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REVIEW ARTICLE

SEISMIC TORSIONAL BEHAVIOR OF A TESTED FULL-SCALE STEEL BUILDING

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ARTICLE DETAILS

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ABSTRACT

Based on shaking experiment results of a full-scale 4-story steel building conducted on E-Defense – the world largest shaking table in Japan, the characterization of twisting behavior can be achieved. Exploration on twisting motion of the specimen building is presented in this paper, addressing global rotational responses in various increasing excitation levels. Study results show that the torsion movement of the building is mainly due to story mass eccentricity. On the other hand, the shaking-table also causes considerable influence on the building twisting response. System identification and mode superposition of response translational acceleration at floor mass centers are carried out. Some justifications for stiffness of non-structural are also presented, through which we can get a more precise basis to determine stiffness contribution of each component.

KEYWORDS

Shaking Experiment, Twisting, Mass Eccentricity

1. INTRODUCTION

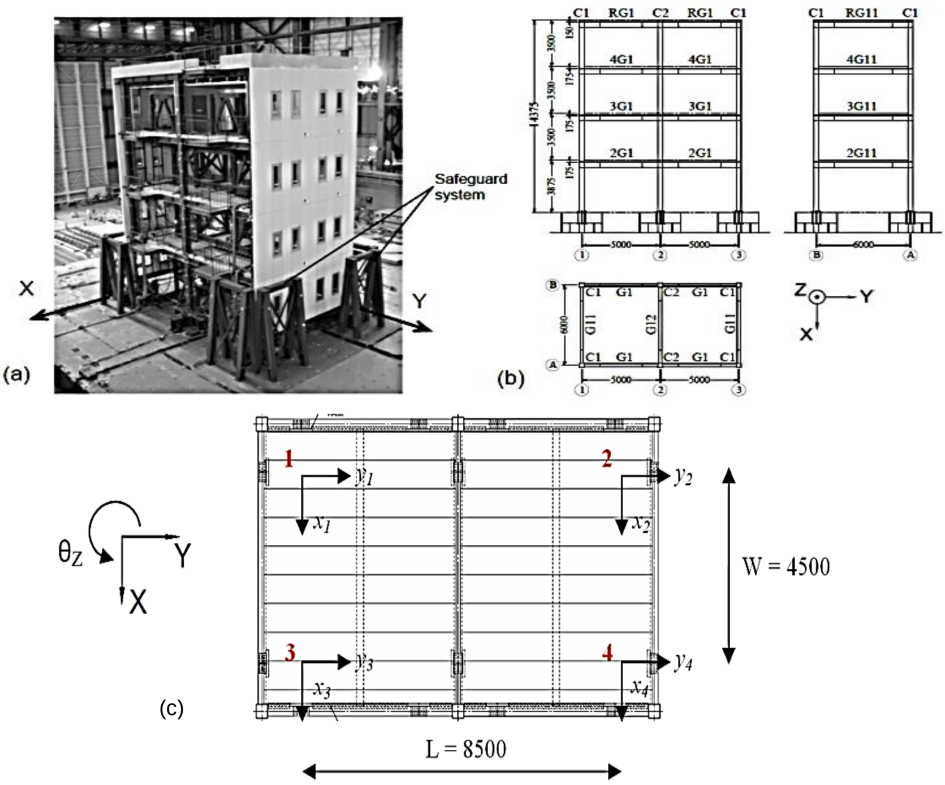

Figure 1: Specimen building: (a) overview, (b) elevation and plan, (c) accelerometer layout

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The experimental responses of the specimen building under the weak, strong and collapse shaking levels were formerly reported by (Suita et al., 2009; Yamada et al., 2009; Shimada et al., 2010). Some other researchers such as numerically simulated and analyzed the building responses during the shaking test. Almost studies focused on the physics of structural behavior, such as evaluated the collapse response on global perspective; whereas and examined local behavior of beams, panel zones and columns. Behavior of non-structural components observed in the test was particularly described by (Isobe et al., 2013; Kasai et al., 2016; Pan et al 2008; Miyamura et al., 2014; Yu et al., 2010; Tada et al., 2008; Maison et al., 2009; Yamada et al., 2009; Shimada et al., 2010; Matsuoka et al., 2009). However, there have not been any studies mentioning the eccentricity and twisting motion of the specimen building. Hence, this paper provides a further exploration on the test results, addressing torsional eccentricity and its effect on the global rotational responses in varying excitation levels.

Torsional deformation of a building during seismic incidents is relatively small and thus commonly negligible in structural design. However, based on a shaking-table experimental record of a full-scale four-story steel building twisting motion of the frame, in contrast to its translational response, was inverse proportional to excitation load levels (Kasai et al, 2016). The specimen building is a full-scale four-story steel moment frame figure 1, shaken to collapse on the E-Defense shaking-table facility in Japan. The ground acceleration histories recorded at Takatori station during the 1995 Japan Kobe earthquake (herein referred to as Takatori motion) were used as the input for the test. Accelerometers are installed at four corners of the floor. By taking the difference between those records, the torsional acceleration at the floor center can be obtained.

2. Torsional Motion of The Building

Due to the fact that the shaking-table contains certain torsional component in the input motion, especially when the shaking level increases from 20% to 40% and 60% as shown in figure 2, torsional input motion is definitely one of the causes of the building's twisting motion. Natural torsional vibration period of the building can be evaluated from Fast Fourier transform (FFT) of the building's response torsional acceleration, as shown in figure 3. It indicates that the natural period of torsion increases from 0.58 to 0.65 sec when the excitation level strengthens.

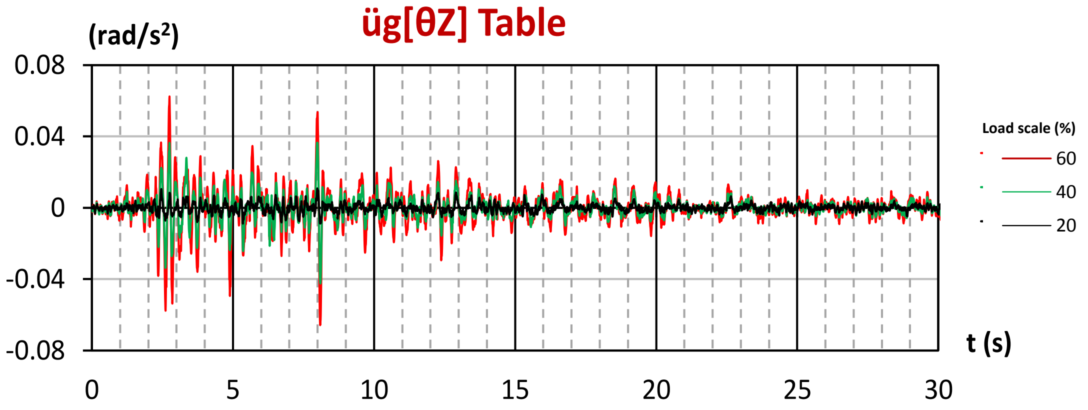

Figure 2: Input torsional acceleration (applied by the shaking-table)

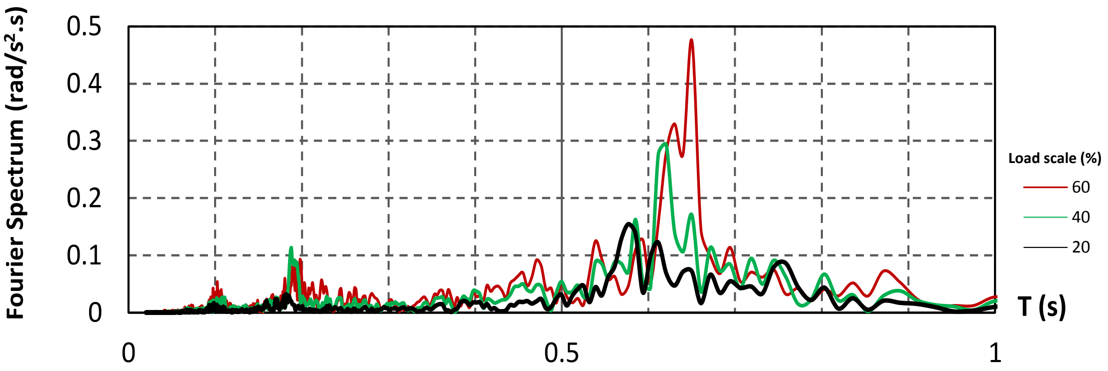

Figure 3: Fourier spectrum of absolute torsional acceleration (RF)

Assuming damping ratio h=0.03, response spectrum for the torsional input motion of each excitation level is plotted in figure 4. Spectral torsional angle corresponding to the building's natural torsional period can be approximately evaluated as follows: 0.0002 rad, 0.0005 rad and 0.0008 rad for 20%, 40% and 60% Takatori load scales, respectively.

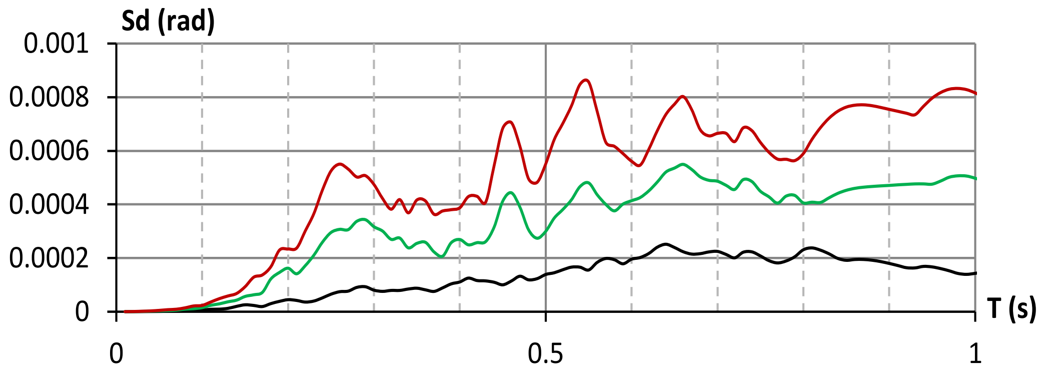

Figure 4: Response rotation spectra of the input torsional motions (damping ratio h=0.03)

3. Torsional-translational Coupling

The relative torsional angle at the building's equivalent height (H_{eq}) is computed approximately equal to 2/3 of relative rotation angle at the roof floor, and plotted in figure 5. It is apparent that the peak magnitude of the wave curve during the post-shaking time (i.e. from 13.0 to 30.0 sec) is consistent with the spectral rotation angle obtained above. This confirms the effect of input torsional motion that causes the building's twisting behavior during this time.

Detailed clarification is given in figure 6 which compares the relative torsional angle at H_{eq} between experimental record and SDOF analytical result assuming damping ratio h=0.03. An example of torsion behavior in case of 40% load scale is selected to show in the figure. The analytical result almost agrees with the experiment record during the post-shaking time. Significant difference is exhibited only in the beginning stage when the translation motion is large. Torsional-translational coupling due to the building eccentricity is thought to be the reason for this phenomenon.

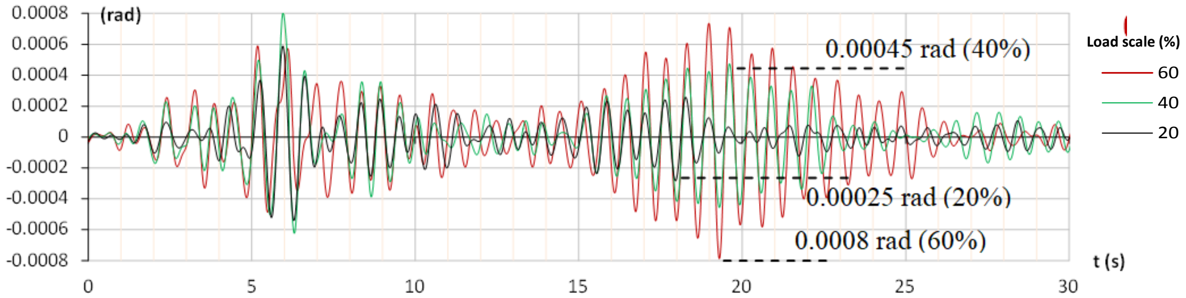

Figure 5: Experimental torsional relative rotation angle at H_{eq} = 2/3H

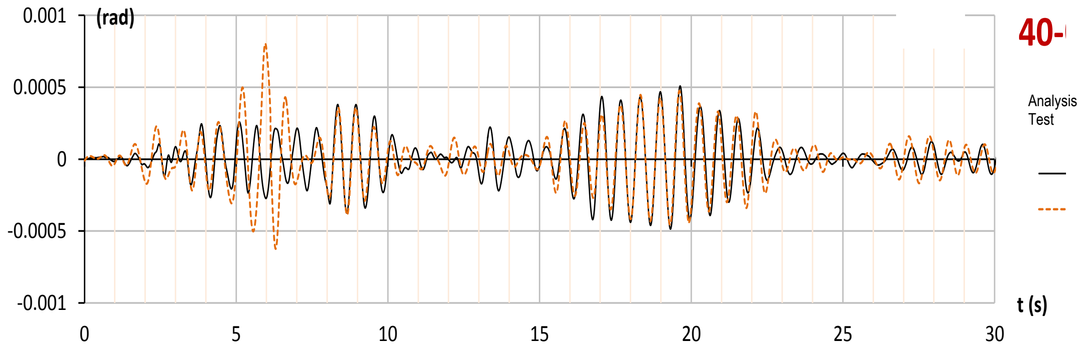

Figure 6: Relative torsional angle at H_{eq} (40% Takatori loading)

Torsional-translational coupling is created when the center of mass and the center of rigidity in the building do not coincide. Because the configuration of this building mostly has the eccentricity in the X direction figure 7, it is necessary to calculate the center of mass (x_{CM}), center of rigidity (x_{CR}) and torsional eccentricity (e_X) of each story with respect to the X direction. The results are given in table 1. Note that, in order to obtain center of rigidity, story shear stiffness of non-structural components ($K_{ns,Y}$) is computed by taking difference between the inertial-force-based story shear stiffness ($K_{bu,Y}$) and the frame-based story shear stiffness ($K_{fr,Y}$). Then, assuming claddings and partition walls having same stiffness, we can use Eq. 2 to calculate x_{CR} as shown in table 2.

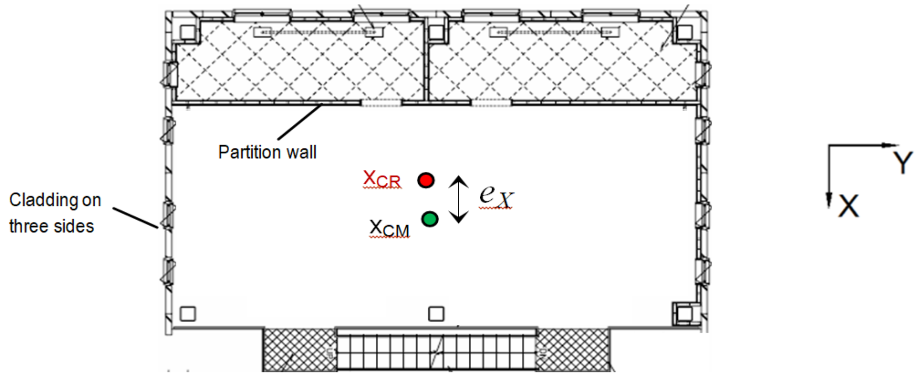

Figure 7: Center of mass and center of rigidity on building plan

Table 1: Story Eccentricity

Story	Center of mass [mm] $x_{CM} = \frac{\sum m_i x_i}{\sum m_i}$ (1)	Center of rigidity [mm] $x_{CR} = \frac{\sum k_{Yi} x_i}{\sum k_{Yi}}$ (2)	Torsional eccentricity [mm] $e_X = x_{CM} - x_{CR}$ (3)
4	-108	-327	219
3	-342	-515	173
2	-383	-489	106
1	-322	-324	2

Table 2: Story Shear Stiffness (Y-dir)

Story	$K_{bu,Y}$ [kN/rad]	$K_{fr,Y}$ [kN/rad]	$K_{ns,Y} = K_{bu,Y} - K_{fr,Y}$ [kN/rad]	$K_{ns,Y} / K_{bu,Y}$	x_{CR} [mm]
4	89500	76400	13100	0.15	-327
3	96800	76400	20400	0.21	-515
2	102000	81600	20400	0.20	-489
1	132900	120200	12700	0.10	-324

The effect of rigidity eccentricity and mass eccentricity on torsional behavior of the building can be proved through identification results by an ambient vibration experiment conducted by (Kanazawa et al., 2008). This study indicates that when the partition walls and ceilings have been completely installed, the building's natural frequency in Y direction rapidly increases by about 15 percent. In contrast, the natural frequency in X direction almost does not change, compared to the time when the bare frame was initially erected. It is because the partition walls are light in weight but strongly contribute additional stiffness in Y direction, therefore natural frequency can increase only in this direction. Torsional mode arises more obviously in both 1st mode X and 1st mode Y, showing the increase of building's torsional eccentricity due to the shifting of rigidity center. Finally, when the building has finished all installation works, torsional mode only appears in 1st mode Y, and almost vanishes in 1st mode X. This is consistent with the building eccentricity which is more dominant on X-side rather than on Y-side.

4. Conclusions

- The study explores twisting motion of the specimen building, addressing global torsional responses in varying excitation levels. Study results show that the torsion movement of the building is mainly due to story torsional eccentricity. On the other hand, the shaking-table also causes considerable influence on the building's twisting response.

- Some justifications for stiffness of non-structural components are also presented. The installation process of those components contributes to the building eccentricity, resulted in torsional-translational coupling effect. However, the additional stiffness disappears in the large deformation state, thus the magnitude of building's torsional angle does not increase proportionally with excitation levels

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