts subjected to seismic forces.

In the present study, the seismic analysis of plane and space frames is performed using SAP2000, which is a integrated finite element analysis and design program, for various structures including dynamic analysis. The forces in the columns at the foundation level are determined for seismic loads applied using three different approaches viz. seismic coefficient method, response spectra method and time history analysis. The effect of earthquake has been studied with respect to the variation of axial forces and hence, in the pressure distribution diagram for the raft.

PROBLEM CONSIDERED

General

A ground plus four storey RC office building of plan dimensions 19 m x 10 m located in seismic zone III on medium soil is considered. It is assumed that there is no parking floor for this building. Seismic analysis is performed using the codal seismic coefficient method and Response Spectrum method as per in IS:1893-2002.

Plan of the building and sectional elevations of different RC frames are shown in Figures 2a, 2b and 2c. The sizes of the beams and columns are given in Figure 2a.

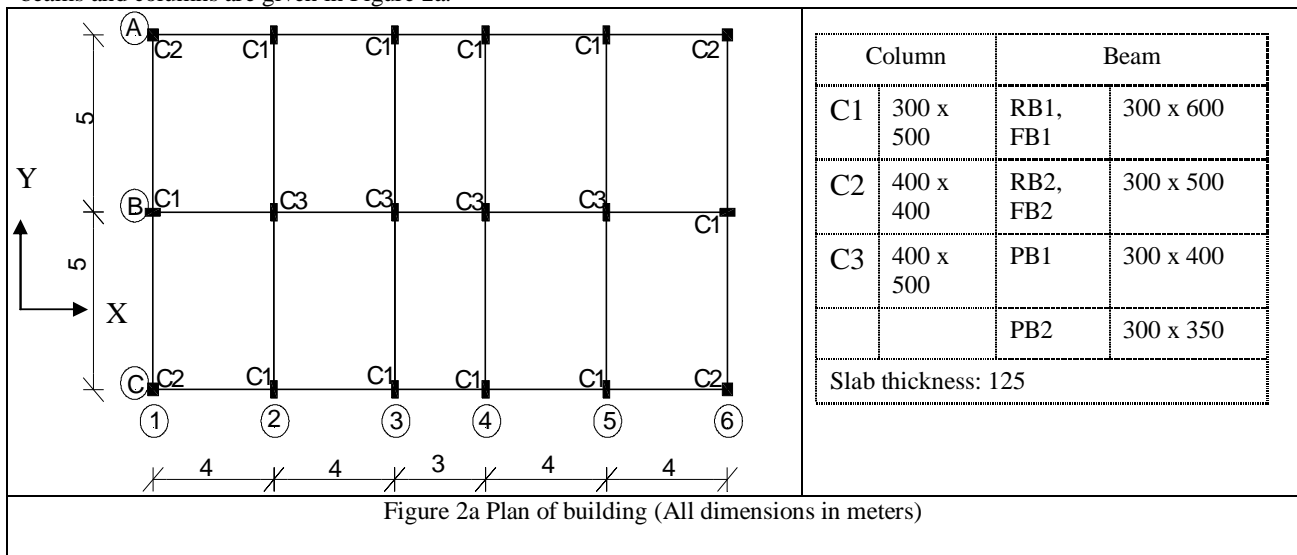


Figure 2a Plan of building (All dimensions in meters)

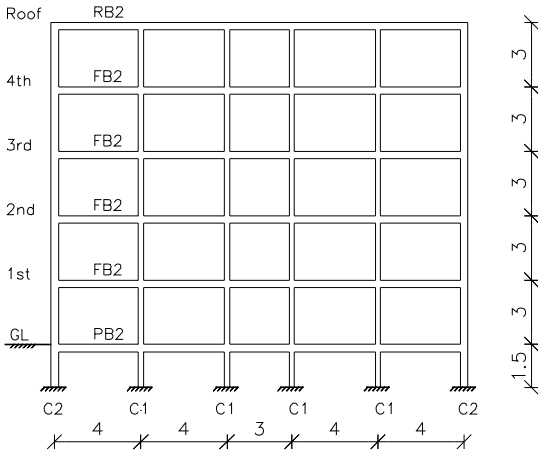


Figure 2b Elevation of frame A, B & C

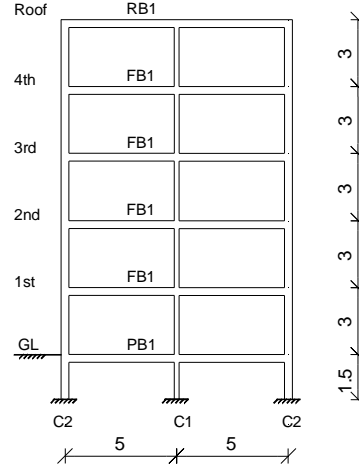


Figure 2c Elevation of transverse frame 1&6

Earthquake Weight (Mass) Calculations

Table-1 gives Weight calculations at each floor level for whole building. Figure 3 shows weights at each floor level.

Table-1 Calculation of Weights at various levels (kN)

Level	Slab+ Finish	Parapet wall	BK Wall	LL	Beams	Columns	Total load
Roof	784	267	555	-	220	69	1895
4 th	784	-	1110	48	220	138	2300
3 rd	784	-	1110	48	220	138	2300
2 nd	784	-	1110	48	220	138	2300
1 st	784	-	555*	48	220	138	1745
GL	-	-	-	-	-	-	-
Total	3920	267	4440	192	1100	621	10540

The earthquake forces distribution, storey wise, is shown in Figure-3a. Figure 3b and Figure 3c shows earthquake force applied on the mathematical model.

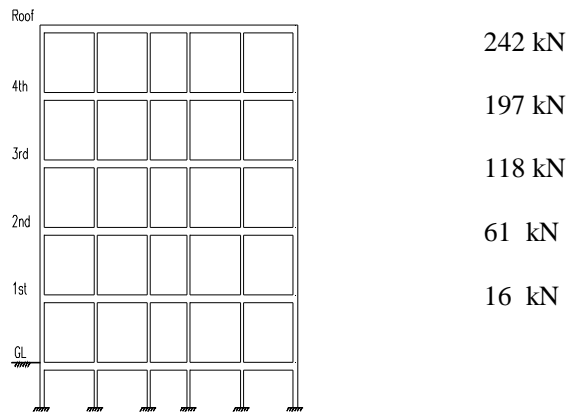


Figure 3.a Earthquake Force Distribution

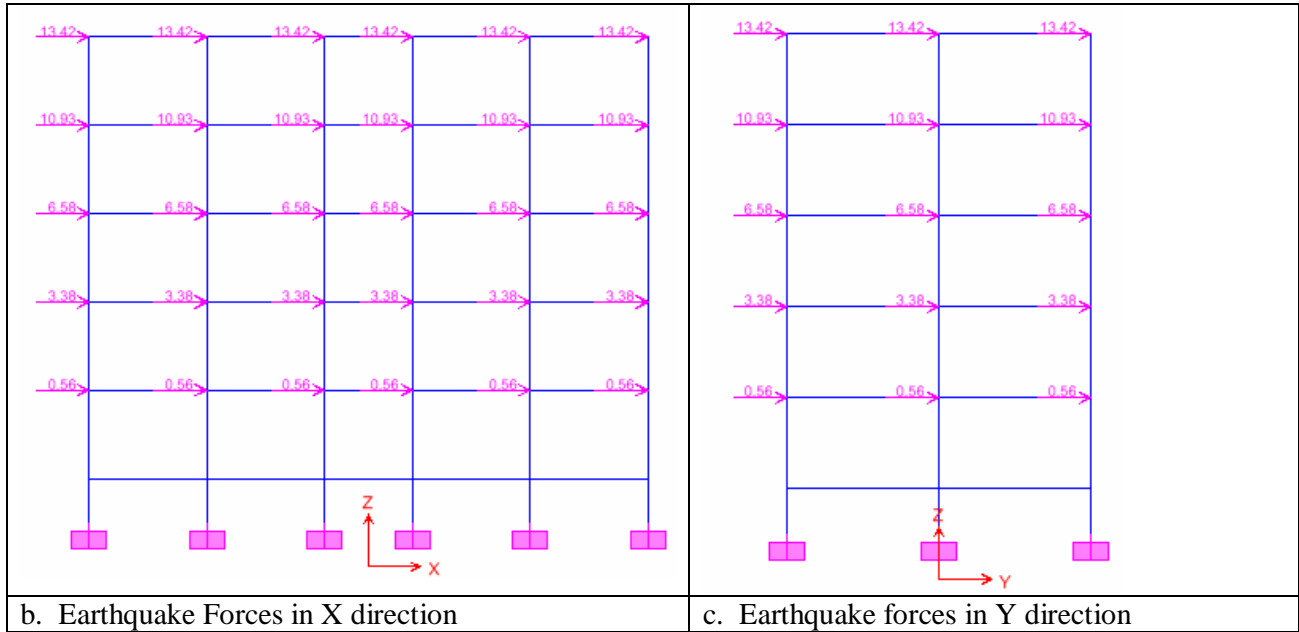


Figure 3 Loading diagram for showing codal coefficient earthquake forces

Analyses

Two widely used methods of dynamic analysis of structures viz. seismic coefficient method and Response spectrum method are studied. For both these methods i.e. Seismic coefficient method and Response Spectrum method for earthquake analysis, procedure stated in IS-1893 is followed. The analysis is performed for rigid and flexible (in bending) rafts.

Rigid Raft

The analysis is performed and the column forces are transferred to the raft for further analysis. The maximum and minimum pressures for one component of earthquake, is tabulated in Table-2 for transverse frame and Table-3 for longitudinal frame. The mathematical model is shown in Figure 4. Figure 5 show the pressure distribution at bottom of raft in transverse direction The pressure is evaluated assuming the raft as rigid.

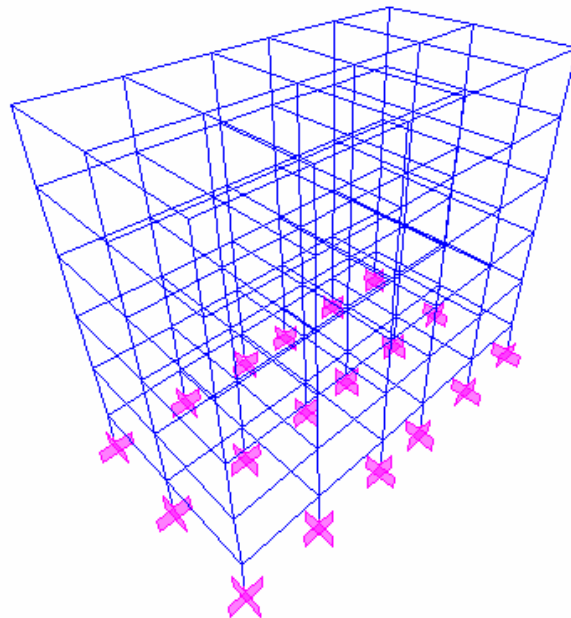


Figure 4 Mathematical model (fixed at bottom)

The pressure s_1 is evaluated as moment due to unbalance load divided by section modulus of the area i.e. moment about center divided by section modulus ($132 \times 2 \times 5 \times 6 / (4 \times 10 \times 10) = 19.80 \text{ kN/sqm.}$). In case of response spectrum method, as the force is action in one direction, there will be only vertical force. Hence the vertical force is used to calculate the uniform pressure. ($120 + 120 / (4 \times 10) = 6 \text{ kN/sqm.}$)

Table 2 – Pressure variation under raft for transverse frame

	s_1 (kN/sqm)	s_2 (kN/sqm)	Remarks
SCM	+19.80	-19.80	Triangular Pressure
RSM	± 6.00	± 6.00	Uniform rectangular pressure

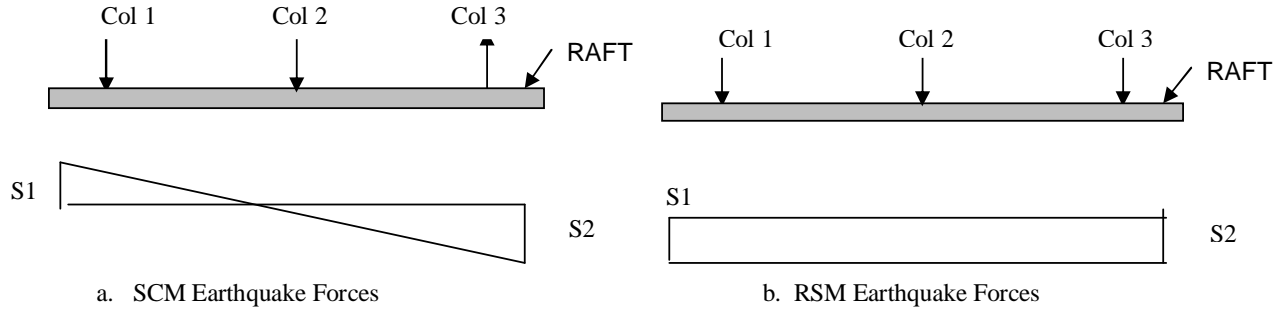


Figure 5 Schematic Pressure Diagram below Raft in transverse direction

Similar results for the maximum and minimum values of pressure distribution at the corners of raft are obtained for longitudinal direction earthquake and they are presented in Table 3 and Figure 6.

Table 3 – Pressure variation under raft for longitudinal frame

	s_1 (kN/sqm)	s_2 (kN/sqm)	Remarks
SCM	+12.67	-12.67	Triangular Pressure
RSM	± 5.00	± 5.00	Uniform rectangular pressure

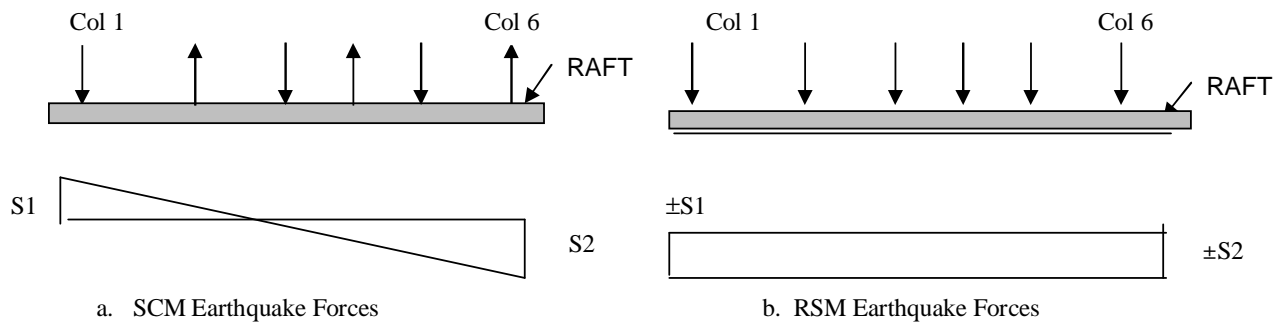
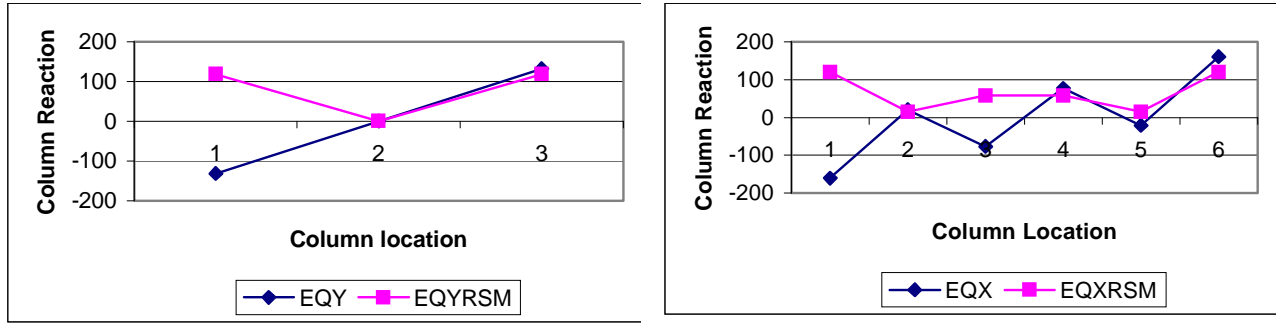


Figure 6 Schematic Pressure Diagram below Raft

Figure 7 shows the graphical presentation of column reactions due to codal co-efficient method and response spectrum method in transverse and longitudinal direction.



a. Transverse Frame

b. Longitudinal frame

Figure-7 Plot showing column reactions

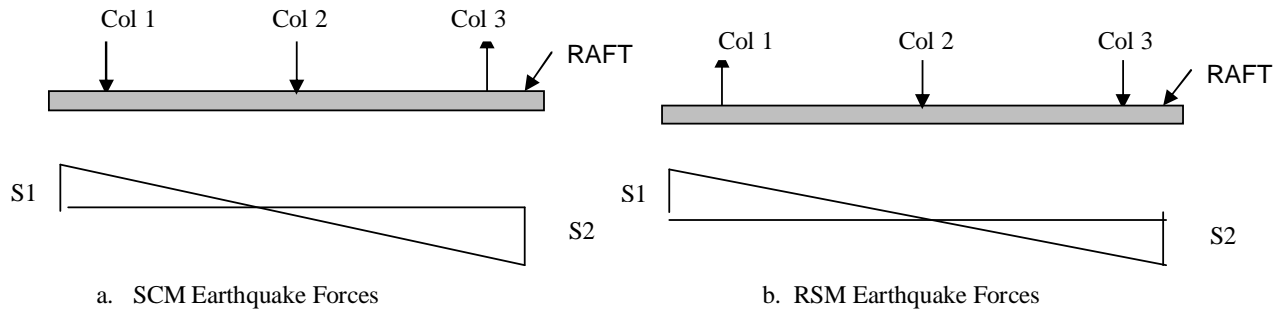
It can be seen that the center of gravity of the pressure changes when response spectrum results are used without any sign. This may lead to change in pressure distribution under the raft when combined with other load cases.

Modified Response Spectrum forces

As the signs of forces in response spectrum method are lost, as an alternative the signs of seismic coefficient method can be attached to the response spectrum results and the analysis can be performed. To study this effect few models are analyzed with the same and the variation in the pressure under raft can be observed from the graphs. The results are shown in Table- 4 and Figure 8.

Table 4 – Pressure variation under raft in transverse direction

	s1 (kN/sqm)	s2 (kN/sqm)	Remarks
SCM	+19.80	-19.80	Triangular Pressure
RSM	+17.90	-17.90	Uniform rectangular pressure



a. SCM Earthquake Forces

b. RSM Earthquake Forces

Figure 8 Schematic Pressure Diagram below Raft with modified Response spectrum forces

Similar results for the maximum and minimum values of pressure distribution at the corners of raft are obtained for longitudinal direction earthquake and the results are shown in Table- 5 and Figure 9.

Table 5 – Pressure variation under raft in longitudinal direction

	s1 (kN/sqm)	s2 (kN/sqm)	Remarks
SCM	19.80	19.80	Triangular Pressure
RSM	±6.00	±6.00	Uniform rectangular pressure

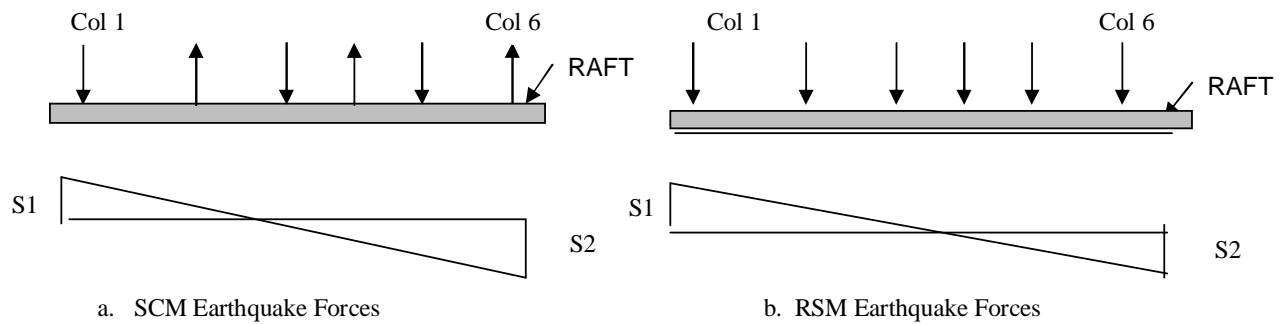


Figure 9 Schematic Pressure Diagram below Raft with modified Response spectrum forces

Flexible Raft

The raft is modeled as plate elements supported by springs as per Winkler Hypothesis[2]. The raft foundation considered here is main beams between the column as raft slab spanning between these beams. Modulus of subgrade reaction assumed as 10,000 kN/cum for the soft soils. The modulus of subgrade is assumed in such a way that the dynamic properties (i.e. frequency of predominant mode) is same with as compared with the fixed base mathematical model. The mathematical model is shown in figure 10. The pressure diagram below raft along the transverse frame and longitudinal frame is shown in Figure 11 and 12.

The analysis is performed with the seismic forces obtained using codal co-efficient method (EQX, EQY), Response spectrum method (RSMEQX, RSMEQY) in transverse and longitudinal direction. The pressure diagram obtained with these four cases is compared with statically applying column reactions on the raft at the location of the columns. These cases are presented as PREQX, PRRSMEQX, PREQY and PRRSMEQY for codal co-efficient forces and Response spectrum forces in transverse and longitudinal direction.

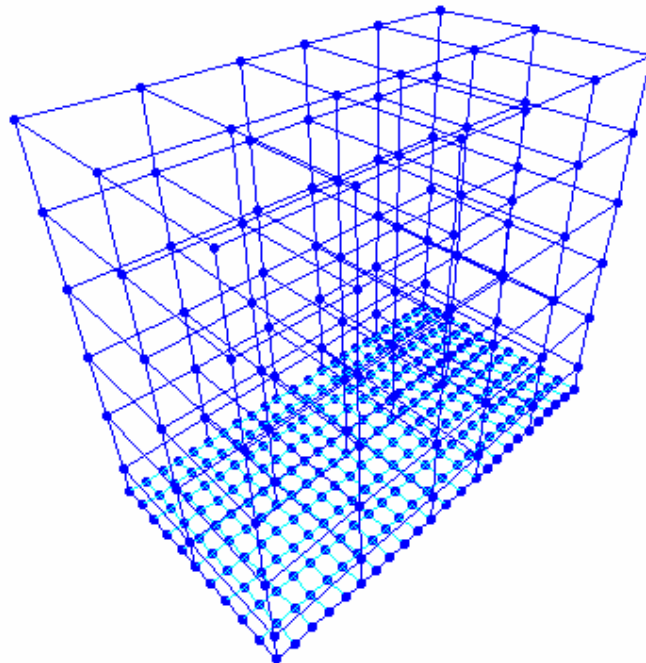


Figure 10 Mathematical model with raft modeled

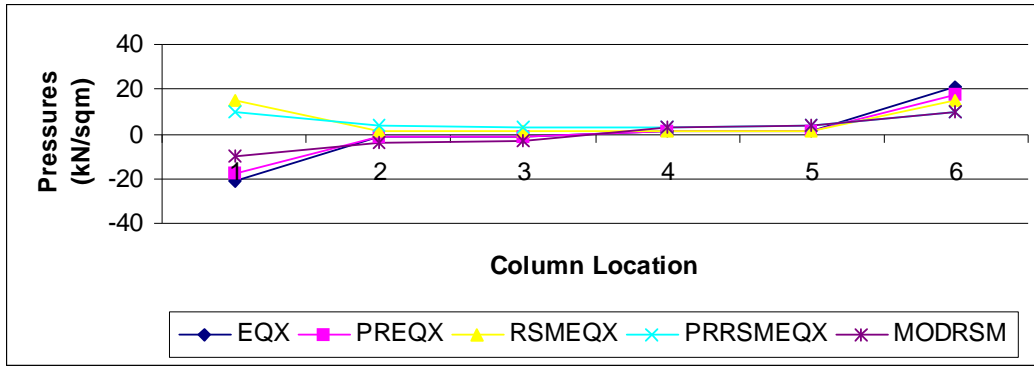


Figure 11 Pressure distributions along transverse direction

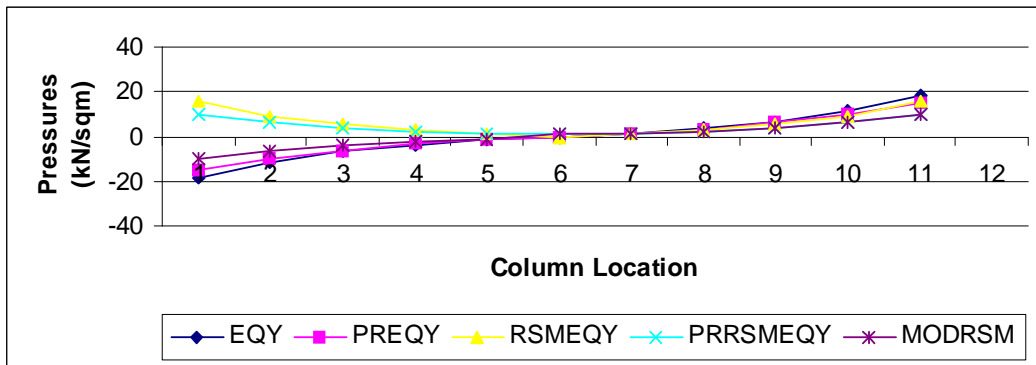


Figure 12 Pressure distribution along longitudinal direction

It can be seen that if the response spectrum forces are used with the sign attached with the codal co-efficient results, the pressure diagram represents proper distribution as expected with lateral forces.

CONCLUSIONS

It is important to note that the Response Spectrum results are always positive, and that the correspondence between different values has been lost. It can be seen that the center of gravity of the pressure changes when response spectrum results are used without any sign. This may lead to change in pressure distribution under the raft when combined with other load cases. This problem can be overcome by attaching the sign of the codal co-efficient results to response spectrum forces. This also may help in performing nonlinear analysis in combination with gravity forces.

REFERENCES

1. IS 1893 (2002). *Criteria for Earthquake Resistant Design of Structures*, Part I, Bureau of Indian Standards, New Delhi.
2. Bowles J. E. (1997). *Foundation analysis and design*, McGraw-Hill International Companies. Inc.