9th US National and 10th Canadian Conference on Earthquake Engineering: *Reaching Beyond Borders*
toronto july 25-29, 2010
9ième Conférence Nationale Américaine et 10ième Conférence Canadienne de Génie Parasismique: *Au delà des Frontières*

Conference Co-Sponsors
Earthquake Engineering Research Institute
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HOW DIFERENT SEISMIC CODES DEFINE TORSIONALLY UNBALANCED STRUCTURE?

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ABSTRACT

Intensive research in restricting inelastic damage in torsionally unbalanced building has been done. But it is not clear what can be defined as a torsionally irregular building? In this study, the torsional irregularities criteria as suggested by 54 countries seismic codes are compared with each other.

Generally, seismic codes consider either in plan eccentricity or/and story drift for assessing torsionally irregularity. But seismic codes differ from each other in two aspects: 1) Definition of the above parameters (i.e. plan eccentricity and story drift) 2) The numerical limits of the above parameters where a building can be considered torsionally balanced system.

In order to compare various code provisions, we classified one 8 stories either as regular or irregular according to different codes. The results were in contradiction to each other, i.e. while the building was regular according to some codes, it was irregular due to others.

These contradictory results are mainly due to non uniform definition for an unbalanced system. The complexity involved in determining parameters such as location of center of rigidity can be another reason for contradiction results. Hence, it seems that more research is needed to reach generally accepted criteria for defining a torsionally unbalanced system.

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Key Words: Torsionally Unbalanced Systems, Torsional Irregularity criteria, Plan eccentricity, Story Drift

Introduction

It is well known that irregular buildings have been shown poor behavior during an earthquake.

Irregularities in a building can be either in plan or height. A building which has stiffness eccentricity or strength eccentricity are sensitive to torsion and when eccentricities exceeds certain value refer as torsionally irregular buildings.

When torsionally irregular buildings are subjected to earthquakes, an interaction between the lateral and torsional responses occurs. This interaction of responses can lead to more damage in irregular building compared to a regular building. This extra damage has been a concern in seismic building codes and has been the subject of many researches.

Although various seismic codes have defined irregularities, but there is much difference between codes in definition of a torsional irregular building.

This paper clarifies fundamental differences of building codes in definition of torsional building. For these purpose torsional irregularities criteria for 54 seismic codes have been gathered and compared. Also an illustrative example 8 stories building is classified according to several codes.

In general, story drift (roof displacement) and static eccentricities are major parameters in recognizing torsional irregular building between various seismic codes. But they have major drawbacks that we clarify as below:

Static eccentricity

Based on most building code, A building classified as torsionally irregular building if e_s exceeds a certain value λ, i.e.:

$$e_s > \lambda \tag{1}$$

Where e_s static eccentricity; λ is a parameter differs from various codes that detailed as follows:

$$\lambda \begin{cases} 1-\alpha\, b \\ 2-\beta\, r_s \\ 3-\gamma\, r_e \end{cases} \tag{2}$$

Where b plan dimension of the j-th floor perpendicular to the direction of ground motion; and α, δ and β are specified constants; r_s torsional radius; r_e Radius of inertia. Using equations (2) and values α; β, γ depend on the specific code.

eq. 1 has the following drawbacks:

1- No generally acceptance definition of the static eccentricities for multistory buildings exists among codes (Kan and Chopra 1981). In the other hand, although the concept of eccentricity static is used, there is no agreement in the definition of eccentricity. Some codes define eccentricity as a distance between center of mass and shear center. Others define eccentricity as a distance measured from center of rigidity.

2- In addition, unlike one-story buildings there are several difficulties in locating of center of rigidity in multistory buildings.

For instance, seismic codes in the united state use center of rigidity as a parameter for determination of torsional buildings but they have not addressed clear guidelines to locate centers of rigidity in multistory buildings.

3- Nevertheless of all above, numerical value λ that limit regular building are not same between seismic codes and varies significantly in different seismic codes, for example:

α Vary from (10, 1 5, 16.6, 20, 13) % b;

β Vary from (15, 30) % r_s;

And γ Vary from (15, 20) % r_e; that

: $r_e = \sqrt{\frac{I_o}{m}}$ Radius of inertia; $r_s = \sqrt{\frac{k_\theta}{k_h}}$ torsional radius

The provisions of seismic codes for plan eccentricity and story drift is summarized in tables 1, 2 (World list 2002).

Table 1. Torsional irregularity an aspect of various seismic codes-story drift criteria

<table>
<tr><th>Group</th><th colspan="9">Torsional irregularities definition</th></tr>
<tr><td rowspan="2">Group 1</td><td>United State of America</td><td>Iran IS- 2800 3rdEdition</td><td>India, IS-02</td><td>Chile</td><td>Colombia</td><td>Ecuador</td><td>Korea</td><td>Philippines</td><td>Turkey</td></tr>
<tr><td colspan="9">Maximum story drift, computed including accidental torsion, at the end of the structure transverse to an axis is more than 1.2 times the average of the story drifts at the two ends of the structure.</td></tr>
<tr><td rowspan="2">Group 2</td><td colspan="9">Yugoslavia</td></tr>
<tr><td colspan="9">Maximum story drift, computed including accidental torsion, at the end of the structure transverse to an axis is more than 1.4 times the average of the story drifts at the two ends of the structure.</td></tr>
<tr><td rowspan="2">Group 3</td><td colspan="9">SI 413-1995</td></tr>
<tr><td colspan="9">The maximum calculated story drift, including torsional effect, shall not be greater than 50% of the drift at the opposite end of same story.</td></tr>
<tr><td rowspan="2">Group 4</td><td colspan="9">NBCC-05</td></tr>
<tr><td colspan="9">Maximum displacement on a diaphragm in the direction of loading is 1.7 times the Average displacement of the diaphragm in the direction of loading (McKevitt, 2003).</td></tr>
<tr><td rowspan="2">Group 5</td><td colspan="9">NZS 4203-92</td></tr>
<tr><td colspan="9">The ratio of the horizontal displacements at the ends of an axis transverse to the Direction of the applied lateral forces shall be in the range 3/7 to 7/3.</td></tr>
</table>

Table 2. Torsional irregularity an aspect of various seismic codes- eccentricity criteria

Country/Code	Torsional Irregularities definition
America El Salvador Switzerland Hungary Mexico	Buildings having an eccentricity between the static center of mass and the static center of resistance in excess of 10 percent of the building dimension perpendicular to the direction of their seismic force.
Albania Algeria Portugal	Eccentricity between the static center of mass and the static center of resistance in excess of 15 percent of the building dimension perpendicular to the direction of the seismic force.
Jordan	Eccentricity exceeds 1/6 the total length of the structure perpendicular to the direction of the earthquake.
Iran Turkey Egypt	Eccentricity between the center of mass and the center of rigidity is not greater than 20 percent of the plan dimension perpendicular to the direction of loading.
Indonesia New Zealand	The horizontal distance between the shear center at any level and the center of mass of all levels above shall neither exceed 0.3 times the maximum plan dimension of the structure at the particular level, measured perpendicular to the direction of the applied lateral forces.
Japan	Eccentricity of each story to be obtained by the following formula dose not exceeds 15/100 or Stiffness ratio of each story is 6/10 or more.
Venezuela	The eccentricity between the shear action line and rigidity center of a given level surpasses 30% of the value of the torsional radius in any direction.
Eurocode8-03	At each level and for each direction of analysis x and y, the structural eccentricity e_o and the torsional radius r shall be in accordance with the two conditions below, which are expressed for the direction of analysis y $e_{ox} \leq 0,30 \cdot r_x$; $r_x \geq l_s$
Ghana	At any story distance the between the center of mass and that of stiffness do not exceed 15% of the resistance radius.
Greece	The angle of torsional stiffness relative to the mass center of each diaphragm is smaller or equal to the radius of inertia of the diaphragm.
Israel	The distance between the mass and stiffness centers shall not exceed 15% of the rigidity radius.

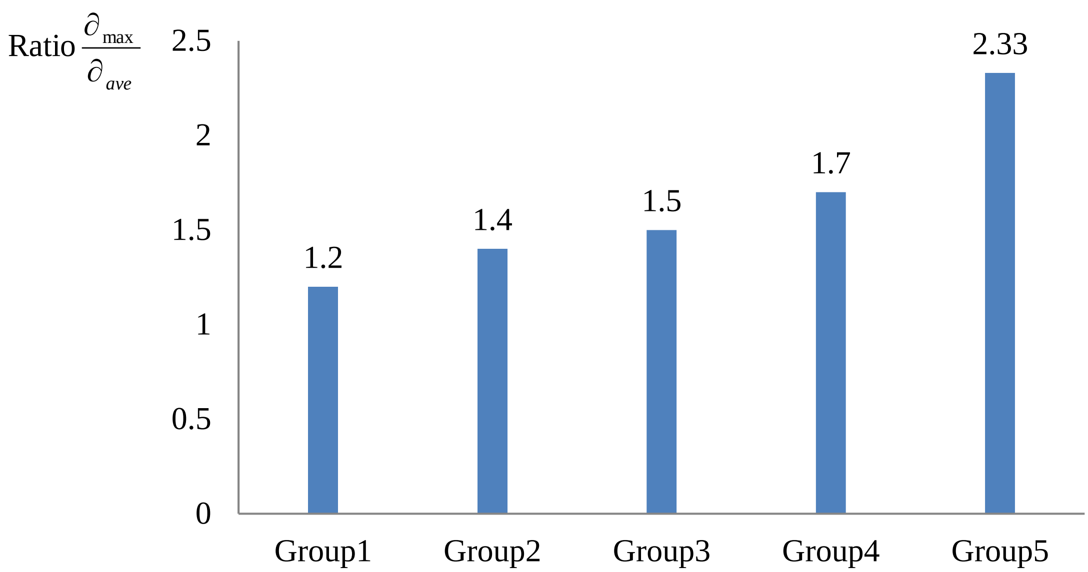

Figure 1. Comparison of buildings classification provision with story drift

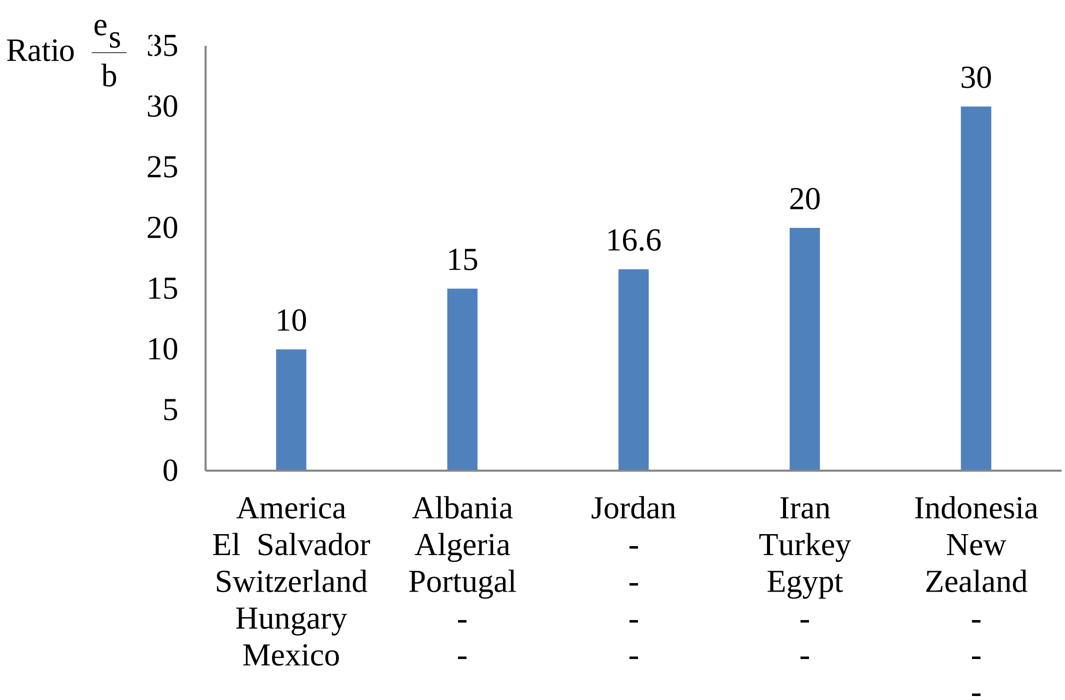

Figure 2. Comparison of buildings classification provision with plan eccentricity

According to Figs. 1, 2 there is no clear target that we can obviously determined torsionally unbalanced buildings.
Illustrative example

An eight stories building as shown in fig.3 consider as case study. The building has uniform story heights of 3m. Concentric braced frame is assumed as lateral resisting system in the y- direction and in the x- direction moment frame system is assumed. Framing, column and bracing plan of the building is shown in figs. 3, 4 and member sizes are shown in table 3.

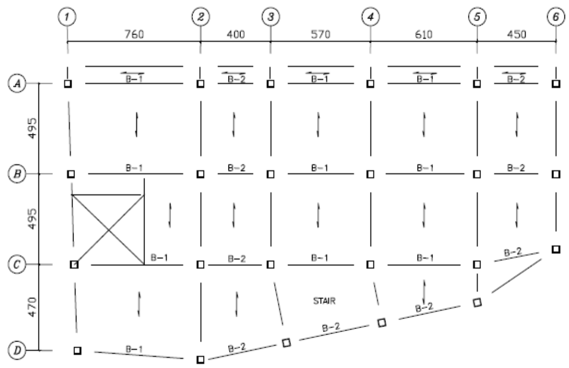

Figure 3. Typical framing plan of 8 story building

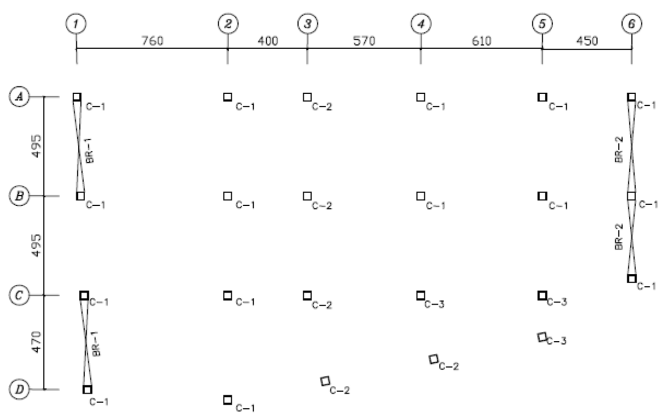

Figure 4. Column & bracing plan of 8 story building

Table 3. Member sizes of eight stories building

Section properties	C-1		C-2		C-3	
	h_w	t_w	h_w	t_w	h_w	t_w
Story 1-3	350	25	300	25	300	15
Story 3-6	350	20	300	20	300	12
Story 6-8	350	15	300	15	300	10

Section properties	B-1				B-2			
	h_w	t_w	b_f	t_f	h_w	t_w	b_f	t_f
Story 1-3	400	10	250	25	400	10	250	20
Story 4-6	400	10	250	20	350	10	200	20
Story 5-8	350	10	200	20	350	10	200	15

BR-1	BR-2
2UNP200 (story1-5) ,2UNP180 (story6-8)	2UNP180 (story1-5) ,(story6-8) 2UNP160

Table 4 shows the location of center of mass and center of rigidity for all floors as well as corresponding eccentricities. Classification of the building according to various seismic codes is Summarized in table 5.

Floor	CMS		CRS		Plan Ecc. x dir.	Plan Ecc. y dir.	Plan Ecc. ratio	
J	X_{CMj} (m)	Y_{CMj} (m)	X_{CRj} (m)	Y_{CRj} (m)	$e_{sxj} = (x_m)_j - (x_R)_j$ (m)	$e_{syj} = (y_m)_j - (y_R)_j$ (m)	e_{sxj}/l_j -	e_{syj}/b_j -
1	13.356	8.174	14.192	7.774	0.836	0.4	0.03	0.034
2	13.449	8.002	14.609	7.459	1.16	0.543	0.04	0.046
3	13.824	9.303	15.138	7.324	1.314	1.979	0.05	0.167
4	13.809	9.313	15.7	7.354	1.891	1.959	0.07	0.166
5	13.832	9.33	16.192	7.455	2.36	1.875	0.08	0.158
6	13.883	9.355	16.644	7.619	2.761	1.736	0.10	0.147
7	13.845	9.351	17.006	7.71	3.161	1.641	0.11	0.139
8	13.72	9.377	17.323	7.81	3.603	1.567	0.13	0.132
					Max 3.603	Max 1.979	Max 0.13	Max 0.167

Table 4. Location of center of rigidity at various levels of 8 stories building

Table 5. Classification of the e stories building with various codes

Country	λ	Max $(e_s)_y$	Max (e_s/λ)	Classification
America El Salvador Switzerland Hungary Mexico	10%b =1.176	1.979	1.68	Irregular building
Albania Algeria Portugal	15%b =1.764	1.979	1.12	Irregular building
Jordan	16.6%b =1.95	1.979	1.02	Irregular building

Iran Egypt Turkey	20%b =2.35	1.979	0.84	Regular building
Indonesia New Zealand	30%b =3.53	1.979	.59	Regular building

It should be mentioned here that various codes classification criteria lead to contradictory results. On the other hand, building is regular according to codes while it is irregular according to others.

Conclusion

Structures shall be classified as regular or irregular based on the specified criteria in the seismic codes. A review of the various seismic building codes clearly shows that there is no unique acceptance definition for an irregular torsional building.

The complexity involved in determining parameters such as static eccentricity. Building code provisions to classified torsional buildings are based on centre of rigidity or shear center of the building while, Seismic codes do not have unique and acceptance definition for center of rigidity. Also, a general procedure to locate center of rigidity or center of shear in multistory buildings is not yet available.

Besides, Story drift is another classification criterion. But certain nominal limit for story drift does not exist and it widely varies among various codes.

Therefore, it is desirable to develop an alternative method that can be clearly distinguishing torsion ally irregular buildings.

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