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Seismic Response of Building with Irregular Geometric Configurations

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Abstract*-Earthquake is the most unpredictable and devastating natural disaster. Each and every year, our structures get damaged by this devastating natural disaster. The behavior of a building during an earthquake depends on several factors such as, mass, stiffness, strength, geographic location and geometric configurations. However, out of these factors, geometric configuration is the most common one that can be seen frequently in the reality. In the present study four common type of building configurations such as C, L, H, T shapes are taken into consideration to observe the effects of building configurations on seismic responses. Both the static and dynamic analyses were carried out. The base shear was considered as a parameter of interest. The static results were compared with the dynamic results and the responses of the regular building were compared with the building with irregular configurations. It was found that the building with irregular configurations have higher seismic responses as compared to the regular building.*

Keywords: Building configuration, Seismic response, Time History Analysis, Base shear and Story displacement

1. INTRODUCTION

Earthquake Ground Motions are the most dangerous natural hazards where both economic and life losses occur. Most of the losses are due to the damage of civil engineering structures. However, out of these structures, building is the most common which one is get damaged during earthquake. The structure should possess main attributes to perform well in earthquake, such as simple and regular configuration, adequate lateral strength, stiffness and ductility [1].

The behavior of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are shaking the ground [2]. In these modern days, most of the structures are involved with architectural importance and it is highly impossible to plan with regular shapes due to the limitations of property line, sufficient open space and recreational purposes. As a result, a large number of structures are being built with irregular shape. These irregular buildings are more susceptible to damage under the dynamic action of earthquake than regular one [3]. The irregularities of the asymmetric distribution of mass, stiffness and strength are main source of severe damages due to excessive floor rotations and translations [4]. So, the design of irregular buildings needs special care and enhancement of member sizes at regions of Irregularity. The plan configurations of structure have significant impact on the seismic response of structure in terms of base shear, displacement, story drift and acceleration [5].

Irregular buildings in our country are mostly designed based on the Equivalent Static Method according to BNBC. In Equivalent Static Method, a lateral force is applied on the building to simulate the earthquake load. However, the earthquake exerts a dynamic effect on the structures. If these buildings are designed in Static Method, their exact seismic response will not be predicted. Therefore, it is important to examine how the dynamic responses of irregular buildings vary from a static response. Moreover, the practical buildings possess different type of irregularities such as C shape, T shape, L shape, and H shape as shown in Fig. 1. Depending on the length (L) and width (B) of the building, the degree of irregularities will vary and thereafter the seismic response. However, in previous studies, these issues were now taken into consideration in details.

In this study, we considered four common shapes i.e. C, L, H and T. The degree of irregularities was defined based on the L/B ratio. Four L/B ratios were considered for each of those irregular shapes. In all the cases, the number of grid, dimension of slab, beam and column were kept same to ignore the effect of inertia. Both the static and dynamic analyses were carried by finite element based software namely; ETABS. The base shear is considered as a parameter of interest to observe the seismic response of irregular building.

Table 1: L/B ratios for various cases of C, L, H & T shapes.

	L/B		L/B		L/B		L/B
C1	2.4	L1	2	H1	3	T1	1.67
C2	1.67	L2	1.5	H2	1.6	T2	1.143
C3	1.33	L3	1.143	H3	1.167	T3	0.67
C4	1.1673	L4	0.875	H4	0.625	T4	0.417

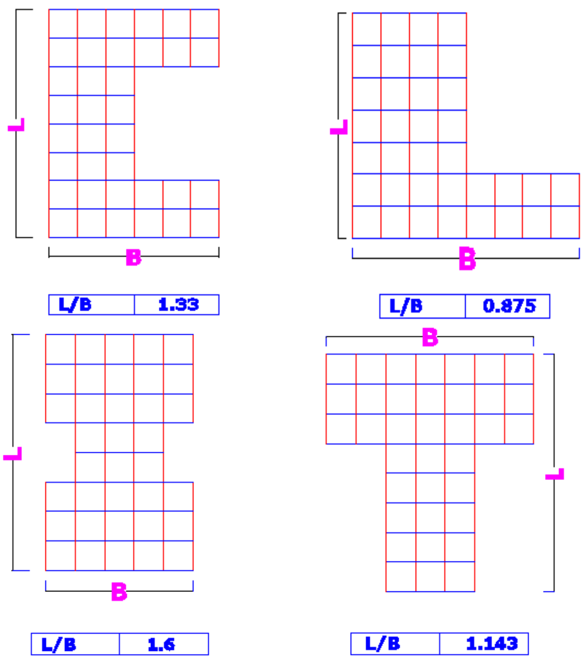

Fig. 1: Different parameters i.e. L/B for C, L, H & T shapes

2. METHODOLOGY

In Equivalent static method the total design base shear for a seismic zone is given by,[6]

$$V = \frac{ZIC}{R}W \qquad (1)$$

Lateral force calculated from the above equation known as base shear V, shall be distributed along the height of the structure in accordance with the following equation

$$V = F_t + \sum_{i=1}^{n} F_i \qquad (2)$$

Where, F_i = Lateral force applied at storey level i and F_t = Concentrated lateral force considered at the top of the building in addition to the force F_i.

For dynamic analysis method, Linear Time history analysis was carried out. It is a common technique for structural seismic analysis especially when the evaluated structural response is linear. To perform such an analysis, a representative earthquake time history is required for a structure being evaluated. Time history analysis is a step-by-step analysis of the dynamic response of structure to a specified loading that may vary with time. Time history analysis is used to determine the exact seismic response of a structure under dynamic loading of representative earthquake. In this study, it is applied in ETABS software.

To find the full time history of a structure's response, one must solve the structure's equation of motion. The general equation of motion is therefore,

$$[M]\{\ddot{D}\} + [C]\{\dot{D}\} + [K]\{D\} = \{F\} \qquad (3)$$

This gives the theoretical time history of the structure due to a load F. Where, M is the mass matrix, C is the damping matrix and K is the stiffness matrix. Finite Element method was used to solve this equation of motion and to obtain the seismic responses of the structure.
At first, all the target buildings were modeled, analyzed and designed by using ETABS. Then, a time-history function which characterizes load variation over time was defined and time history analysis was carried out. In the present study, three earthquake ground motions namely, Tokachi, Miyagi and Kumamoto were considered. The earthquake ground motions were scaled down or up to match the response spectrum of the BNBC recommendation. The Tokachi Oki earthquake occurred in 2003, Miyagi in 2003 and Kumamoto in 2016.

3. RESULT AND DISCUSSION

Table 1 summarizes the static base shear results of various shapes. As can be seen depending on the type and *L/B* ratio the magnitude of base shear alters a lot. Out of all these shapes, the maximum base shear is experienced by the C-shape building with a *L/B* ratio of 2.4. Tables 2 and 3 summarizes the dynamic base shear obtained from time history analysis in the X and Y-directions respectively. The magnitude of dynamic base shear is much higher than the static one. For better visualization, obtained base shears are plotted in Figs.2 and 3.
For any direction and type of building, the Tokachi earthquake has the highest responses and the Kumamoto has the lowest one. It can be seen the earthquake excitation, the type of building configuration and the degree of L/B ratio has noticeable influence on the base shear. In general, with increase in L/B ratio, the base shear decreases first, then with the further increase in L/B ratio the base shear increases. Out of these four shapes of building, the H shape has the highest responses. So it is the weakest shape. However, in case of static analysis, C shape had the highest base shear responses. In case of H shape, the base shear decreases with the increase in L/B ratio for X direction of earthquake. However, under Y direction earthquake the base shear increases with the L/B ratio. It was also found that out of all these shapes in terms of dynamic base shear values, L shapes shows the minimum responses. The L shape with a L/B ratio of 0.875 has the lowest value of base shear. In this paper, only base shear values are discussed. However, other dynamic responses such modal frequencies, roof acceleration, floor displacement and drift values also require to be explored for better understanding the effect of building configuration on seismic response of building.

Table 2: Base Shear Data of Different Shapes of Building Configuration for Static Analysis.

STATIC			
SHAPE	B/L	BASE -SHEARX (KN)	-BASE SHEARY (KN)
C1	2.4	2363.77	2363.77
C2	1.67	2351.90	2351.90
C3	1.33	2327.74	2313.06
C4	1.167	2304.17	2304.17

STATIC			
SHAPE	B/L	BASE -SHEARX (KN)	-BASE SHEARY (KN)
L1	2	2304.17	2304.17
L2	1.5	2304.17	2304.17
L3	1.143	2304.17	2304.17
L4	0.875	2304.17	2304.17

STATIC			
SHAPE	B/L	-BASE SHEARX (KN)	-BASE SHEARY (KN)
H1	3	2339.75	2339.75
H2	1.6	2304.17	2304.17
H3	1.167	2304.17	2304.17
H4	0.625	2328.19	2328

STATIC			
SHAPE	B/L	-BASE SHEARX (KN)	-BASE SHEARY (KN)
T1	1.67	2316.62	2316.62
T2	1.143	2304.17	2304.17
T3	0.67	2304.17	2304.17
T4	0.417	2328	2328

Table 3: Base Shear Dataof Different Shapes of Building Configuration for Tokachi, Miyagi and Kumamoto Earthquakes in X-direction.

		BASE SHEAR-X (kN)		
	L/B	TOKACHI	MIYAGI	KUMAMOTO
C1	2.4	33557.37	11418.58	7517.49
C2	1.67	32058.32	10880.35	7081.57
C3	1.33	27917.03	9955.12	5831.62
C4	1.167	30150.04	10622.35	6481.06

		BASE SHEAR-X (kN)		
	L/B	TOKACHI	MIYAGI	KUMAMOTO
L1	2	25719.61	16431.72	7940.07
L2	1.5	23241.95	13851.76	6414.33
L3	1.143	22788.23	12148.09	5813.82
L4	0.875	23566.67	12833.11	6116.30

		BASE SHEAR-X (kN)		
	L/B	TOKACHI	MIYAGI	KUMAMOTO
H1	3	23704.56	10524.49	5484.66
H2	1.6	30728.30	11147.24	6214.16
H3	1.167	32311.87	12281.54	6854.71
H4	0.625	48619.04	18024.19	9319.02

		BASE SHEAR-X (kN)		
	L/B	TOKACHI	MIYAGI	KUMAMOTO
T1	1.67	41724.30	17192.37	8082.42
T2	1.143	24474.11	12352.71	6045.13
T3	0.67	33383.89	12957.66	7081.57
T4	0.417	23468.81	8891.99	4657.29

Table 4: Base Shear Data of Different Shapes of Building Configuration for Tokachi, Miyagi and Kumamoto Earthquakes in Y-direction.

		BASE SHEAR-Y (kN)		
	L/B	TOKACHI	MIYAGI	KUMAMOTO
C1	2.4	40100.52	15929	6219.67
C2	1.67	33067.92	12250.3	5631.42
C3	1.33	27089.54	9207.77	4774.83
C4	1.167	26649.17	12277	6094.03

		BASE SHEAR-Y (kN)		
	L/B	TOKACHI	MIYAGI	KUMAMOTO
L1	2	40025.00	17405.80	7679.50
L2	1.5	33806.32	16308.10	6120.00
L3	1.143	30243.31	14608.11	6187.45
L4	0.875	23473.15	12681.18	5800.45

		BASE SHEAR-Y (kN)		
	L/B	TOKACHI	MIYAGI	KUMAMOTO
H1	3	45416.12	19082.8	8969.00
H2	1.6	32374.00	12502.1	7068.19
H3	1.167	27151.81	11125.0	6213.86
H4	0.625	26813.75	11093.0	6756.80

		BASE SHEAR-Y (kN)		
	L/B	TOKACHI	MIYAGI	KUMAMOTO
T1	1.67	39807.00	18433.30	7986.30
T2	1.143	32049.28	14176.40	6530.30
T3	0.67	22854.85	11067.10	6456.60
T4	0.417	27254.12	16009.00	7526.40

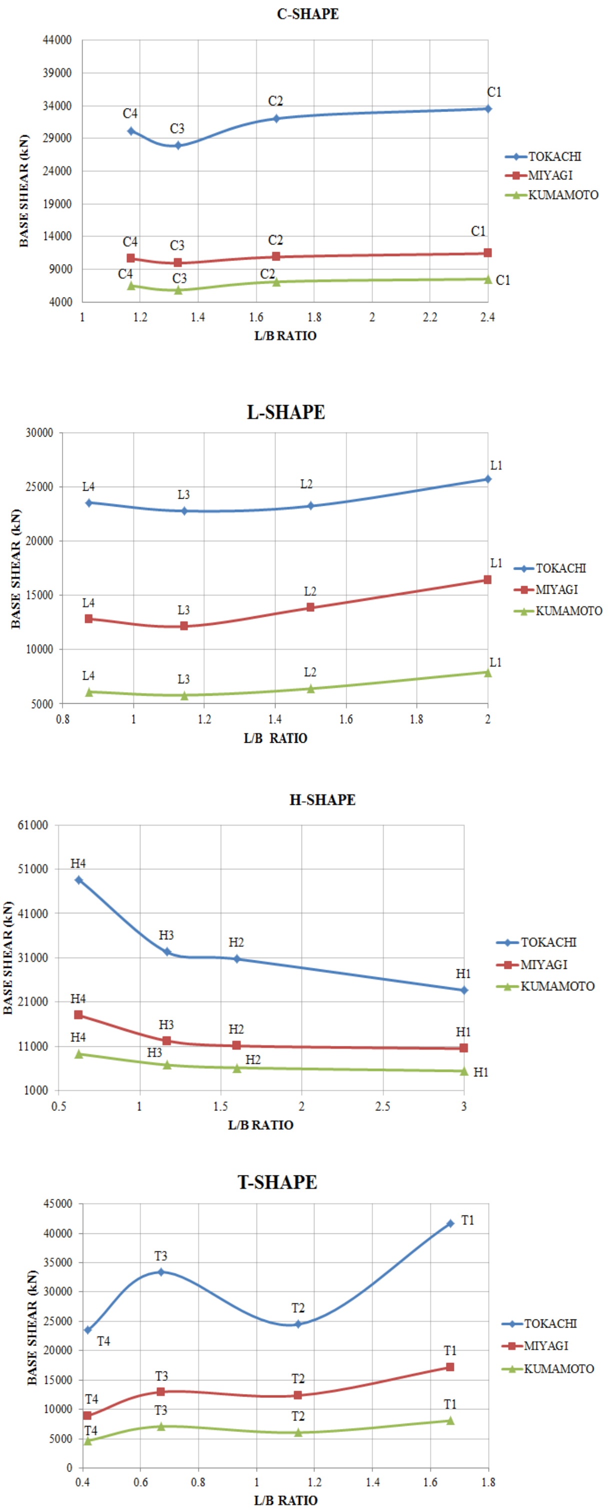

Fig. 2: Base shear Vs. L/B ratio graph of C, L, H & T shape building in X- Direction

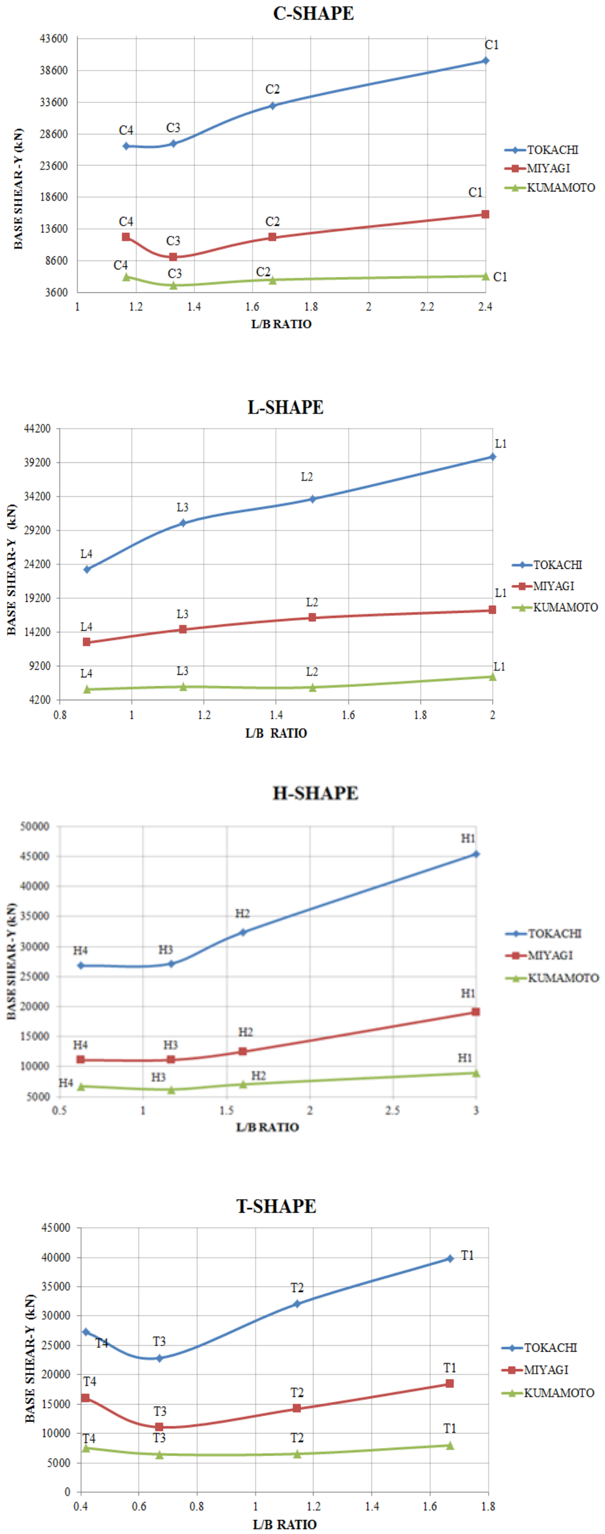

Fig. 3: Base shear Vs. L/B ratio graph of C, L, H & T shape building in Y- Direction

4. CONCLUSION

From the obtained results, following conclusions can be made:

1. The dynamic analysis must be carried to analyze and design of irregular shaped buildings as it was found that base shear increases significantly during the time of dynamic analysis as compared to the static one.

2. The irregularity of building has significant impact on the seismic response of structure.

3. The nature of building configuration and the magnitude of L/B ratio affect the seismic responses of structure.

4. Out of these four building configurations we

considered, it was found that the H shape has the highest base shear as compared to the other building configurations. So it can be said that, H shape is the weakest shape.

In the present analysis, only base shear was considered as a parameter of interest, however, further detail analysis is required by taking into consideration the other important responses such as modal frequencies, displacement, acceleration and drift etc.

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6. NOMENCLATURE

Symbol	Meaning	Unit
Z	Seismic zone co-efficient	Dimensionless
I	Structural importance co-efficient	Dimensionless Dimensionless
C	Numerical co-efficient	Dimensionless
T	Time Period	(s)
C_t	Numerical Coefficient	Dimensionless
h_n	Height of structure	(m)
S	Site Coefficient	Dimensionless
R	Response modification co-efficient	Dimensionless
W	Total seismic dead load	(kN)
V	Base Shear	(kN)