International Journal of Scientific Research in Science and Technology
Print ISSN: 2395-6011 | Online ISSN: 2395-602X (www.ijsrst.com)
doi : https://doi.org/10.32628/IJSRST218262

Comparative Study on Overturning Moment and Eccentricity of A I-Shaped Building by Equivalent Lateral Force and Modal Response Spectrum Method Using ETABS Software

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ABSTRACT

Article Info
Volume 8, Issue 4
Page Number : 173-179

Publication Issue
July-August-2021

Article History
Accepted : 02 July 2021
Published : 09 July 2021

Extended Three-Dimensional Analysis of Building System (ETABS) (version19) is a powerful software, used for building analysis and design. This software used for analysis purpose to this study. The study in this paper mainly strengthens on overturning moment and eccentricity of I-shaped fifteen storied building in both equivalent lateral force method and modal response spectrum method. The analyses are carried out as per ASCE7-16 and BNBC 2020 guidelines. It is observed that the overturning moment is approximately 11% greater in equivalent lateral force method than modal response spectrum method while in eccentricity approximately 2% greater in modal response spectrum method than equivalent lateral force method.

Keywords : ETABS, Analysis, Overturning moment, eccentricity, equivalent lateral fore method, modal response spectrum method.

I. INTRODUCTION

Lateral loads or earthquake loads are more sensitive to high-rise building. But when the eccentricity between mass centre and stiffness centre more the building induce irregularity and more vulnerable to seismic hazard [1]. The eccentricity depends on mass distribution and stiffness of each story on which centre of mass positioned. Due to eccentricity torsional effect induced. When earthquake shaking produce this torsional effect is more dangerous to building stability [2].

Building subjected to earthquake loading produce shear force in each story of building. These forces are produces overturning moment of the building. For rectangular regular shape building is less susceptible to overturning moment than I-shaped building.

The objectives of this work to study the eccentricity and overturning moment of I-shaped building in both equivalent lateral force method and modal response spectrum method.

II. METHODS AND MATERIAL

This work is based on software. A software name Extended Three-Dimensional Analysis of Building System (ETABS) version 19 used for this study. 15 (fifteen) storied residential building of I-shaped considered to study eccentricity and overturning moment. Equivalent Lateral Force Method and Modal Response Spectrum Analysis were used to perform for analysis. At first Equivalent Lateral Force Method was performed and then Modal Response Spectrum Analysis was performed. In analysis the materials properties considered as tabulated in table 2.1. The section properties tabulated in table 2.2. The load case and load combination tabulated in 2.3 and 2.4 respectively. For modal response spectrum analysis, the modes were selected 3 (three) times the number of stories. 2D plan, beam information, column information, shear wall position shown in figure 2.1, 2.2, 2.3, 2.4 respectively. Also, 3D view shown in figure 2.5.

Table 2.1: materials properties

Material type	Strength
Concrete for column and shear wall	3500 psi
Concrete for beam and slab	3000 psi
Rebar	60 grade

Table 2.2: section properties

Type	Size
Column 1 (C1)	12''x25''
Column 2 (C1)	12''x27''
Column 3 (C1)	14''x30''
Column 5 (C1)	12''x18''
Floor beam (B1-B5)	10''x24''
Grade beam	12''x24''
Shear wall	10''
Slab (shell thin)	5.5''

Table 2.3: load cases

Name	Type
Dead	Linear Static
Modal	Modal - Ritz
WALL	Linear Static
PW	Linear Static
FF	Linear Static
LIVE	Linear Static
HOSPITAL LIVE	Linear Static
STAIR LIVE	Linear Static
ROOF LIVE	Linear Static
LIFT DL	Linear Static
LIFT LL	Linear Static
OHWT	Linear Static
EQX	Linear Static
EQY	Linear Static
WX	Linear Static
WY	Linear Static
RSX	Response spectrum
RSY	Response spectrum

Table 2.4: Basic load combination

1.4D
1.2D+1.6L
1.2D+1.0L
1.2D+1.6W+1.0L
1.2D+1.0 E+1.0 L
0.9D+1.6W
0.9D+1.0 E

Loads acting on the structure are dead load (DL), live load (LL), earthquake load, wind load. Self-weight consists of the weight of beam, column, slab and shear wall of the building. Wall Loads are Super Imposed Dead Load (SIDL). These loads are the loads of the brick walls which are located on the beams. Wall loads are calculated as per linear foot and applied on the model simultaneously as per wall positions.in this study wall load 0.5k/ft applied. Partition Wall Loads are also Super Imposed Dead Load (SIDL). This load are the loads of the brick walls which are located on the slab panels. Partition wall loads are calculated as per square foot and applied on the model simultaneously as per wall positions. In this study 75psf applied Floor Finish Loads are also Super Imposed Dead Load (SIDL). These loads are the loads of the tiles, plasters on the slab panels. Floor finish loads are calculated assuming unit weight 145 pcf. and thickness of floor finish 1.5 inch.

Floor finish= 1.5inX (145pcf) =18.125 psf. ≈ 20 psf. For Lift machine Load's shaft size Assumed 5'-4"X4'-8". From Public Works Department schedule, total load=8 tons = 17600lb. Machine room floor area= 7'X6'=42 sq.ft. So, total lift machine load = 176000/42 = 419.05 psf. Portion of total load assumed as Dead load = 50% of total load= 209.52 psf. Portion of total load assumed as Live load = 50% of total load= 209.52 psf. Floor live load and roof live loads are applied separately on each floor and top of the floor. Stair live load applied in stair slab. Live load on the residential floor slabs = 42 psf. Live load on the roof slab = 100 psf. Live load on the stair = 100 psf. Live load for hospital floors=100 psf. Wind load are applied in X and Y direction as per BNBC 2020, PART 6, Chapter 2. For seismic load: soil type: SC, Importance factor: 1, Response reduction factor:7, Damping: 5%, seismic zone: III as per BNBC 2020, PART 6, Chapter 2 [3].

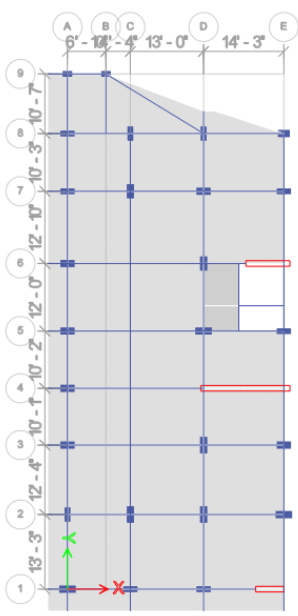

Fig.2.1 Plan of building

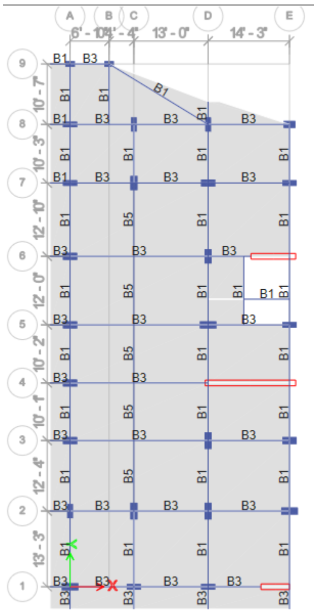

Fig.2.2 Beam information

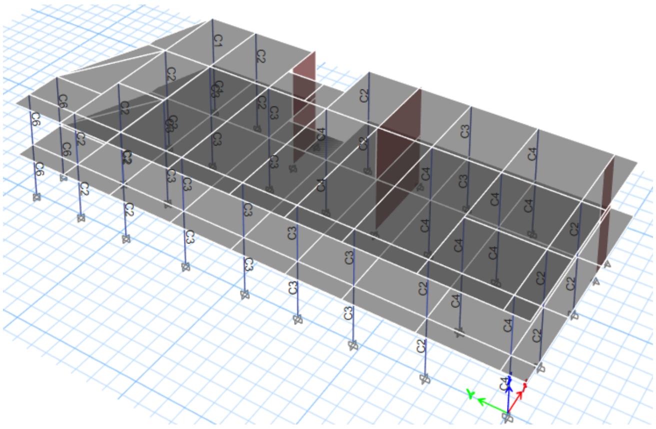

Fig2.3 Column information

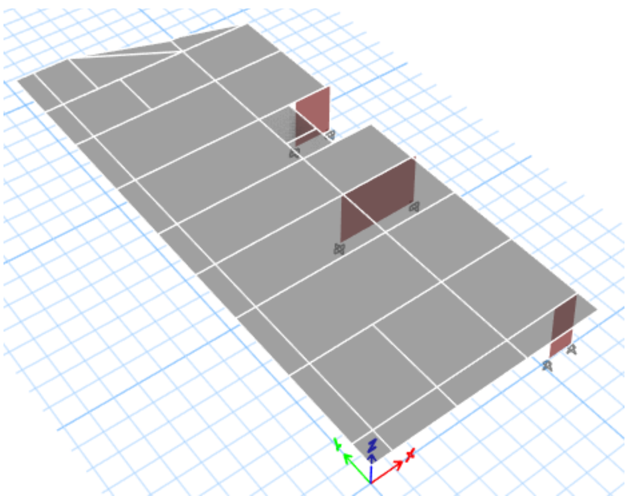

Fig2.4 Shear wall position

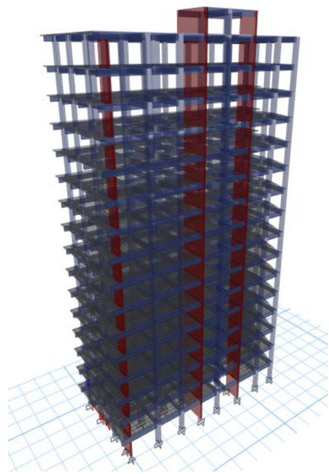

Fig.2.5 3D view of the building

III.RESULTS AND DISCUSSION

After completing the model, static force method and modal response analysis were running. The structure shall be designed to resist overturning effects caused by the seismic forces. At any story, the increment of overturning moment in the story under consideration shall be distributed to the various vertical force resisting elements in the same proportion as the distribution of the horizontal shears to those elements. The overturning moments at level x, Mx determined as follows:

$$M_x = \sum_{i=x}^{n} F_i(h_i - h_x) \qquad \text{.................. (3.1)}$$

where,

F_i= Portion of the seismic base shear, V induced at level i

h_i, h_x = Height from the base to level i or x.

Overturning moment for earthquake load for equivalent lateral force method in x direction was found as 63718 kip-ft which calculation shown in the table 3.1, where in modal response spectrum analysis was found as 56308 kip-ft. shown in table 3.2. In Y direction overturning moment was found as 63318 kip-ft in equivalent lateral force method shown in table 3.3 where in response spectrum analysis was found as 56442 kip-ft shown in table 3.4.

Table3.1: The calculation of overturning moment for earthquake load in x direction in equivalent lateral force method

Level	Story Ht	Elev.	ETABS Cum. Story Force/ Shear (Vx)	Individual Story Force/ Shear (Vx)	Overturning Moment (OM)
ROOF	10	160	58.641	58.641	9382.56
F14	10	150	128.141	69.5	11120
F13	10	140	190.722	62.581	9387.15
F12	10	130	246.636	55.914	7827.96
F11	10	120	296.145	49.509	6436.17
F10	10	110	339.52	43.375	5205
F9	10	100	377.046	37.526	4127.86
F8	10	90	409.018	31.972	3197.2
F7	10	80	435.75	26.732	2405.88
F6	10	70	457.571	21.821	1745.68
F5	10	60	474.834	17.263	1208.41
F4	10	50	487.918	13.084	785.04
F3	10	40	497.239	9.321	466.05
F2	10	30	504.296	7.057	282.28
F1	10	20	508.102	3.806	114.18
GF	10	10	509.452	1.35	27
				Base Shear= 509	Total OM= 63718

Table : 3.2 The calculation of overturning moment for earthquake load in x direction in modal response spectrum analysis method

Level	Story Ht	Elev.	ETABS Cum. Story force/ Shear (Vx)	Individual Story Force/ Shear (Vx)	Overturning Moment (OM)
ROOF	10	160	21.438	21.438	3430.08
F14	10	150	98.327	76.889	12302.24
F13	10	140	169.273	70.946	10641.9
F12	10	130	219.589	50.316	7044.24
F11	10	120	256.572	36.983	4807.79
F10	10	110	284.918	28.346	3401.52
F9	10	100	307.599	22.681	2494.91
F8	10	90	327.239	19.64	1964
F7	10	80	346.589	19.35	1741.5
F6	10	70	368.074	21.485	1718.8
F5	10	60	392.315	24.241	1696.87
F4	10	50	418.372	26.057	1563.42
F3	10	40	444.605	26.233	1311.65
F2	10	30	469.632	25.027	1001.08
F1	10	20	495.992	26.36	790.8
GF	10	10	515.853	19.861	397.22
				Base Shear = 516	Total OM = 56308

Table3.3: The calculation of overturning moment for earthquake load in Y direction in equivalent lateral force method

Level	Story Ht	Elev.	ETABS Cum. Story Force /Shear (Vy)	Indivitual Story Force /Shear (Vy)	Overturning Moment (OM)
ROOF	10	160	58.641	58.641	9382.56
F14	10	150	128.141	69.5	11120
F13	10	140	190.722	62.581	9387.15
F12	10	130	246.636	55.914	7827.96
F11	10	120	296.145	49.509	6436.17
F10	10	110	339.52	43.375	5205
F9	10	100	377.046	37.526	4127.86
F8	10	90	409.018	31.972	3197.2
F7	10	80	435.75	26.732	2405.88
F6	10	70	457.571	21.821	1745.68
F5	10	60	474.834	17.263	1208.41
F4	10	50	487.918	13.084	785.04
F3	10	40	497.239	9.321	466.05
F2	10	30	504.296	7.057	282.28
F1	10	20	508.102	3.806	114.18
GF	10	10	509.452	1.35	27
				Base Shear = 509	Total OM = 63718

Table : 3.4 The calculation of overturning moment for earthquake load in Y direction in modal response spectrum analysis method

Level	Story Ht	Elev.	ETABS Cum. Story Force/ Shear (Vy)	Indivitual Story Force/Shear (Vy)	Overturning Moment (OM)
ROOF	10	160	17.61	17.61	2817.6
F14	10	150	84.88	67.27	10763.2
F13	10	140	157.717	72.837	10925.55
F12	10	130	215.638	57.921	8108.94
F11	10	120	260.382	44.744	5816.72
F10	10	110	294.161	33.779	4053.48
F9	10	100	319.567	25.406	2794.66
F8	10	90	339.365	19.798	1979.8
F7	10	80	356.345	16.98	1528.2
F6	10	70	373.198	16.853	1348.24
F5	10	60	392.049	18.851	1319.57
F4	10	50	413.953	21.904	1314.24
F3	10	40	438.725	24.772	1238.6
F2	10	30	464.924	26.199	1047.96
F1	10	20	494.811	29.887	896.61
GF	10	10	519.267	24.456	489.12
				Base Shear = 519	Total OM = 56442

From the above tables it observed that the overturning moments are higher in both direction in equivalent lateral force method than response spectrum method. Overturning moment in top floor is high cause the story shear is high and multiply with highest distance from bottom to top for equivalent lateral force method while in response spectrum method the story shear is so less.

From figure 3.1and 3.2 it shown that overall overturning moment in equivalent lateral force method is 11.63% greater than the response spectrum method in X direction and 11.42% in Y direction.

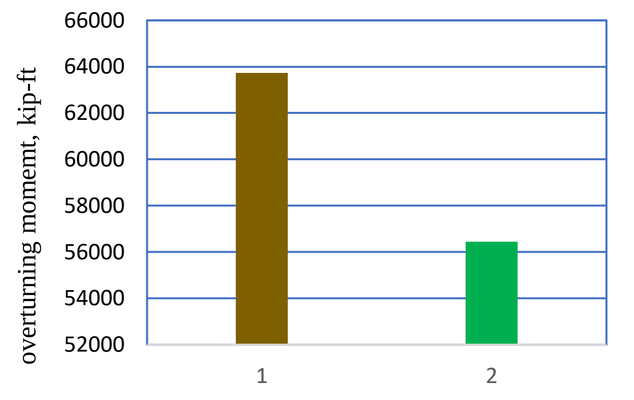

Fig. 3.1: variation of overturning moment in X direction

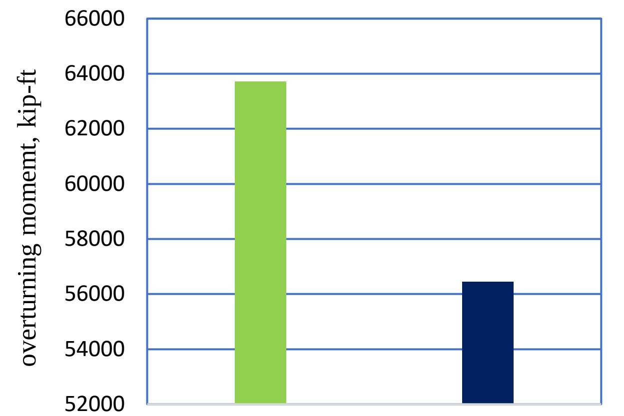

Fig. 3.2 : variation of overturning moment in Y direction

The eccentricity between the centre of mass and the geometric centroid of the building at that level shall not exceed 15% of the overall building width along each principal axis considered at each level [4]. In table 3.5 and table 3.6 eccentricity calculations are shown.

Table 3.5: The calculation of eccentricity in equivalent lateral force method

Story	C.M		C.R		Eccentricity	
	x_m	y_m	XCR	YCR	e_x	e_y
ROOF	18.6198	41.5682	19.80	38.58	1.18	2.99
F14	17.0505	41.996	19.73	38.61	2.68	3.39
F13	17.0505	41.996	19.67	38.67	2.62	3.33
F12	17.0505	41.996	19.61	38.73	2.55	3.26
F11	17.0505	41.996	19.55	38.80	2.50	3.20
F10	17.0505	41.996	19.49	38.85	2.44	3.15
F9	17.0505	41.996	19.44	38.89	2.39	3.11
F8	17.0505	41.996	19.38	38.92	2.33	3.08
F7	17.0505	41.996	19.34	38.93	2.29	3.07
F6	17.0505	41.996	19.29	38.91	2.24	3.09
F5	17.0505	41.996	19.24	38.87	2.19	3.13
F4	17.0505	41.996	19.20	38.79	2.15	3.21
F3	17.0505	41.996	19.15	38.67	2.10	3.33
F2	16.9067	42.1302	19.08	38.49	2.17	3.64
F1	16.9027	42.1098	18.96	38.33	2.06	3.78
GF	16.9805	42.2318	18.67	37.94	1.69	4.29

Table 3.6: The calculation of eccentricity in modal response spectrum method

Story	C.M		C.R		Eccentricity	
	x_m	y_m	XCR	YCR	e_x	e_y
ROOF	18.6198	41.5682	19.86	38.47	1.24	3.10
F14	17.0505	41.996	19.79	38.50	2.74	3.49
F13	17.0505	41.996	19.73	38.56	2.68	3.43
F12	17.0505	41.996	19.68	38.63	2.63	3.37
F11	17.0505	41.996	19.62	38.69	2.57	3.31
F10	17.0505	41.996	19.57	38.75	2.52	3.25
F9	17.0505	41.996	19.51	38.79	2.46	3.20
F8	17.0505	41.996	19.46	38.82	2.41	3.17
F7	17.0505	41.996	19.41	38.84	2.36	3.16
F6	17.0505	41.996	19.36	38.83	2.31	3.16
F5	17.0505	41.996	19.31	38.80	2.26	3.20
F4	17.0505	41.996	19.26	38.73	2.21	3.27
F3	17.0505	41.996	19.21	38.62	2.15	3.37
F2	16.9067	42.1302	19.12	38.46	2.22	3.67
F1	16.9027	42.1098	18.99	38.31	2.09	3.80
GF	16.9805	42.2318	18.69	37.93	1.71	4.30

From the table 3.7 and table 3.8 it shown that the eccentricity value increased 2.7% average in modal response spectrum method than equivalent lateral force method in X direction and 2.28% in Y direction.

Table 3.7: percent difference in eccentricity in X direction

Level	e_x, equivalent lateral force method	e_x, modal response spectrum method	% Difference
ROOF	1.18	1.24	4.83871
F14	2.68	2.74	2.189781
F13	2.62	2.68	2.238806
F12	2.55	2.63	3.041825
F11	2.5	2.57	2.723735
F10	2.44	2.52	3.174603
F9	2.39	2.46	2.845528
F8	2.33	2.41	3.319502
F7	2.29	2.36	2.966102
F6	2.24	2.31	3.030303
F5	2.19	2.26	3.097345
F4	2.15	2.21	2.714932
F3	2.1	2.15	2.325581
F2	2.17	2.22	2.252252
F1	2.06	2.09	1.435407
GF	1.69	1.71	1.169591

Table 3.8: percent difference in eccentricity in Y direction

level	ey, equivalent lateral force method	ey, modal response spectrum method	% Difference
ROOF	2.99	3.1	3.548387
F14	3.39	3.49	2.86533
F13	3.33	3.43	2.915452
F12	3.26	3.37	3.264095
F11	3.2	3.31	3.323263
F10	3.15	3.25	3.076923
F9	3.11	3.2	2.8125
F8	3.08	3.17	2.839117
F7	3.07	3.16	2.848101
F6	3.09	3.16	2.21519
F5	3.13	3.2	2.1875
F4	3.21	3.27	1.834862
F3	3.33	3.37	1.186944
F2	3.64	3.67	0.817439
F1	3.78	3.8	0.526316
GF	4.29	4.3	0.232558

IV. CONCLUSION

Equivalent lateral force method gives higher value for overturning moment especially in high-rise building which is more conservative than response spectrum method. Equivalent lateral force method gives lower value for eccentricity than response spectrum method. High value of overturning moment is more important in I-shaped building for stability of the building. During earthquake response overturning moment affect the foundation of the building. However as for equivalent lateral force method is more conservative response spectrum method can be used for high rise building. Though eccentricity is greater in response spectrum method but the values are less difference in percentage in both analysis method.

Conclusion are based on findings of the study; further study should be done using different shape of building with plan irregularity and height. Also, torsional moment effect due to eccentricity should be studied in further.

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Cite this article as :

M. T. Hasan, M. L. Hossain, "Comparative Study on Overturning Moment and Eccentricity of A I-Shaped Building by Equivalent Lateral Force and Modal Response Spectrum Method Using ETABS Software", International Journal of Scientific Research in Science and Technology (IJSRST), Online ISSN : 2395-602X, Print ISSN : 2395-6011, Volume 8 Issue 4, pp. 173-179, July-August 2021. Available at
doi : https://doi.org/10.32628/IJSRST218262
Journal URL : https://ijsrst.com/IJSRST218262