Seismic Analysis of Building with Mass and Vertical Geometric Irregularity by Response Spectrum and Seismic Coefficient Method in Zone V and III

Chetan Raj[1], Vivek Verma[2], Bhupinder Singh[3], Abhishek Gupta[4]
[1]M.Tech Student, Deptt. of Civil Engg., IGCE, Abhipur, Mohali,Indi
[2]Assistant Professor, Deptt. of Civil Engg., IGCE, Abhipur, Mohali,India
[3]Assistant Assistant Professor, Deptt. of Civil Engg., IGCE, Abhipur, Mohali,India
[4]Assistant Professor, Deptt. of Civil Engg., Baddi university , Baddi , India

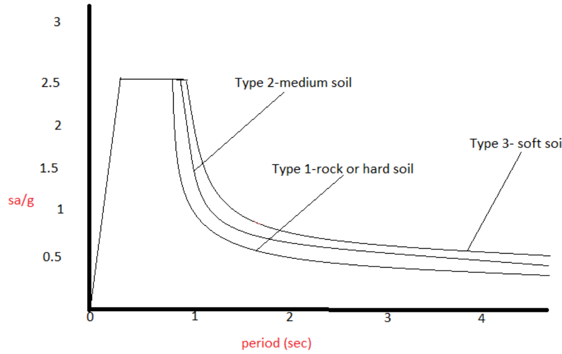
Abstract- Since the evolution of the earth, Earthquakes have caused great disasters in the form of destruction of property, injury and loss of life to the population. The effective design and construction of earthquake resistant structures has much greater importance in this country due to rapid industrial development and concentration of population in cities. In the present study the earthquake analysis of building with mass and vertical geometric irregularity is done by the response spectrum and seismic coefficient method , where natural frequencies , period , base shear , lateral forces are calculated by STAAD-PRO software as well as manually by seismic coefficient method. Also the modal combination rule for the response spectrum analysis is CQC as per the code IS 1893:2002. The methods include seismic coefficient method (by empirical formula) and modal analysis using response spectrum method of IS Code in which the stiffness matrix of the building corresponding to the dynamic degrees of freedom is generated by considering the building as shear building. The responses obtained by above methods are considered for extreme zones as mentioned in IS code i.e. zone V and zone III . Test results including base shear, storey shear, node displacements, lateral forces are presented to get effective lateral load resisting system.

Keywords : base shear , response spectra , modal combination , seismic coefficient.

I. INTRODUCTION

Earthquakes caused by the movement under the earth surface result in different levels of ground shaking leading to damage and collapse of buildings and civil infra structures. A large portion of India is susceptible to damaging levels of seismic hazards. Hence, it is necessary to take into account the seismic load for the design of high rise structure. In tall building the lateral loads due to earthquake are a matter of concern, these lateral forces can produce critical stresses in structure induce undesirable stresses and vibrations in the structure , or cause excessive lateral sway of the structure. Seismic design approaches are stated , as the structure should be able to ensure the minor and frequent shaking intensity without sustaining any damage , thus leaving the structure serviceable after the event. The energy released due to earthquake as seismic wave is propagated from the epicenter to the earth surface. This seismic wave causes the ground shaking which in turn causes severe damages to the structure overlying on the surface.

In the present study a 14 story building with height 40.5 is considered to analyze the behavior of RC irregular type frame of building constructed in the areas prone to earthquake such as north east regions (zone v) and zone III . A structure can be classified as irregular if it contains irregular distributions of mass, stiffness and strength or due to irregular geometrical configurations. Different codes prescribe different limits for these irregularities like as per IS 1893:2002, a storey in a building is said to contain mass irregularity if its mass exceeds 200% than that of the adjacent storey. In reality, many existing buildings contain irregularity due to functional and aesthetic requirements. However, past earthquake records show the poor seismic performance of these structures and This is due to ignorance of the irregularity aspect in formulating the seismic design methodologies by the seismic codes .This Building was analyzed in accordance with seismic provisions proposed by I.S CODE – 1893 :2002 to investigate the performance of buildings if exposed to seismic loads, also IS 456:2000 is used for designing purposes. Test results including base shear, storey shear, node displacements, lateral loads are presented to get effective lateral load resisting system.



II. Objective Of Studies

[1] To analyze the building as per code IS 1893-2002 part I criteria for earthquake resistant structure.
[2] Dynamic analysis of the building using response spectrum and seismic coefficient method.
[3] Building irregular frame with is code specification and study different lateral stiffness systems .
[4] To get economical and efficient lateral stiffness system

III. METHODOLOGY

Procedures are followed as per Indian standard code has instructed for seismic analysis

The codal provisions as per IS:1893-2002 (PART1) for response spectrum analysis of multi-story building is also summarized: As per IS 1893 (part1)-2002, Dynamic analysis shall be performed to obtain the design seismic force, and its distribution to different levels along the height of the building and to the various lateral load resisting elements, for the following buildings: a) **Regular buildings** -Those greater than 40 m in height in Zones IV and V, and those greater than 90 m in height in Zones II and III.

b) **Irregular buildings** - All framed buildings higher than 12 m in Zones IV and V, and those greater than 40 m in height in Zones II and III.

Dynamic analysis may be performed by The Response Spectrum Method. Procedure is summarized in following steps .

a) Modal mass (M_k) – Modal mass of the structure subjected to horizontal or vertical as the case may be, ground motion is a par of the total seismic mass of the Structure that is effective in mode k of vibration. The modal mass for a given mode has a unique value, irrespective of scaling of the mode shape.

$$M_k = \frac{\left[\sum w_i \ \phi_{ik}\right]^2}{g \sum w_i \ \phi_{ik}^2}$$

Where

g = acceleration due to gravity

ϕ_{ik} = mode shape coefficient at floor i in mode k

b) Modal Participation factor (Pk) – Modal participation factor of mode k of vibration is the amount by which mode k contributes to the overall vibration of the structure under horizontal or vertical earthquake ground motions. Since the amplitudes of 95 percent mode shape can be scaled arbitrarily, the value of this factor depends on the scaling used for the mode shape.

$$P_k = \frac{\sum w_i \ \phi_{ik}}{\sum w_i \ \phi_{ik}^2}$$

c) Design lateral force at each floor in each mode – The peak lateral force (Q_{ik}) at floor i in Mode k is given by

$Q_{ik} = Ah_k \ \phi_{ik} \ P_k \ W_i$

Where,

Ah_k = Design horizontal spectrum value using natural period of vibration (T_k) of mode k.

$= Z \ I \ Sa/2 \ R \ g$

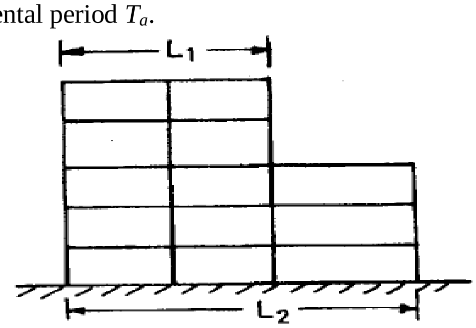
Z= zone factor for the maximum considered earthquake ,
I= Importance factor depending upon the functional use of the structures, R= Response Reduction factor Sa/g= Average response acceleration coefficient for rock or soil sites as given by response spectra and based on appropriate natural periods and damping of the structure.

d) Storey shear forces in each mode – The peak shear force (V_{ik}) acting in storey i in mode k is given by

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

e) Storey shear force due to all modes considered : The peak storey shear force (V_i) in storey i due to all modes considered is obtained by combining those due to each mode as per SRSS. If the building does not have closely spaced modes, than the peak response quantity due to all modes considered shall be obtained as per Square Root of Sum of Square method

Dynamic analysis may be performed either by time history method or by the response spectrum method. However in either method, the design base shear *VB* shall be compared with a base shear (V_b) calculated using a fundamental period T_a.



When V_B is less than all the response quantities shall be multiplied by V_b/V_B.

SEISMIC COEFFICIENT ANALYSIS OF BUILDINGS USING IS 1893 (PART 1)-2002

As per IS 1893 (part1)-2002, Seismic Coefficient analysis Procedure is summarized in following steps

a) Design Seismic Base Shear- The total design lateral force or design seismic base shear (V_b) along any principal direction of the building shall be determined by the following expression

($V_B = Ah * W$)   Where, *Ah* = Design horizontal seismic coefficient

W = Seismic weight of the whole building.

b) Seismic Weight of Building- The seismic weight of each floor is its full dead load plus appropriate amount of imposed load as specified. While computing the seismic weight of each floor, the weight of columns and walls in any storey shall be equally distributed to the floors above and below the storey. The seismic weight of the whole building is the sum of the seismic weights of all the floors. Any weight supported in between the storey shall be distributed to the floors above and below in inverse proportion to its distance from the floors.

c) Fundamental Natural Time Period- The fundamental natural time period (T_a) calculates from the expression

$T_a = 0.075h$^0.75 for RC frame building

$T_a = 0.085h$^0.75 for steel frame building

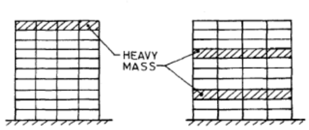
If there is brick filling, then the fundamental natural period of vibration, may be taken as

T_a = 0.09H/SQ.ROOT OF d

d) Distribution of Design Force- The design base shear, *VB* computed above shall be distributed along the height of the building as per the following expression.

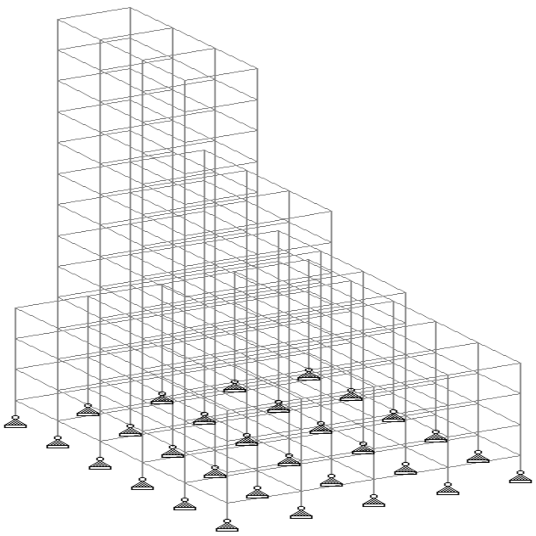
$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2}$$

IRREGULARITY PROVISIONS IN CODE:

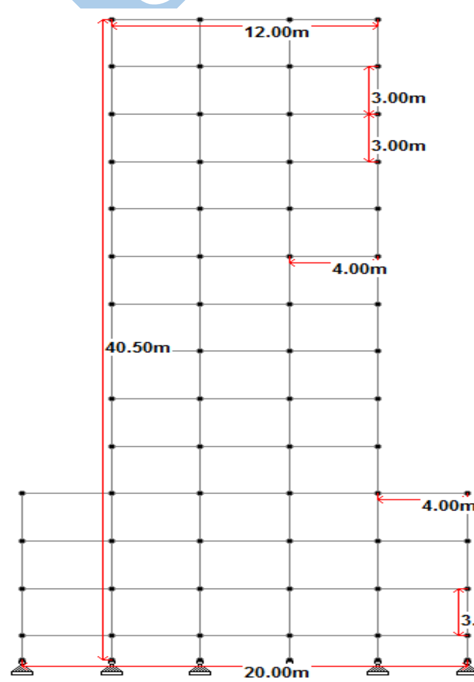


Vertical geometric irregularity   mass iregularity

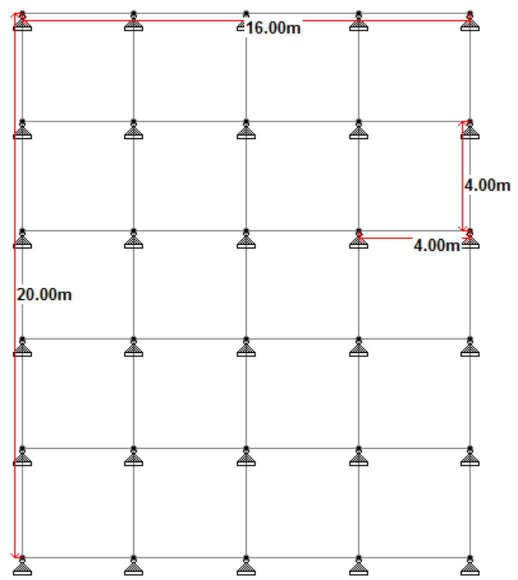
Here (L2) must be greater then (1.5 L1) , whereas a storey in a building is said to contain mass irregularity if its mass exceeds 200% than the adjacent storey .The irregular type building is shown in Figures below. The seismic analysis of buildings are done by Seismic Coefficient and response spectrum methods with given above procedures for zone V and zone III. The obtained results of both methods are compared with each other.



Isometric view



elevation



plan of building is show in building yet the building is of vertical geometric irregularity therefore, the size of floors may vary at different levels.

3.1 Response Spectrum Method The response spectrum represents an envelope of upper bound responses, based on several different ground motion records. For the purpose of seismic analysis, the design spectrum given in figure 1 of IS: 1893 (Part 1): 2002 is used. This spectrum is based on strong motion records of eight Indian earthquakes. This method is an elastic dynamic analysis approach that relies on the assumption that dynamic response of the structure may be found by considering the independent response of each natural mode of vibration and then combining the response of each in same way. This is advantageous in the fact that generally only few of the lowest modes of vibration have significance while calculating moments, shear and deflections at different levels of the building.

IV. ANYLYSIS OF BUILDING BY RESPONSE SPECTRUM METHOD USING STAAD PRO

This is accurate method of analysis. The design lateral force at each floor in each mode is computed by STAAD Pro : The software provides results for design values, modal masses and storey base shear.

STAAD utilizes the following procedure to generate the lateral seismic loads: [1]
Program calculates time periods for first six modes or as specified by the user. [2]
Program calculates Sa/g for each mode utilizing time period and damping for each mode.
[3] The program calculates design horizontal acceleration spectrum A_k for different modes.
[4] The program then calculates mode participation factor for different modes.
[5] The peak lateral seismic force at each floor in each mode is calculated.
[6] All response quantities for each mode are calculated. [7]
The peak response quantities are then combined as per method (CQC or SRSS or ABS or TEN or CSM) as defined by the user to get the final results.

LOAD COMBINATION AS PER IS CODE 1893: 2002

1) 1.5(DL+lL)
2) 1.2(DL+LL+EL) , 1.2 (DL+LL-EL)
3) 1.5(DL+EL) , 1.5 (DL-EL)
4) 0.9DL+ 1.5EL , 0.9DL-1.5EL

WHERE ; DL=dead load , LL=live load , EL= earthquake load.

V. RESULTS AND GRAPHS:

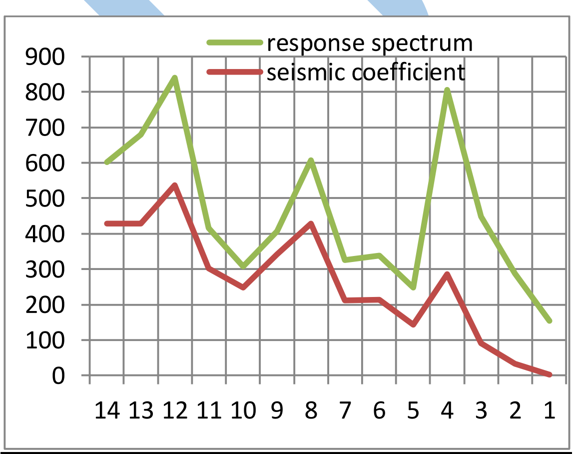
Natural frequencies , periods with reference to their modes of building has been shown below in the TABLE 1.

Modes	Natural frequency	Period (sec)
1	0.603	1.658
2	0.614	1.628
3	0.918	1.089
4	1.230	0.813
5	1.329	0.752
6	1.524	0.656
7	2.067	0.483
8	2.144	0.466
9	2.364	0.422
10	2.951	0.338
11	3.379	0.295
12	3.794	0.263
13	3.815	0.262
14	3.940	0.253

Table 2 showing Comparison between lateral forces and storey shear by response spectrum method and seismic coefficient method in ZONE V BUILDING:

STORY NUMBER	LATERAL FORCE (KN)		STORY SHEAR (KN)	
	SEISMIC COEFFICIENT METHOD	RESPONSE SPECTRUM METHOD	SEISMIC COEFFICIENT METHOD	RESPONSE SPECTRUM METHOD
14	428.124	173.09	428.124	173.09
13	428.489	251.44	856.613	424.53
12	526.888	303.15	1393.501	727.68
11	302.342	114.09	1695.843	841.77
10	247.495	59.63	1943.339	901.41
9	342.755	63.57	2286.094	964.97
8	429.380	178.62	2715.474	1143.59
7	211.199	113.87	2926.673	1257.46
6	214.333	124	3141.006	1381.46
5	143.479	105.29	3284.485	1486.75
4	286.042	519.4	3570.527	2006.15
3	91.052	358.21	3661.579	2364.36
2	32.779	255.06	3694.357	2619.42
1	3.382	151.44	3697.739	2770.86
			Base shear= 3697.739	Base shear= 2770.86

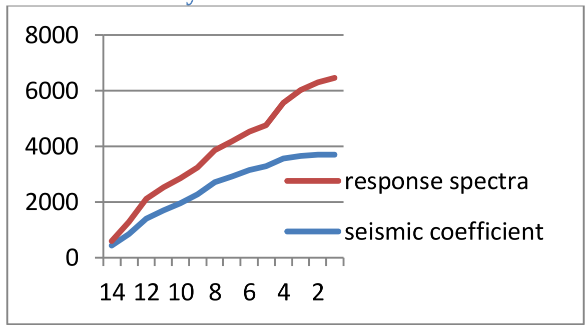
Graph of lateral forces at different levels in a irregular building in zone v



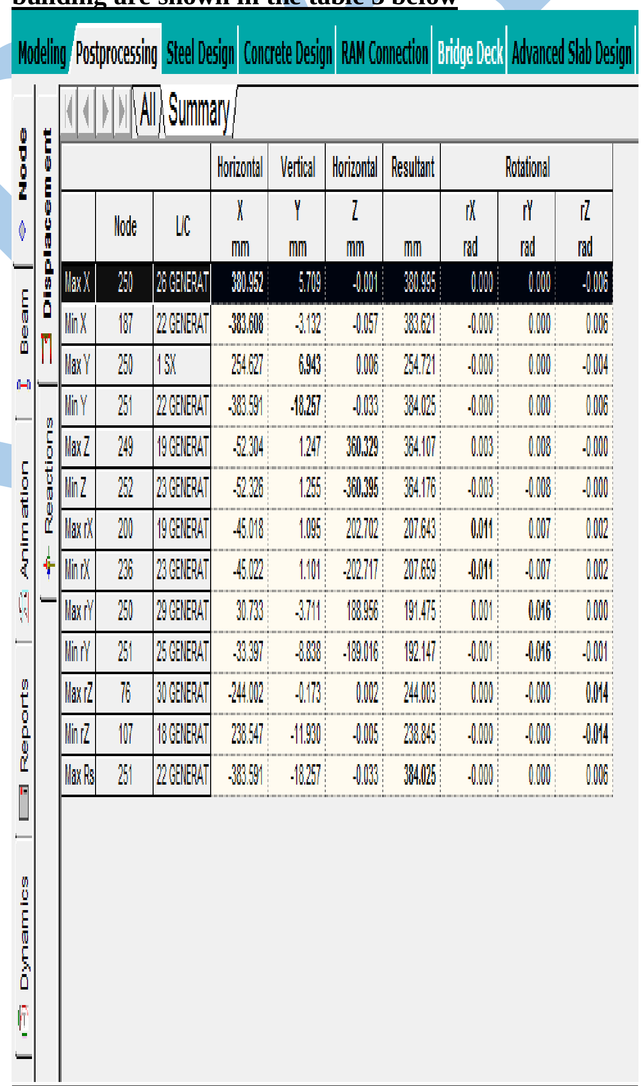
lateral forces are on Y -AXIS and storey numbers are on X -AXIS

Graph of shear shear at different levels in a irregular building in zone v

Y-AXIS shows storey shear and X-AXIS shows number of storeys

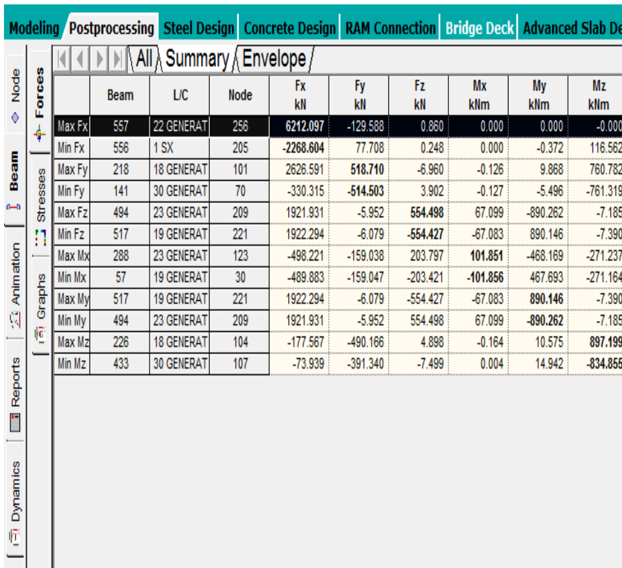


Most critical nodes displacements in the (zone v) building are shown in the table 3 below



	Node	L/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm	Resultant mm	Rotational rX rad	rY rad	rZ rad
Max X	250	26 GENERAT	380.952	5.709	-0.001	380.995	0.000	0.000	-0.006
Min X	187	22 GENERAT	-383.608	-3.132	-0.057	383.621	-0.000	0.000	0.006
Max Y	250	1 SX	254.627	6.943	0.006	254.721	-0.000	0.000	-0.004
Min Y	251	22 GENERAT	-383.591	-18.257	-0.033	384.025	-0.000	0.000	0.006
Max Z	249	19 GENERAT	-52.304	1.247	360.329	364.107	0.003	0.008	-0.000
Min Z	252	23 GENERAT	-52.326	1.255	-360.395	364.176	-0.003	-0.008	-0.000
Max rX	200	19 GENERAT	-45.018	1.095	202.702	207.643	0.011	0.007	0.002
Min rX	236	23 GENERAT	-45.022	1.101	-202.717	207.659	-0.011	-0.007	0.002
Max rY	250	29 GENERAT	30.733	-3.711	188.956	191.475	0.001	0.016	0.000
Min rY	251	25 GENERAT	-33.397	-8.838	-189.016	192.147	-0.001	-0.016	-0.001
Max rZ	76	30 GENERAT	-244.002	-0.173	0.002	244.003	0.000	-0.000	0.014
Min rZ	107	18 GENERAT	238.547	-11.930	-0.005	238.845	-0.000	-0.000	-0.014
Max Rs	251	22 GENERAT	-383.591	-18.257	-0.033	384.025	-0.000	0.000	0.006

Most critical beam end forces are shown in the table 4 below



Modeling | Postprocessing | Steel Design | Concrete Design | RAM Connection | Bridge Deck | Advanced Slab De

All | Summary | Envelope

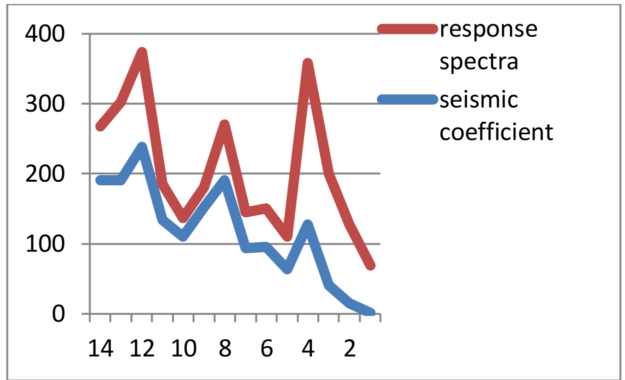
	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	557	22 GENERAT	256	6212.097	-129.588	0.860	0.000	0.000	-0.000
Min Fx	556	1 SX	205	-2268.604	77.708	0.248	0.000	-0.372	116.562
Max Fy	218	18 GENERAT	101	2626.591	518.710	-6.960	-0.126	9.868	760.782
Min Fy	141	30 GENERAT	70	-330.315	-514.503	3.902	-0.127	-5.496	-761.319
Max Fz	494	23 GENERAT	209	1921.931	-5.952	554.498	67.099	-890.262	-7.185
Min Fz	517	19 GENERAT	221	1922.294	-6.079	-554.427	-67.083	890.146	-7.390
Max Mx	288	23 GENERAT	123	-498.221	-159.038	203.797	101.851	-468.169	-271.237
Min Mx	57	19 GENERAT	30	-489.883	-159.047	-203.421	-101.856	467.693	-271.164
Max My	517	19 GENERAT	221	1922.294	-6.079	-554.427	-67.083	890.146	-7.390
Min My	494	23 GENERAT	209	1921.931	-5.952	554.498	67.099	-890.262	-7.185
Max Mz	226	18 GENERAT	104	-177.567	-490.166	4.898	-0.164	10.575	897.199
Min Mz	433	30 GENERAT	107	-73.939	-391.340	-7.499	0.004	14.942	-834.855

Node | Beam | Animation | Reports | Dynamics | Forces | Stresses | Graphs

Table 5 showing Comparison between lateral forces and storey shear by response spectrum method and seismic coefficient method in ZONE III BUILDING:

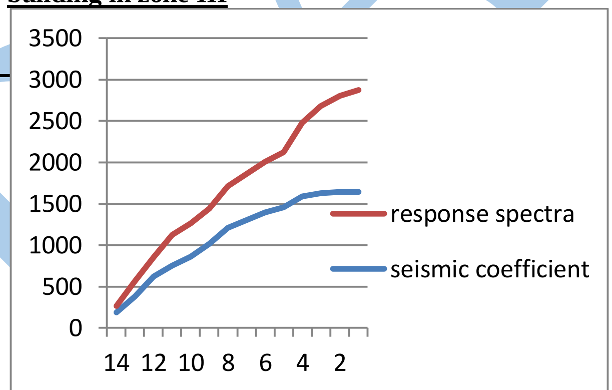
STORY NUMBER	LATERAL FORCE (KN)		STORY SHEAR (KN)	
	SEISMIC COEFFICIENT METHOD	RESPONSE SPECTRUM METHOD	SEISMIC COEFFICIENT METHOD	RESPONSE SPECTRUM METHOD
14	190.277	76.930	190.277	76.930
13	190.440	111.750	380.717	188.680
12	238.617	134.740	619.334	323.420
11	134.374	50.700	753.708	374.120
10	109.998	26.500	863.706	400.620
9	152.335	28.250	1016.041	428.870
8	190.835	79.250	1206.877	508.260
7	93.866	50.610	1300.743	558.870
6	95.259	55.110	1396.002	613.980
5	63.769	46.800	1459.771	660.780
4	127.130	230.840	1586.900	891.620
3	40.467	159.210	1627.368	1050.830
2	14.568	113.360	1641.936	1164.190
1	1.503	67.300	1643.439	1231.490
			Base shear= 1643.439	Base shear= 1231.490

Graph of lateral forces at different levels in a irregular building in zone III



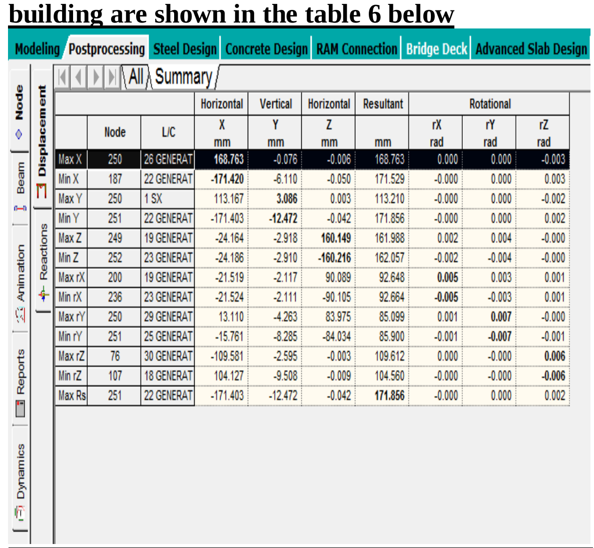
lateral forces are on Y -AXIS and storey numbers are on X -AXIS

Graph of shear shear at different levels in a irregular building in zone III



Y-AXIS shows storey shear and X-AXIS shows number of storeys

Most critical nodes displacements in the (zone III) building are shown in the table 6 below



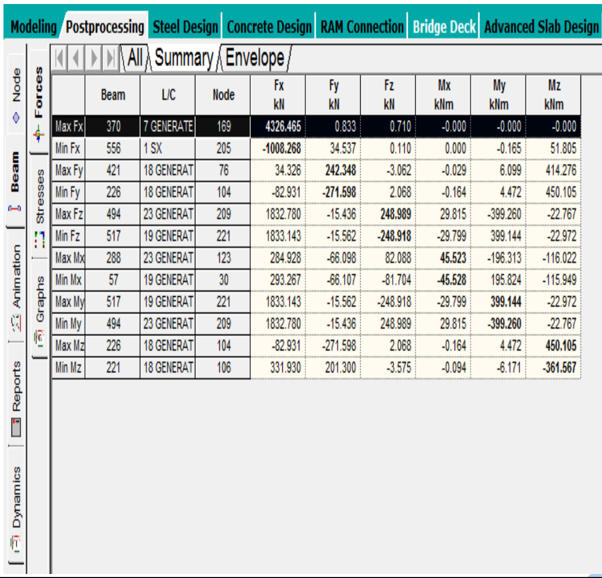
Modeling | Postprocessing | Steel Design | Concrete Design | RAM Connection | Bridge Deck | Advanced Slab Design

All | Summary

	Node	L/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm	Resultant mm	Rotational rX rad	rY rad	rZ rad
Max X	250	26 GENERAT	168.763	-0.076	-0.006	168.763	0.000	0.000	-0.003
Min X	187	22 GENERAT	-171.420	-6.110	-0.050	171.529	-0.000	0.000	0.003
Max Y	250	1 SX	113.167	3.086	0.003	113.210	-0.000	0.000	-0.002
Min Y	251	22 GENERAT	-171.403	-12.472	-0.042	171.856	-0.000	0.000	0.002
Max Z	249	19 GENERAT	-24.164	-2.918	160.149	161.988	0.002	0.004	-0.000
Min Z	252	23 GENERAT	-24.186	-2.910	-160.216	162.057	-0.002	-0.004	-0.000
Max rX	200	19 GENERAT	-21.519	-2.117	90.089	92.648	0.005	0.003	0.001
Min rX	236	23 GENERAT	-21.524	-2.111	-90.105	92.664	-0.005	-0.003	0.001
Max rY	250	29 GENERAT	13.110	-4.263	83.975	85.099	0.001	0.007	-0.000
Min rY	251	25 GENERAT	-15.761	-8.285	-84.034	85.900	-0.001	-0.007	-0.001
Max rZ	76	30 GENERAT	-109.581	-2.595	-0.003	109.612	0.000	-0.000	0.006
Min rZ	107	18 GENERAT	104.127	-9.508	-0.009	104.560	-0.000	-0.000	-0.006
Max Rs	251	22 GENERAT	-171.403	-12.472	-0.042	171.856	-0.000	0.000	0.002

Node | Beam | Animation | Reports | Dynamics | Displacement | Reactions

Most critical beam end forces are shown in the table 7 below



	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	370	7 GENERATE	169	4326.465	0.833	0.710	-0.000	-0.000	-0.000
Min Fx	556	1 SX	205	-1008.268	34.537	0.110	0.000	-0.165	51.805
Max Fy	421	18 GENERAT	76	34.326	242.348	-3.062	-0.029	6.099	414.276
Min Fy	226	18 GENERAT	104	-82.931	-271.598	2.068	-0.164	4.472	450.105
Max Fz	494	23 GENERAT	209	1832.780	-15.436	248.989	29.815	-399.260	-22.767
Min Fz	517	19 GENERAT	221	1833.143	-15.562	-248.918	-29.799	399.144	-22.972
Max Mx	288	23 GENERAT	123	284.928	-66.098	82.088	45.523	-196.313	-116.022
Min Mx	57	19 GENERAT	30	293.267	-66.107	-81.704	-45.528	195.824	-115.949
Max My	517	19 GENERAT	221	1833.143	-15.562	-248.918	-29.799	399.144	-22.972
Min My	494	23 GENERAT	209	1832.780	-15.436	248.989	29.815	-399.260	-22.767
Max Mz	226	18 GENERAT	104	-82.931	-271.598	2.068	-0.164	4.472	450.105
Min Mz	221	18 GENERAT	106	331.930	201.300	-3.575	-0.094	-6.171	-361.567

Comparison results

1. Table 2 and 5 shows that there is a gradual increase in the value of lateral forces from bottom floor to top floor in the Seismic Coefficient Method yet there is abrupt increase in lateral force at some floors in comparison to adjacent floors due to mass irregularity provided.
2. In Response Spectrum Method also there is a gradual increase in the value of lateral forces from the bottom floor , but there is a fluctuation in the forces after 4th floor onwards, which is due to the mass irregularity.
3. The lateral forces obtained by Seismic Coefficient Method are more for upper floors and are less for lower floors when compared to Response Spectrum Method in both the methods studied . The variation of lateral forces is shown in graphs.
4. Table 2 and 5 shows the percentage of Storey Shear in both Seismic Coefficient and Response Spectrum Methods decrease with increase in height of the building in both Zone V and zone III .Also the graphs show a gradual increase of shear from top to bottom of building .
5. When compared to Response Spectrum Method , the Storey Shears obtained by Seismic Coefficient Method are not much close Each Other For Zone V Whereas In Case Of Zone III Storey Shears Are Twice The Shear Of Response Spectra. The variation of storey shears is shown in the graph.
6. Node displacement has been shown in the table 3 and 6 which depicts that the displacement of the nodes at the roof of the building show maximum displacement (i.e 384.025mm for zone v and 171.876mm for zone III) with the most critical load case which is combination of seismic and dead loads on the building for zone V and III.
7. Beam displacement has been shown in table 4 and 7 which show that the most critical beam number and column number with their moment values (i.e max value Mz= -834.856) in specific load cases.

VI. CONCLUSION:

1. As a result of comparison between mentioned analysis, it is observed that the displacements and beam end forces obtained in zone V are higher than zone III .
2. Seismic coefficient method of dynamic analysis is not sufficient for high rise buildings or high rise irregular building as it is conservative as compared to response spectra method and it is necessary to provide dynamic analysis because of specific and non linear distribution of forces.
3. Dynamic analysis predicts more accurate structural response in comparison of static method (i.e seismic coefficient method).
4. The Seismic Coefficient Method is conservative at top floors compared to response Spectrum method and vice-versa
5. The values of lateral forces of static and dynamic analysis at lower stories are insignificant but it increases in higher stories and reached at its peak in top storeys.
6. The values of storey shear of static and dynamic analysis at top stories are insignificant but it increased in lower stories and reached at its peak in bottom storey therefore called the base shear of the whole building.
7. The frame was adequate enough to resist the applied seismic loads.

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