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Dynamic Analysis of Building with Plan Irregularity

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Abstract *IS 1893 (part1):2002 describes various types of irregularities in building as per clause 7.1 and suggests Dynamic analysis by Time History Method (THA)or Response Spectrum Method (RSA) for irregular buildings. Equivalent Static Analysis (ESA) based on empirical time period is suggested for Regular building. From previous research it is seen that behaviour of irregular building during earthquake is more vulnerable. In irregular building excessive stresses or forces may develop in particular portion of the structure which may cause severe damage during earthquake. It is necessary to identify the performance of such building during earthquake and design it for better performance. This paper is focused on irregularity in plan due to Re-entrant corner. Buildings with large projections of Re-entrant corners results in torsion.*

1. INTRODUCTION

Plan irregularity is due to asymmetric distributions of mass, stiffness, strength, geometric discontinuity and diaphragm discontinuity. Sometimes the buildings may be regular initially, but in future as per requirement many changes has been done which makes the buildings Irregular. So the Irregularity may increases as the life of structure. This in future may subject to devastating earthquakes. The behavior of a building during an earthquake depends on several factors, stiffness, adequate lateral strength, ductility, simple and regular configurations. The buildings with regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation suffer much lessdamage compared to irregular configurations. But nowadays need and demand of the latest generation and growing population has made the architects or engineers inevitable towards planning of irregular configurations.If building is irregular, then excessive stresses or forces get developed in certain portion and they cause serious damages. It is necessary to identify the performance of the structures to withstand against disaster for both new and existing one.

Amongst all natural calamities, earthquake is non-predictable, and quite devastative in terms of loss of property and life. India has active fault boundary of Eurasian and Austrian plate in north-east part (ie, Himalayan region). Along this plate boundary, India has seen some of the biggest earthquake in the pastBihar-Nepal (8.4, 1934), Kangra (8.6, 1905), Assam (8.5, 1950), Bhuj (7.7, 2001) etc. and the latest one Nepal(7.9, 2015).Indian standard (IS 1893) is suggested for earthquake resistant design of structure. In its fifth revision, IS 1893(part 1):2002, suggests three methods of analysis, namely Equivalent Static Analysis, Response Spectrum Analysis and Time History Analysis. Out of these, ESA is to be used for regular buildings of height less than 40 m in zone IV and zone V and less than 90m in zone II and III. For irregular buildings ESA is suggested for height less than 12m in zone IV and zone V and less than 40m in zone II and III. RSA and THA are used for irregular buildings with height greater than 12 m in zone IV and V and those greater than 40m in zone II and III.IS 1893(part 1):2002, has given detailed description of types of irregularity in buildings in clause 7.1.

In the present paper, building with re-entrant corner, which is a plan irregularity is considered.Aim of this study is to quantify the seismic response irregular building and effect of large extent of re-entrant corner in building.For the analysis purpose six models of G+12 storied building plans are selected. One is regular other five are irregular with different projection of re-entrant corner.All the building models are analyzed using ESA, RSA and THA and their results are compared.

2. DETAILS OF MODEL

The buildings considered are Reinforced concrete building of G+12 storeys with Plan irregularity due to Re-entrant corner as per IS 1893. Plan of five models, Model-R, Model-L1, Model-L2, Model-L3, Model-L4, Model-L5, are shown in Figure 1and elevation of all the models is same and shown in Figure 2. All the columns are of size 0.75m x 0.75m, beam size is 0.45m x 0.5m, 0.23m thick external and 0.15m thick internal infill wall is provided. Grade of concrete is M30, Soil type is considered as medium soil, seismic zone 5 and damping is 5%. Floor live load is 3KN/m^2 and roof live load is 1KN/m^2. Floor to floor height is 3.1m. Height of all building models is 40.3 m.

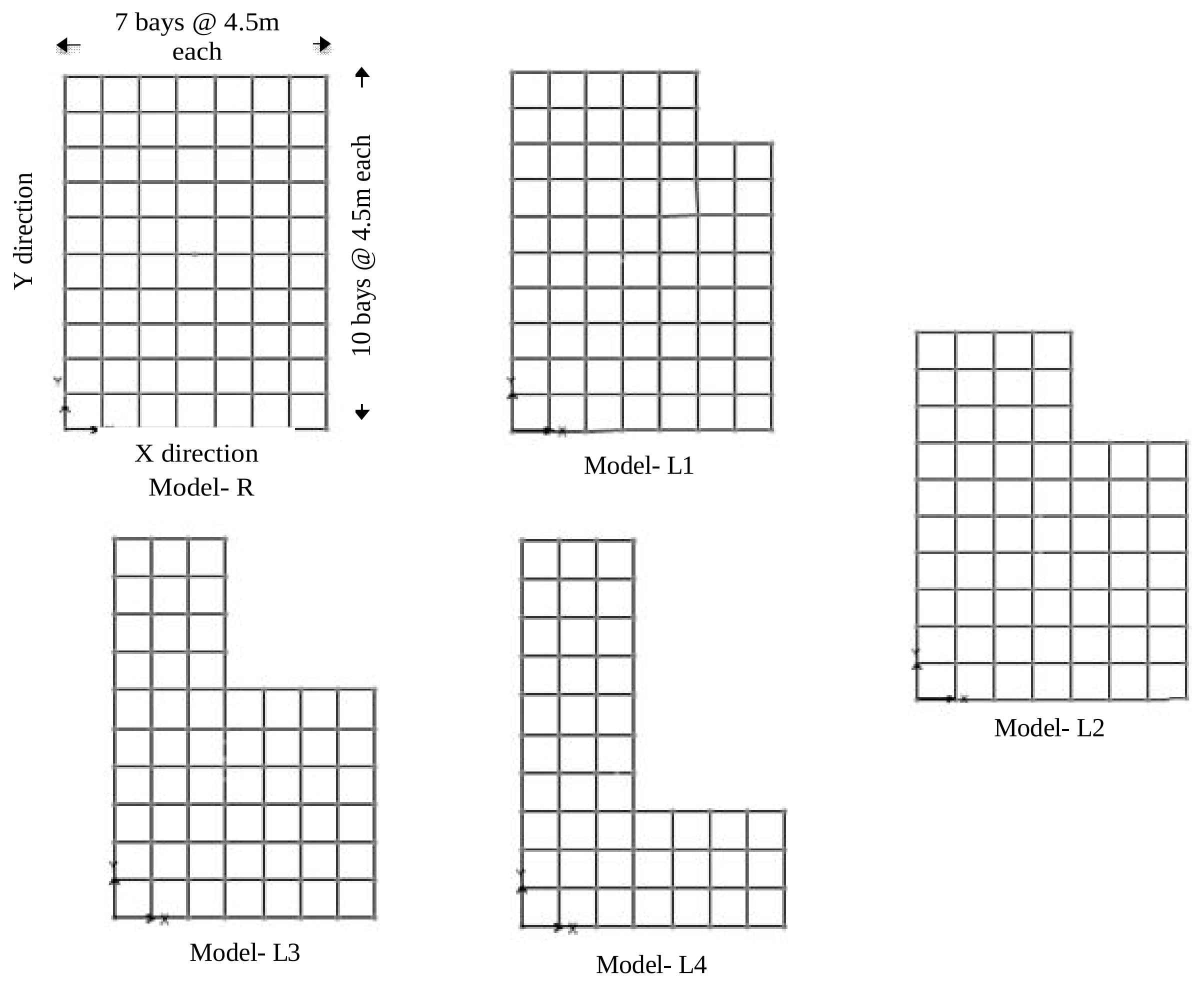


Figure 1. Plan of the building models

The plan configuration consist of
Model R: – Building in rectangularshape.
Model L1:– Re-entrant corner in L shape.Both projections provided are 28.57% & 20% in X-direction and Y-direction respectively.
Model L2:– Re-entrant corner in L shape.Both projections provided are 42.8% & 32% in X-direction and Y-direction respectively.
Model L3:– Re-entrant corner in L shape.Both projections provided are 57% & 40% in X-direction and Y-direction respectively.
Model L4:– Re-entrant corner in L shape.Both projections provided are 57% & 50% in

X-direction and Y-direction respectively.
Model L5:– Re-entrant corner in L shape.Both projections provided are 57% & 70% in X-direction and Y-direction respectively.

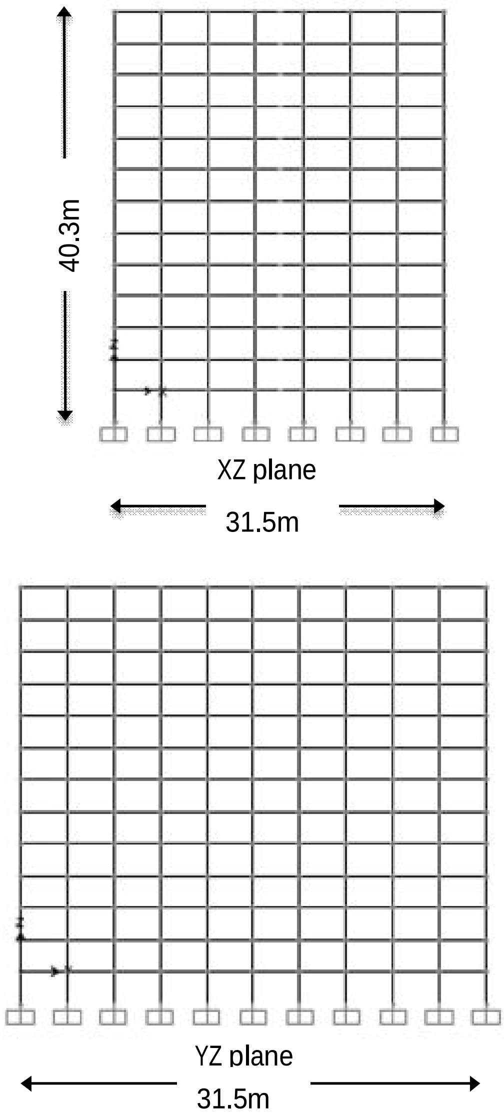


Figure2. Elevation of the building model

3. ANALYSIS DETAILS

3.1. Equivalent Static Method (ESA)

Equivalent Static Analysis (ESA) is linear static analysis. In this method a three dimensional structure or building is converted into an equivalent lumped mass system with springs connected with them. The stiffness of the springs is equal to summation of the stiffness of columns of the framed system at that level. ESA is performed as per IS 1893 (part 1):2002 and empirical formulas are given in Code. The approximate time period is obtained by,

$$T_a = \frac{0.09\,h}{\sqrt{d}} \qquad (1)$$

Where h = Height of building in m,
d= Base dimension of the building at the plinth level in m, along the considered direction of the lateral force.
Design Horizontal Seismic Coefficient, A_h

$$A_h = \frac{Z}{2} \cdot \frac{I}{R} \cdot (S_a/g) \quad (2)$$

Design Base shear is given by

$$\bar{V}B = A_h . W (3)$$

Distribution of Base Shear along height of building is given by,

$$Q_i = \bar{V}B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2} \qquad (4)$$

Where, Z= Zone factor, I= Important factor and R=Response reduction factor. For the present analysis Z=0.36, I=1, R=5.0. The analysis is performed in X and Y-direction. The results of approximate time period, T_a and base shear $\bar{V}B$ are shown in Table-1 and Table-2

Table-1: ESA Approximate Time Period

Models	Tax (sec)	Tay (sec)
R	0.646	0.54
L1	0.646	0.54
L2	0.646	0.54
L3	0.646	0.54
L4	0.646	0.54
L5	0.646	0.54

Table-2: ESA Approximate Time Period

Models	Tax (sec)	Tay (sec)
R	0.646	0.54
L1	0.646	0.54
L2	0.646	0.54
L3	0.646	0.54
L4	0.646	0.54
L5	0.646	0.54

Table-2: ESA Approximate Base Shear

Base Shear $\bar{V}_B$ (in kN)		
Model	ESAX	ESAY
	$\bar{V}$Bx	$\bar{V}$By
R	19563	23240
L1	18571	22061
L2	17330	20587
L3	15594	18524
L4	14601	17345
L5	14211	16882

Table-2: ESA Approximate Time Period

Models	Tax (sec)	Tay (sec)
R	0.646	0.54
L1	0.646	0.54
L2	0.646	0.54
L3	0.646	0.54
L4	0.646	0.54
L5	0.646	0.54

For ESA the base shear calculated as shown in Table-2. Is distributed along the height of building by using Eq.(4) and applied to each floor level at the Centre of rigidity (CR) for regular building model-R1 and at design eccentricity (e_{di}) for irregular building models like L1, L2 L3, L4 and L5. According to clause 7.9.2 of IS 1893 it gives two design eccentricity positive and negative. ESA is applied at both eccentricity in both X and Y direction naming as ESAX1, ESAX2, ESAY1, ESAY2 etc. Deflection of each floor at CR and forces in the column due to ESA is note down. The Deflection of top floor for ESA is given in Table-6.Comparison of forces in column are given in Table-7 to Table-11.

Table-3: Base shear by RSA

Base Shear V_B (in kN)								
	RSAX (SRSS		RSAY (SRSS)		RSAX (CQC)		RSAY (CQC)	
Model	Fx	Fy	Fx	Fy	Fx	Fy	Fx	Fy
R	8813	0	0	8995	8848	0	0	9030
L1	8339	369	369	8531	8391	82	82	8577
L2	7690	162	162	7906	7801	75	75	8003
L3	6567	767	767	6819	6929	136	136	7183
L4	5840	1317	1317	6063	6421	223	223	6702
L5	4440	2062	2062	4619	5412	441	441	5714

3.2. Response Spectrum Analysis (RSA)

Response Spectrum Analysis (RSA) is linear Dynamic Method. RSA is followed by the Free Vibration (un-damped) analysis of structure by using methods of structural dynamics. Free Vibration analysis gives fundamental time periods and the mode shape coefficients of the structure. The time period of the structure gives the spectral acceleration coefficient, S_a/g from Response Spectra given in IS 1893 (Part 1): 2002. Design horizontal seismic coefficient, A_h is calculated from Eq. (2) for all modes.

Thereafter the modal mass, M_k for the mode k is calculated as,

$$M_k = \frac{\left[\sum_{i=1}^{n} W_i \Phi_{ik}\right]^2}{g \sum_{i=1}^{n} W_i (\Phi_{ik})^2} \quad (5)$$

Then, the modal participation factor, P_k is calculated as,

$$P_k = \frac{\left[\sum_{i=1}^{n} W_i \Phi_{ik}\right]}{\sum_{i=1}^{n} W_i (\Phi_{ik})^2} \quad (6)$$

The Design lateral force at each floor in each mode is given by,

$$Q_{ik} = A_k \Phi_{ik} P_k W_i \quad (7)$$

The peak shear force acting on the storey i in the particular mode k is given by

$$V_{ik} = \sum_{j=i+1}^{n} Q_{ik} (8)$$

In this manner the lateral forces for all the storeys are determined in all the modes of the building.

Thereafter they are combined by using Modal combination rules toobtain the final results considering all the modes. IS 1893 (Part1): 2002 suggest three techniques of modal combination namely Complete Quadratic Combination method (CQC), Square Root of Sum of Squares (SRSS) and Absolute Sum Method (ABS). In this paper SRSS and CQC is used.

The RSA is performed with SAP2000 for all six building models by using 12 modes of vibration from free vibration analysis (i.e. modal analysis). The Design Spectrum [*Clause 6.4.2*] as per IS 1893 (Part1): 2002 is used. Medium soil condition is considered.

The result of base shear by RSA as shown in Table-3. Comparison of time period by modal analysis in SAP is given in Table-4. Comparison of deflection of top floor nodes is given in Table-6. Andthe results of forces in the columns at base level i.e. ground level are given in Table-7 to Table-11

3.3. Time History Analysis (THA)

THAis linear dynamic method. It is an analysis of dynamic response of the structure at each increments of time, when its base is subjected to a specific ground motion time history. It is assumed that time history analysis defines structure behavior ideally because of the seismic loads directly applied to structure [8]. Recorded ground acceleration Time history of El-Centro earthquake is used (Fig.4).the peak ground acceleration is 0.35g which is quite close to Z=0.36 of IS 1893(part 1):2002, zone V. A typical response timehistory of displacement at top floor displacement isshown in Figure 4 & 5. Results are maximum value of forcesdue to THA in column at the base are shown in Table-7 to Table-11

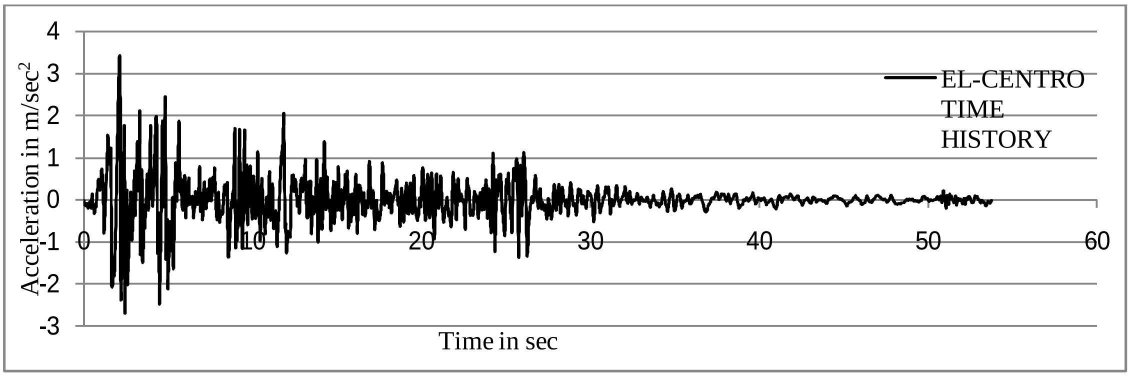


Figure 3. Time History of El-Centro Earthquake

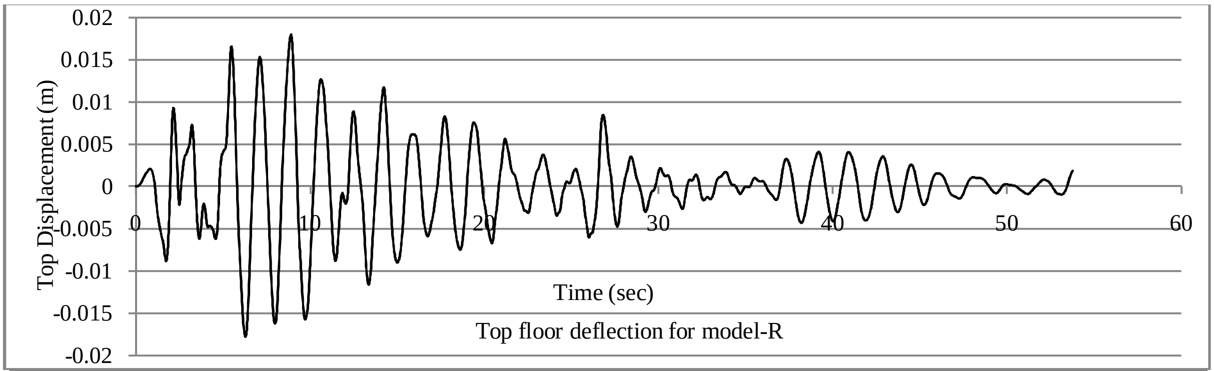
Table-6: Top floor displacement (in mm) at CR

Models	ESAX1		ESAX2		RSAX		THAX	
	Ux (mm)	Uy(mm)	Ux (mm)	Uy(mm)	Ux (mm)	Uy(mm)	Ux (mm)	Uy(mm)
R	77.79	0.00	-	-	28.13	0.00	18.86	0.00
L1	77.9	0.2	78.1	0.1	28.10	1.30	18.90	0.10
L2	78.10	0.30	78.50	0.08	27.90	0.60	18.90	0.20
L3	78.39	0.34	79.36	-0.01	26.81	2.98	18.90	0.23
L4	78.69	0.41	79.87	-0.11	25.68	5.49	18.85	0.44
L5	79.60	0.53	81.00	-0.44	23.00	10.05	18.64	1.12
Models	ESAY1		ESAY2		RSAY		THAY	
	Ux (mm)	Uy(mm)	Ux (mm)	Uy(mm)	Ux (mm)	Uy(mm)	Ux (mm)	Uy(mm)
R	0.00	88.29	-	-	0.00	27.51	0.00	17.92
L1	0.3	88.3	0.1	88.3	1.20	27.50	0.10	17.90
L2	0.40	88.20	0.00	88.40	0.60	27.30	0.10	17.90
L3	0.56	88.21	-0.22	88.49	2.89	26.19	0.22	17.91
L4	0.62	88.18	-0.33	88.61	5.37	24.91	0.43	17.88
L5	0.67	88.15	-0.51	88.96	9.93	22.03	1.11	17.75

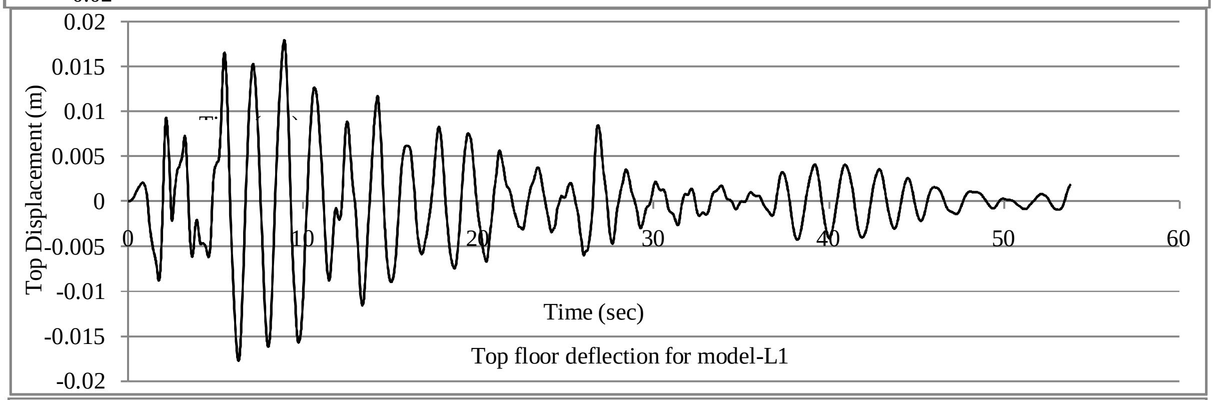
Table-5: Base Shear by THA

Base Shear VB(in kN)				
Model	THAX		THAY	
	Fx	Fy	Fx	Fy

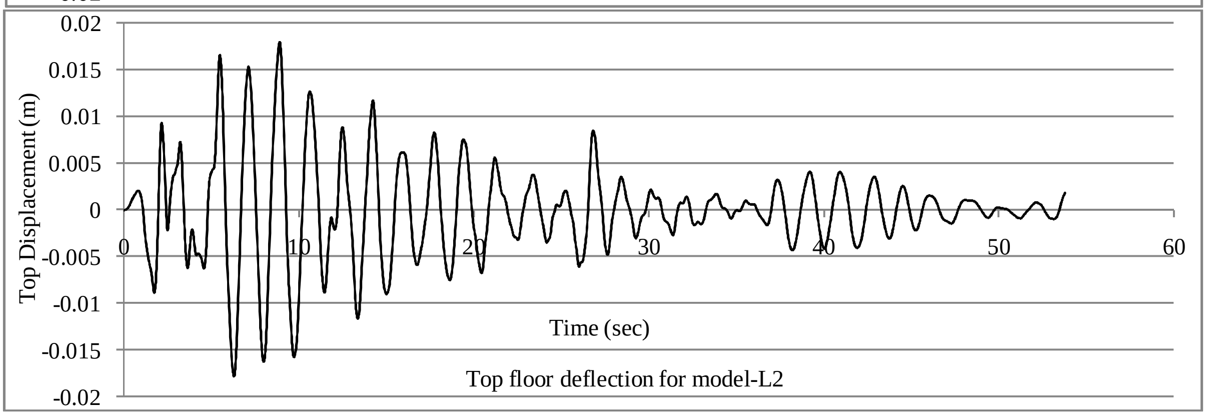
R	5578	0	0	5641
L1	5290	45	45	5276
L2	4929	44	42	5002
L3	4414	61	60	4504
L4	4143	106	102	4219
L5	3593	221	214	3644



Top floor deflection for model-R



Top floor deflection for model-L1



Top floor deflection for model-L2

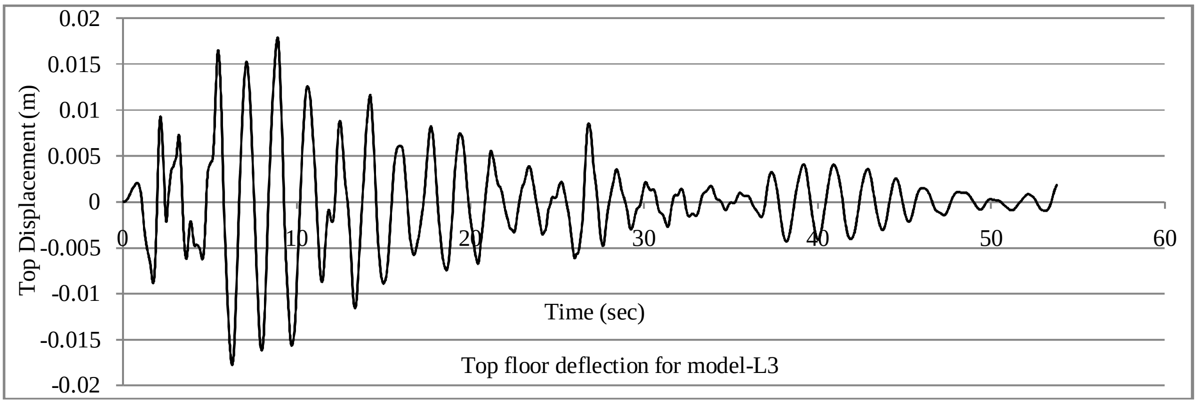
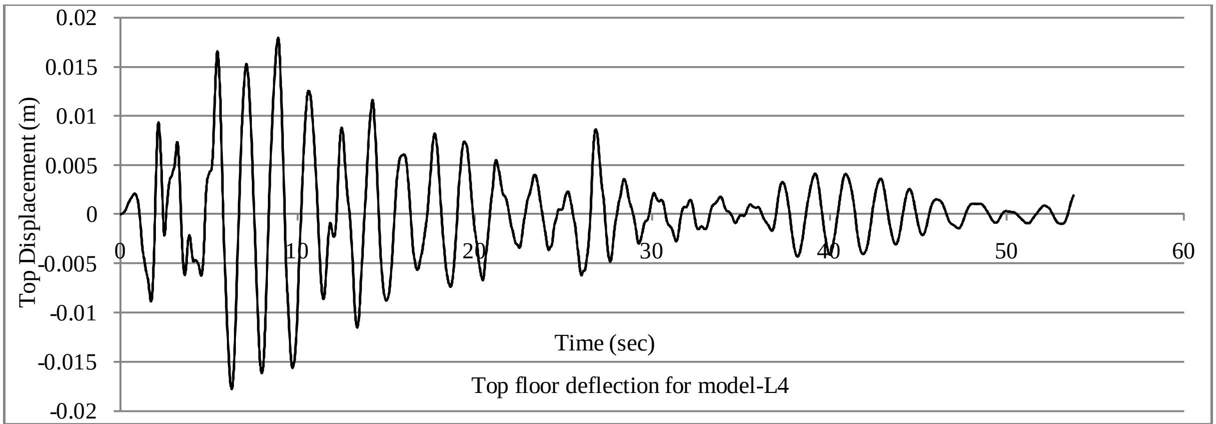


Figure 4.Top floor Displacement by Time History Analysis



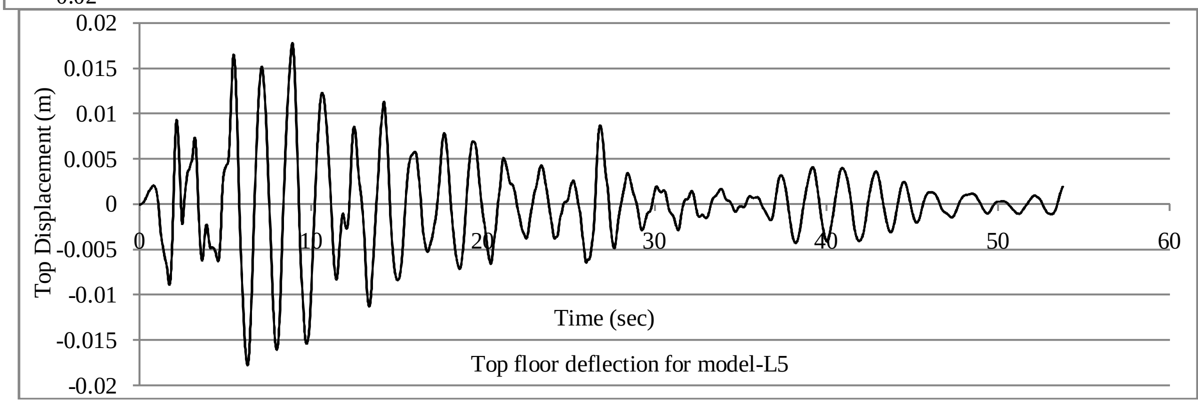


Figure 5.Top floor Displacement by Time History Analysis

For comparison of forces increase in column due to earthquake loading some columns at the Ground level are selected. Result in terms of Axial force (P), Moment (M2 & M3) and Shear force (V2 & V3) for one middle column which is present in all building models are shown in Table-7 to Table-11.

Table-7. Comparison of Axial Forces in column

Axial Force, P (kN)						
Case	R	L1	L2	L3	L4	L5
ESAX1	2	2	1	10	125	1441
ESAX2	-	2	1	10	133	1564
RSAX	1	1	1	3	42	477
THAX	1	1	0	3	32	355

ESAY1	0	0	1	33	147	41
ESAY2	-	0	1	33	140	63
RSAY	0	0	0	10	45	141
THAY	0	0	0	8	31	21

Table-8. Comparison of Moment in column

Moment, M2 (kN-m)						
Case	R	L1	L2	L3	L4	L5
ESAX1	0	8	5	1	2	11
ESAX2	-	9	5	1	5	15
RSAX	0	15	9	34	63	118
THAX	0	2	3	3	5	13
ESAY1	842	847	840	831	824	808
ESAY2	-	832	832	830	830	830
RSAY	322	320	315	301	287	257
THAY	203	203	202	201	200	197

Table-9.Comparison of Moment in column

Moment, M3 (kN-m)						
Case	R	L1	L2	L3	L4	L5
ESAX1	724	717	708	696	691	648
ESAX2	-	728	734	741	743	697
RSAX	322	321	320	314	305	259
THAX	204	204	203	203	203	192
ESAY1	0	5	11	17	18	19
ESAY2	-	4	10	20	24	22
RSAY	0	15	8	18	39	80
THAY	0	2	1	2	5	10

4. CONCLUSIONS

ESA gives same time period for all regular and irregular building.While dynamic analysis gives different time period for regular and irregular buildings.ESA gives different values of Base shear for all regular and irregular building. Base shear decreases from Model R to L5.

RSA gives different and less value of base shear than ESA.THA gives lesser value of Base shear than RSA. For ESA and RSA base shear value in Y-direction is more than X-direction but it is not necessary for THA.

For Irregular models, x-directional RSA and THA gives Base shear value in y direction; this is due to coupling of modes. It is seen that as projection of Re-entrant corner increases (for L1 to L5) the more coupling of modes occurs. RSA using modal combination SRSS gives more coupling of modes while CQC give less coupling. Result of forces in column (common in all building) shows that the variation of P much higher (from L1 to L5).

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