Effect of Orientation on Response Spectrum Analysis of Plan Irregular Building

Mohammad Usman Alvi, M-Tech (Structural and Foundation Engineering)
Rizwanullah, Assistant Professor

Department of Civil Engineering, Al-Falah University, Faridabad, India

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Abstract - *Now a days high rise buildings have become a common trend to accommodate the increasing population in urban areas. These high rise buildings are most commonly are made up of Reinforced concrete. The Reinforced concrete multi storey buildings are subjected to most dangerous earthquakes. The behavior of a building during an earthquake depends on several factors, stiffness, adequate lateral strength and ductility, simple and regular configurations. It was found that main reason for failure of RC building is irregularity in its plan dimension and its lateral force resisting system. At the time of any earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as irregular structures. Irregularities are one of the major reasons of failures of structures during earthquakes. Among all the factors configuration of a building is an important feature which has huge influence on the damage during the earthquake shaking. The feature of the regularity and symmetry in the overall shape of the building both in plan and elevation enormously affects the response of the building under static and dynamic loading. But nowadays the need and demand of the modern era and growing population has made the architects or engineers forced towards planning of Buildings with Plan Irregularity. So if a structure has to perform well in earthquake means it should possess adequate strength, stiffness, ductility and simple configuration. Therefore these types of structures should be well designed under earthquake loading accounting the specified seismic design philosophies so that they can sustain moderate to strong earthquakes. The structures are carefully analyzed by using methods Equivalent static method of analysis and Dynamic method of analysis.*

Key Words-ETABs, Response Spectrum Analysis, Irregular Building, Non-Parallel Lateral Force Resisting System, Time Period, Static Base Shear, Story Stiffness, Story Drift, Over Turning Moments, Design Forces.

1 .INTRODUCTION

IS-1893-2016 (part 1) states that if a building possesses any of the following irregularity, the structure is to be considered as an irregular structure.

1) Torsional Irregularity
2) Re-entrant Corners
3) Floor Slabs having Excessive Cutouts or openings
4) Out of Plane offsets in vertical elements
5) Non-Parallel Lateral Force Resisting System
6) Stiffness Irregularity (Soft Storey)
7) Mass Irregularity
8) Vertical Geometric Irregularity
9) In-Plane Discontinuity in Vertical Elements Resisting Lateral Force
10) Strength Irregularity (Weak Storey)
11) Floating or Stub Column
12) Irregular Modes of Oscillation in Two Principal Plan Directions

Irregularities 1-5 are known as plan irregularities and when the lateral load resisting system is not oriented along mutually orthogonal horizontal directions, the structure shall be designed for the simultaneous effects due to full design earthquake load plus 30 percent of design earthquake along the other direction. Further if, effects due to vertical earthquake shaking are considered, 30 percent of vertical design earthquake load is also included while making load combinations of earthquake effects.

Regular building where the structure are formed by sub-systems which are perpendicular among other and parallel with the global axes, the principal direction of the earthquake loads is parallel with that global axes. However, for the irregular building structure, mostly the direction of the principal axes could not be determined in advance. In this case, the principal direction of earthquake loads shall be calculated using trial & error for a number of possibilities. Hence, it is quite often the Structural Engineer has to perform quite a number of structural analyses of the building, applying static lateral loads in incremental direction angles, e.g. every 5 or 10 degrees to obtain the "maximum" results using a "trial and error" method.

In this paper an investigative study is made to find response of irregular structures having different orientation located in seismic zone V (Tower 1 and Tower 2). For this paper Tower 1 is oriented in Global X and Global Y direction, whereas Tower 2 is rotated 7º in the anti-clockwise direction about the center. Analysis has been made by taking G+20 story building by static and dynamic methods using ETABS 2016 and IS code 1893-2016 (part1). Linear Equivalent Static analysis is performed for regular buildings up to 15m height in zone II, Dynamic Analysis should be performed for regular and irregular buildings in zone II, III, IV and V. Dynamic

Analysis is performed using a linear Response Spectrum Analysis. Behavior of building will be carefully studied in the light of IS-1893-2016 (part1) and comparing responses in the form of time period, static base shear, modal directional factors, modal participating mass ratios, stiffness, story displacement and design forces in an irregular structure having non-parallel lateral force resisting system with different orientation of the structure.

1.1 MODEL CONFIGURATION

Seismic Zone- V
Response Reduction Factor, R- 5
Importance Factor, I- 1
Soil Type- Type II
Height of the Building- 64 m
Column Dimensions- (300X750) mm
Beam Dimensions- (300X450) mm
Slab Thickness- 200 mm

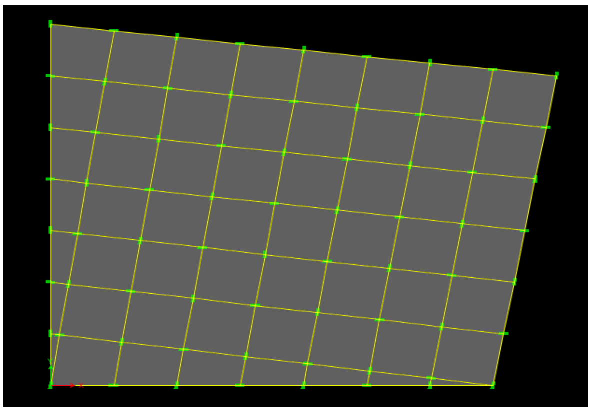

Figure 1.1(a) - Plan View of Tower 1

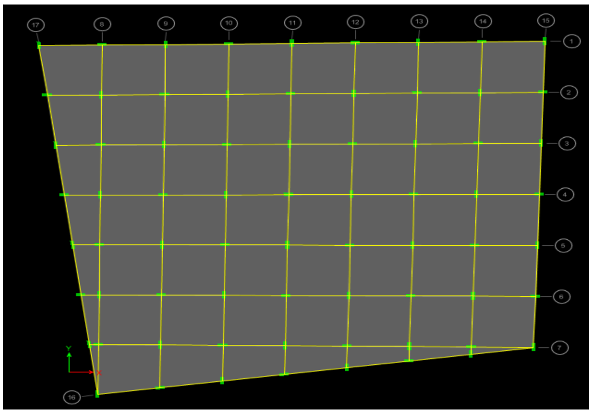

Figure 1.1(b) – Plan View of Tower 2

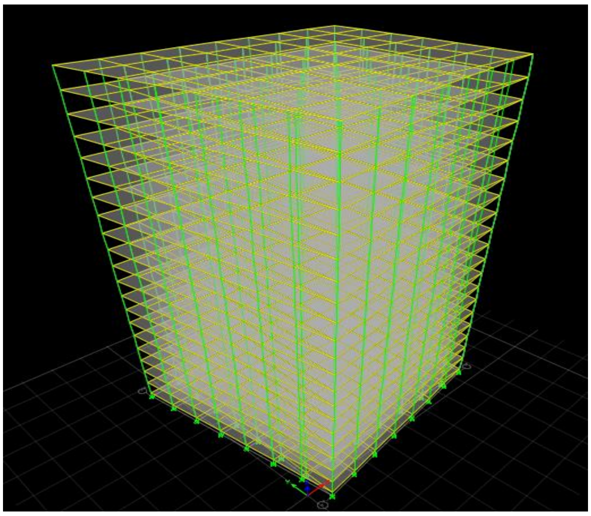

Figure 1.2- 3D View of Tower

1.2 TIME PERIOD

IS-1893-2016 defines different Sa/g values for different values of approximate time period (T).
The natural time period (T) for building with non-structural walls made up of masonry can be calculated by the following formula.

$$T = 0.09 * \frac{h}{\sqrt{d}}$$

Base dimension $\sqrt{d}$ in the direction along the considered direction on shaking (Global X and Global Y) vary with the change in orientation of the building.

Table 1.1- Time Period for Tower 1 and Tower 2

Time Period	Tower 1	Tower 2
Global X	0.9107 sec	0.9076 sec
Global Y	0.9736 sec	0.9776 sec

1.3 DESIGN BASE SHEAR

The design base shear (V_B) of any building can be calculated by using the formula given in IS-1893-2016:

$$V_B = A_h * W$$

Where A_h = Design horizontal seismic coefficient
W = Seismic weight of the building

The Design horizontal seismic coefficient (A_h) is a function of peak ground acceleration (z), Importance Factor (I), Response Reduction Factor (R) and Design acceleration coefficient (S_a/g) for different types of soil normalized corresponding to 5 % damping.

$$Ah = \frac{Z}{2} * \frac{I}{R} * \frac{Sa}{g}$$

Sa/g values for medium soil according to IS-1893-2016,

$$\frac{S_a}{g} = \begin{cases} 2.5 \; for \; 0 < T < 0.55 \; sec \\ \frac{1.36}{T} \; for \; 0.55 < T < 4.0 \; sec \\ 0.34 \; for \; T > 4.0 \; sec \end{cases}$$

Table 1.2- Design Base Shear of Tower 1 and Tower 2 for Equivalent Static Load

Design Base Shear	Tower 1	Tower 2
Global X(KN)	32026.0058	32144.9979
Global Y(KN)	29956.9033	29843.2493

1.4 STIFFNESS

Table 1.3- Story Stiffness of Tower 1 and Tower 2 for Equivalent Static Load in Global X Direction (EQX) in KN/m

Storey	Tower 1	Tower 2
20	454210.5	455530.7
19	616737	618202.2
18	679924.8	681414.5
17	712843.9	714278.2
16	733045.1	734379.5
15	746811.3	748056.2
14	756928.7	758110.1
13	764881.5	765999.5
12	771531.4	772588.5
11	777438.1	778427.2
10	782971.9	783917.4
9	788419.8	789338.4
8	794110.8	795010.4
7	800307.2	801177.2
6	807346.1	808178
5	815757.1	816616.1
4	826819.6	827778.2
3	845663.3	846799.8
2	897228	898557.2
1	1193802	1195242
Ground Floor	14679896	14714969
Base	0	0

Table 1.4- Story Stiffness of Tower 1 and Tower 2 for Equivalent Static Load in Global Y Direction (EQY) in KN/m

Storey	Tower 1	Tower 2
20	409411	412921.5
19	569580	574661.9
18	635252.8	641182.7
17	670096.6	676578.2
16	691637.3	698506.1
15	706480.3	713623.5
14	717465.8	724824.9
13	726075.3	733616.8
12	733264.3	740961.4
11	739605.3	747426.6
10	745633.8	753582.9
9	751675.4	759750.2
8	757875.4	766086.4
7	764668.9	773003.5
6	772411.1	780846.6
4	794204.6	802891.5
3	815163.9	823932.2
2	870338.7	879391.6
1	1172412	1183922

Ground Floor	14432196	14555365
Base	0	0

1.5 MODAL DIRECTIONAL FACTORS

Table 1.5- Modal Direction Factors of Tower 1 for 1-10 Mode

TABLE: Modal Direction Factors					
Mode	Period sec	UX	UY	UZ	RZ
1	4.982	0.128	0.798	0	0.074
2	4.835	0.828	0.159	0	0.013
3	4.499	0.044	0.043	0	0.913
4	1.633	0.157	0.763	0	0.08
5	1.587	0.792	0.195	0	0.014
6	1.482	0.052	0.042	0	0.906
7	0.943	0.22	0.673	0	0.107
8	0.917	0.711	0.277	0	0.012
9	0.866	0.069	0.05	0	0.881
10	0.656	0.274	0.619	0	0.107

Table 1.6- Modal Direction

Factors of Tower 2 for 1-10 Mode

TABLE: Modal Direction Factors					
Mode	Period sec	UX	UY	UZ	RZ
1	4.981	0.226	0.7	0	0.074
2	4.835	0.719	0.268	0	0.013
3	4.499	0.055	0.032	0	0.913
4	1.632	0.261	0.658	0	0.08
5	1.587	0.675	0.311	0	0.013
6	1.482	0.064	0.03	0	0.906
7	0.943	0.332	0.56	0	0.107
8	0.917	0.583	0.405	0	0.012
9	0.866	0.084	0.035	0	0.881
10	0.656	0.392	0.501	0	0.107

1.6 MODAL PARTICIPATING MASS RATIOS

Table 1.7- Modal Participating Mass Ratios of Tower 1 for 1-10 Modes

TABLE: Modal Participating Mass Ratios			
Mode	Period sec	UX	UY
1	4.982	0.0987	0.6138
2	4.835	0.6387	0.1221
3	4.499	0.0338	0.0331
4	1.633	0.0152	0.0749
5	1.587	0.0768	0.0192
6	1.482	0.0049	0.0041
7	0.943	0.0074	0.023
8	0.917	0.0241	0.0094
9	0.866	0.0024	0.0017
10	0.656	0.0048	0.0111

Table 1.8- Modal Participating Mass Ratios of Tower 2 for 1-10 Modes

TABLE: Modal Participating Mass Ratios			
Mode	Period sec	UX	UY
1	4.981	0.174	0.5384
2	4.835	0.5546	0.2062
3	4.499	0.0426	0.0243
4	1.632	0.0253	0.0647
5	1.587	0.0655	0.0306
6	1.482	0.0061	0.003
7	0.943	0.0112	0.0192
8	0.917	0.0197	0.0137
9	0.866	0.0029	0.0012
10	0.656	0.0069	0.009

1.7 MAXIMUM STORY DISPLACEMENTS

Table 1.9- Maximum Story Displacements of Tower 1 for 1st Mode

TABLE: Max Story Displacement			
Story	Elevation	X-Dir	Y-Dir
	m	mm	mm
20	65	0.004129	0.007718
19	61.8	0.004085	0.007625
18	58.6	0.00402	0.007496

17	55.4	0.003933	0.007325
16	52.2	0.003823	0.007114
15	49	0.003691	0.006861
14	45.8	0.003537	0.00657
13	42.6	0.003364	0.006241
12	39.4	0.00317	0.005876
11	36.2	0.002959	0.005478
10	33	0.00273	0.00505
9	29.8	0.002487	0.004594
8	26.6	0.002229	0.004114
7	23.4	0.00196	0.003612
6	20.2	0.001681	0.003092
5	17	0.001393	0.002558
4	13.8	0.001099	0.002015
3	10.6	0.000802	0.001467
2	7.4	0.000507	0.0009254
1	4.2	0.000226	0.0004122
Ground Floor	1	1.70E-05	3.09E-05
Base	0	0	0

Table 1.10- Maximum Story Displacements of Tower 2 for 1st Mode

TABLE: Max Story Displacements			
Story	Elevation	X-Dir	Y-Dir
	m	mm	mm
20	65	0.004606	0.007163
19	61.8	0.004555	0.007077
18	58.6	0.004481	0.006956
17	55.4	0.004382	0.006798
16	52.2	0.004258	0.006601
15	49	0.004109	0.006366
14	45.8	0.003937	0.006095
13	42.6	0.003742	0.00579
12	39.4	0.003526	0.005451
11	36.2	0.00329	0.005082
10	33	0.003035	0.004684
9	29.8	0.002763	0.004261
8	26.6	0.002477	0.003815
7	23.4	0.002177	0.00335
6	20.2	0.001866	0.002867
5	17	0.001546	0.002372
4	13.8	0.00122	0.001868
3	10.6	0.00089	0.00136
2	7.4	0.000563	0.000857
1	4.2	0.000252	0.000382
Ground Floor	1	1.89E-05	2.87E-05
Base	0	0	0

1.8 COLUMN DESIGN FORCES

Table 1.11- Maximum Column Design Forces of Tower 1

TABLE: Column Design Forces T1		
Story	Column	P
		kN
Ground Floor	C1	-14364
Ground Floor	C2	-14988.3
Ground Floor	C3	-15696.2
Ground Floor	C4	-16120.6
Ground Floor	C5	-16099.5
Ground Floor	C6	-16687.4
Ground Floor	C7	-15971.3
Ground Floor	C8	-13845.9
Ground Floor	C9	-13155.8
Ground Floor	C10	-14300
Ground Floor	C11	-14941.6
Ground Floor	C12	-15663
Ground Floor	C13	-15779.6
Ground Floor	C14	-15015.3
Ground Floor	C15	-12005.3
Ground Floor	C16	-14383.1
Ground Floor	C17	-15981.5
Ground Floor	C18	-17706.1
Ground Floor	C19	-18984.2
Ground Floor	C20	-19946.4
Ground Floor	C21	-20046.8
Ground Floor	C22	-19320
Ground Floor	C23	-17319.2
Ground Floor	C24	-13204.5
Ground Floor	C25	-14773.4
Ground Floor	C26	-17520.9
Ground Floor	C27	-20263.5
Ground Floor	C28	-22180.8
Ground Floor	C29	-23157.9
Ground Floor	C30	-23061
Ground Floor	C31	-21743.6

Ground Floor	C32	-19094.7
Ground Floor	C33	-14763.3
Ground Floor	C34	-15857.9
Ground Floor	C35	-18787.5
Ground Floor	C36	-21674.8
Ground Floor	C37	-23644.9
Ground Floor	C38	-24679.4
Ground Floor	C39	-24503.4
Ground Floor	C40	-22982.2
Ground Floor	C41	-20287.9
Ground Floor	C42	-15911.9
Ground Floor	C43	-16260.6
Ground Floor	C44	-18887.9
Ground Floor	C45	-21495.1
Ground Floor	C46	-23413.7
Ground Floor	C47	-24393.3
Ground Floor	C48	-24267.9
Ground Floor	C49	-22787
Ground Floor	C50	-20361.4
Ground Floor	C51	-16646.4
Ground Floor	C52	-16686.8
Ground Floor	C53	-17815.1
Ground Floor	C54	-19844.6
Ground Floor	C55	-21591.5
Ground Floor	C56	-22426.7
Ground Floor	C57	-22429.9
Ground Floor	C58	-21217.2
Ground Floor	C59	-19376.1
Ground Floor	C60	-16565.6
Ground Floor	C61	-16010.8
Ground Floor	C62	-13735.6
Ground Floor	C63	-17619.8
Ground Floor	C64	-18976.6
Ground Floor	C65	-19235
Ground Floor	C66	-19282.2
Ground Floor	C67	-18353.9
Ground Floor	C68	-17375.2
Ground Floor	C69	-15504.6
Ground Floor	C70	-12440.2

Table 1.12- Maximum Column Design Forces of Tower 2

TABLE: Column Design Forces T2		
Story	Column	P
		kN
Ground Floor	C1	-15048.1
Ground Floor	C2	-15551.1
Ground Floor	C3	-16349.9
Ground Floor	C4	-16866.9
Ground Floor	C5	-16937.1
Ground Floor	C6	-17577.4
Ground Floor	C7	-16877.1
Ground Floor	C8	-14438.2
Ground Floor	C9	-13576.2
Ground Floor	C10	-14802
Ground Floor	C11	-15465.6
Ground Floor	C12	-16164.9
Ground Floor	C13	-16248.4
Ground Floor	C14	-15400.2
Ground Floor	C15	-12347.7
Ground Floor	C16	-15098.7
Ground Floor	C17	-16604.9
Ground Floor	C18	-18269.2
Ground Floor	C19	-19625.9
Ground Floor	C20	-20664.1
Ground Floor	C21	-20770.1
Ground Floor	C22	-19974.4
Ground Floor	C23	-17823.4
Ground Floor	C24	-13602.4
Ground Floor	C25	-15482
Ground Floor	C26	-18288.7
Ground Floor	C27	-21019.9
Ground Floor	C28	-23085.5
Ground Floor	C29	-24151.9
Ground Floor	C30	-24044.3
Ground Floor	C31	-22625.3
Ground Floor	C32	-19750.3
Ground Floor	C33	-15246.8
Ground Floor	C34	-16635.5
Ground Floor	C35	-17019.9
Ground Floor	C36	-16432
Ground Floor	C37	-21025.3
Ground Floor	C38	-23963.4

Ground Floor	C39	-25636.9
Ground Floor	C40	-25822.8
Ground Floor	C41	-24692
Ground Floor	C42	-22583.4
Ground Floor	C43	-19677.6
Ground Floor	C44	-17438.4
Ground Floor	C45	-17175.1
Ground Floor	C46	-21084.2
Ground Floor	C47	-23749.2
Ground Floor	C48	-25394
Ground Floor	C49	-25518.1
Ground Floor	C50	-24456
Ground Floor	C51	-22428.7
Ground Floor	C52	-19812.7
Ground Floor	C53	-16686.9
Ground Floor	C54	-17090.2
Ground Floor	C55	-20042
Ground Floor	C56	-22047.8
Ground Floor	C57	-23400
Ground Floor	C58	-23392.1
Ground Floor	C59	-22488.5
Ground Floor	C60	-20639.7
Ground Floor	C61	-18680.2
Ground Floor	C62	-13060
Ground Floor	C63	-16084.1
Ground Floor	C64	-18074.5
Ground Floor	C65	-19165.2
Ground Floor	C66	-20198.4
Ground Floor	C67	-20170.9
Ground Floor	C68	-19880.1
Ground Floor	C69	-18425.5
Ground Floor	C70	-14465.7
Ground Floor	C69	-18425.5
Ground Floor	C70	-14465.7

RESULT, ANALYSIS AND CONCLUSIONS

1) Approximate Time Period of Tower 1 and Tower 2 are different due to different base dimension in the direction of earthquake shaking.

For the Tower 1, base dimension along Global X is 40 m and 35 m in Global Y direction. For the Tower 2, base dimension along Global X is 40.3 m and 34.7 m in the Global Y direction. The Time period for Tower 1 in the Global X direction is 0.9107 seconds and in the Global Y direction is 0.9736 seconds. For the Tower 2, the Global X direction is 0.9076 seconds and in the Global Y direction is 0.9776 seconds.

2) Design Base Shear (V_B) is dependent on the S_a/g values. It is observed that the values of S_a/g are different for Tower 1 and Tower 2 in the Global X and Global Y directions.

Base Shear changes from 32026 KN in Tower 1 to 32144 KN in Tower 2 in the Global X direction. Also Base Shear changes from 29957 KN in Tower 1 to 29843 KN in Tower 2 in the Global Y direction.

3) It has been observed that Story Stiffness of Tower 2 is more than the Story Stiffness of Tower 1 as shown in Table 1.3 and 1.4. Story stiffness is calculated by the formula $12EI/h^3$ and moment of Inertia, I changes along its axis of consideration.

4) Impact of Orientation of building on Response Spectrum Analysis can be seen by Modal Direction Factors in Table 1.5 and 1.6. It is clear from Modal Direction Factors that the building behaves differently when it is rotated by 7º as in Tower 2, than its normal configuration as in Tower 1.

The first two modes are translational and third mode is rotational in nature. For the Tower 1, directional factors of the fundamental mode of oscillation are 0.128 in Global X and 0.798 in Global Y direction. However for the Tower 2, the directional factors of the fundamental mode of oscillation are 0.226 in Global X and 0.7 in Global Y direction.

5) Also from the Figure 1.5 and 1.6, it can be seen that the Time Period for the fundamental mode of oscillation changes for Tower 1 and Tower 2.

For the Tower 1, the Time Period for the fundamental mode of oscillation is 4.982 seconds whereas for the Tower 2, the Time Period for the fundamental mode of oscillation is 4.981 seconds.

6) Similarly variation is also observed in Modal Participating Mass Ratios as seen in the Table 1.7 and 1.8. In the fundamental mode of oscillation, participating mass ratio is 9.87% in Global X direction, whereas in Global Y direction the participating mass ratio is 61.38% in Tower 1.

For Tower 2, the modal participating mass ratio in Global X is achieved about 17.4% and 53.84% in Global Y direction.

7) Maximum Story Displacement is more in Tower 1 as compared to Tower 2 in the first mode of oscillation as shown in Table 1.9 and 1.10.

8) Column Design Forces are more in Tower 2 as compared to Tower 1 as shown in Table 1.11 and 1.12.

REFERNCES

1) Toshihiko Hisada, Masamitsu Miyamura "Studies on the Orthogonal Effects in Seismic Analyses" presented at the proceedings of Ninth World Conference on Earthquake Engineering (August 2-9, 1988).

2) Edward L. Wilson, Iqbal Suharwardy, and Ashraf Habibullah (*1995*) "A Clarification of the Orthogonal Effects in a Three-Dimensional Seismic Analysis".

3) K. Anastassiadis, I.E. Avramidis "Theory and application of orthogonal effects in a 3-D response spectrum analysis" (1996)".