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A MODEL SHAKING TABLE TEST INVESTIGATION ON AN ASSEMBLY FRAME

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A shaking table test on a two-story aluminum alloy space frame model with mortise and tenon joints were carried out. The natural frequency and the damping ratio of the model in two directions were obtained by vibration frequency sweep. Inputting EL-Centro (N-S) 0.1g, 0.2g and 0.4g seismic motion, the strain, displacement and acceleration response of the model structure were investigated. It shows that the mortise and tenon joint frame has lower natural vibration frequency, higher damping ratio, better ductility, and better seismic performance than the corresponding rigid connecting structure.

Keywords: Mortise and tenon connection, Seismic wave, Vibration characteristics, Seismic response.

1 INTRODUCTION

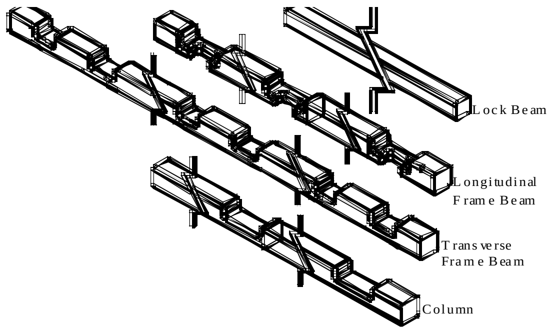
In steel frame design and analysis, the connections of beam-column are usually assumed as either rigid or pinned. Although in this hypothetical case the structure analysis and design procedures are greatly simplified, it is not consistent with the practical situation. In reality, every connection lies somewhere between these two extremes which perform the semi-rigid property. Therefore, the semi-rigid connections are ubiquitous in the engineering projects, and the mechanical behavior of joints, which affect the whole structure, cannot be ignored.

The typical steel beam-to-column fastening connection is composed of deformable parts such as angles, plates, welds, bolts, etc. Many scholars have studied in depth the mechanical behavior of these connections. They set up various databases and calculation models for typical steel beam-column semi-rigid joints, which provided a more reasonable and convenient base for structure analysis.

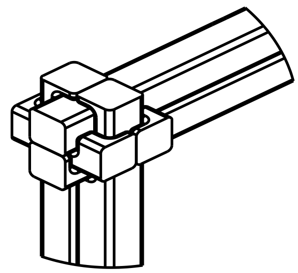
The authors propose a new kind of assembly steel tube space frame with the mortise and tenon joints (Duan et al. 2010, 2011), through researching characteristics of ancient architecture wood structure with the mortise and tenon joints (Carl et al. 2002, Gao et al. 2008) and combining it with a modern light-steel frame. It is constructed by some special components shown in Figure 1. In this paper, a shaking table test on a single span and double-story aluminum alloy space frame model with mortise and tenon joints was carried out and investigated.

2 FRAME MODEL DESIGN

The tests were carried out in Structural laboratory of Shijiazhuang Tiedao University. Considering the limited size and capacity of the shaking table used, a 1:10 scale space frame model was designed. The frame model and shaking table is shown in Figure 2. In the model, the column height is 2 × 450 mm, the beam span in the x-axis is 700 mm, and y-axis 600 mm. Assuming that the acceleration table similitude scale factor is 1:1, the model material selected was 2A12 hard aluminum alloys bar (see Table 1) with a cross section of 20 mm × 20 mm. The frame model density similitude scale factor is satisfied by an additional weight of 20kg for every floor.



(a) Elements



(b) Mortise and tenon joints

Figure 1. Assembly space frame and its components.

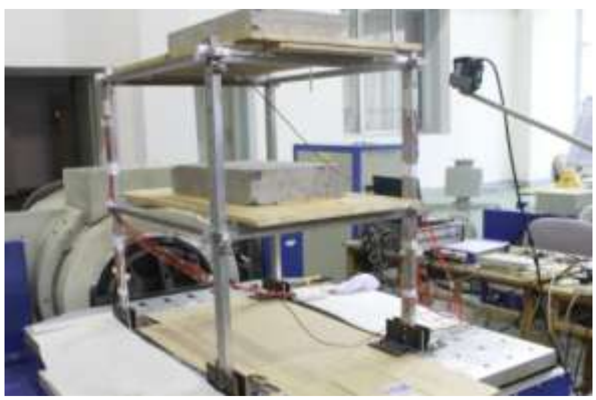


Figure 2. Frame model and shaking.

3 SHAKING TABLE TEST INVESTIGATION

3.1 Input Motions and Arrangement of Measuring Transducers

The excitation tests to the model were carried out in the x and y axis respectively. A high precision laser displacement sensor KEYENCE was installed to capture the horizontal displacement at the column top with a frequency of 50 Hz. Three accelerometers were installed to capture the acceleration responses for the different floors. Twenty strain gauges were installed at the critical positions of the column to assess the stress state of the frame.

The input motions for every direction consisted of two parts: (1) Sine wave excitation test for getting the frame vibration characteristics by sweep excitation; (2)

Seismic wave excitation test in three consecutive stages with increasing magnitudes of earthquake excitations, in which the 1940 EL Centro earthquake (EW direction) record was selected as the input motion. The sequence of the shaking table tests is shown in Table 2.

Table 1. Material properties of the model.

Material	Young's modulus E (Gpa)	Poisson ratio μ	Density ρ ($kg{\cdot}m^{-3}$)	Tensile strength / (Mpa)	Compressive strength (Mpa)
2A12 aluminum alloys	70	0.33	2700	425	275

Table 2. Sequence of the shaking table tests.

Type of test	Order number	Excitation	Vibration direction	Input value(g)	
				set	actual
sweep	1	Sine wave	*x*	0.1	-
	2	Sine wave	*y*	0.1	-
Stage 1	3	EL-Centro	*x*	0.1	0.098
	4	EL-Centro	*y*	0.1	0.115
Stage 2	5	EL-Centro	*x*	0.2	0.311
	6	EL-Centro	*y*	0.2	0.285
Stage 3	7	EL-Centro	*x*	0.4	0.476
	8	EL-Centro	*y*	0.4	0.498

3.2 Model Vibration Characteristics

From vibration frequency sweep to the model for the *x* and *y* directions, the corresponding the first-order natural vibration frequencies and the damping ratios are obtained as shown in Table 3.

The first-order natural vibration frequency of the model frame in the *x*-axis is bigger than the one along the *y*-axis, because the lateral stiffness of the model in the *x*-axis is higher than the one along the y-axis, due to the span, connection, the special joint structure, and so on. For the corresponding rigid connection fame, the first-order natural vibration frequency is 13.4 Hz by analysis, which is well over the present.

Table 3. Sequence of the shaking table tests.

Vibration direction	First-order vibration frequency (Hz)	Damping ratio (%)
x	6	8.7
y	4	11.4

The damping ratio of the model along the *x*-axis is smaller than the one along the *y*-axis, but both bigger than 0.05, whose value is the damping ratio of the rigid steel frame by the GB50011-2010. In the present model, impact and friction occur between the contact surfaces of the mortise and tenon, and earthquake energy is dissipated in the frame vibration, so its better seismic performance can be confirmed.

3.3 Seismic Responses

In order to save space, the strain and acceleration responses by strong earthquake excitations (0.4 g) are only demonstrated as follows:

3.3.1 *Typical cross-section strain*

(1) Model excitation in the *x*-axis: The strain response at the column foot in the *x*-axis is shown in Figure 3. The tensile and compressive strains for same cross section are approximately symmetrical. The maximum normal stress of 15.3 Mpa is far less than the model material strength, so the model frame materials are in a linear state.

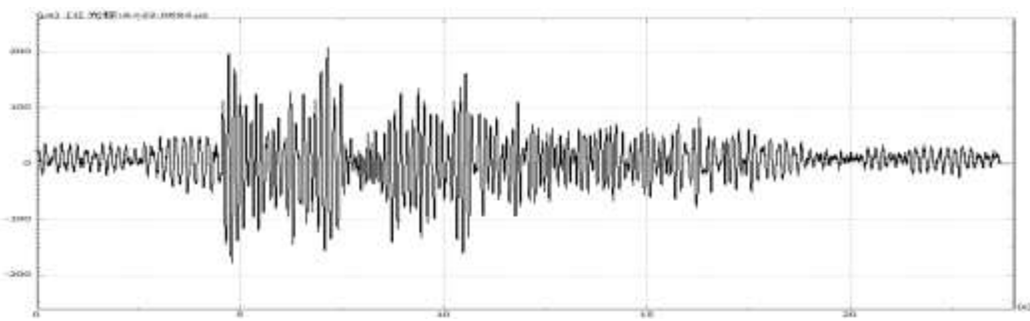


Figure 3. Strain response at the column foot in the *x*-axis.

(2) Model excitation in the *y*-axis: The strain response at the column foot in the *y*-axis is shown in Figure 4. It shows the distribution characteristics similar to the *x*-axis, but the strain response is greatly reduced.

3.3.2 *Acceleration and its amplification factor*

(1) Model excitation in the *x*-axis: The acceleration response at the top floor in the *x*-axis is shown in Figure 5. The amplification factor of acceleration is defined as the ratio of the maximum value at floor *i* to the maximum value at the shaking table (Table 4). Note that acceleration response increases with the input acceleration increase; the amplification factor of acceleration has a relatively small increase from base to first floor as compared with first to second floor; the acceleration variation is small in general, response values basically are in the range of 1 to 2.

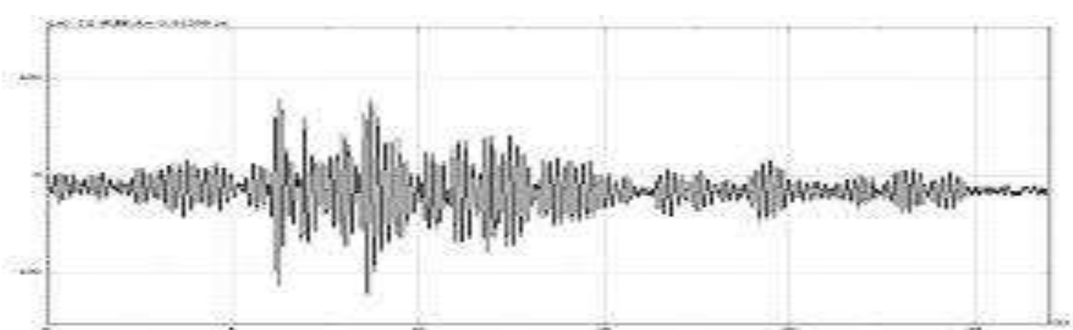


Figure 4. Strain response at the column foot in the *x*-direction.

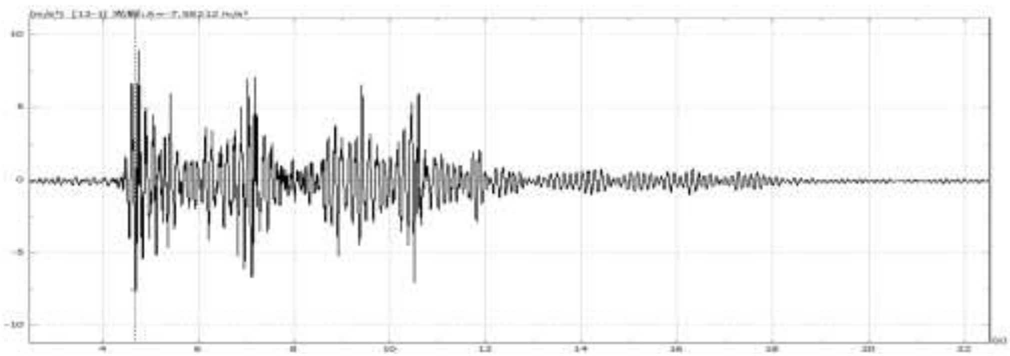


Figure 5. Acceleration response at the top floor in the *x*-direction.

Table 4. Acceleration peak value and its amplification factor *K* in the *x*-direction.

location	response	stage		
		0.1 g	0.2 g	0.4 g
foot	peak value (g)	0.109	0.239	0.431
	amplification (K)	1.000	1.000	1.000
first floor	peak value (g)	0.139	0.354	0.565
	amplification (K)	1.275	1.481	1.311
top floor	peak value (g)	0.372	0.503	0.843
	amplification (K)	3.413	2.105	1.956

(2) Model excitation in *y*-direction. The acceleration response at the top floor in the *y*-direction is shown in Figure 6. It shows that the responses are similar to the *x* direction, but the values are greatly reduced due to the bigger damping ratio.

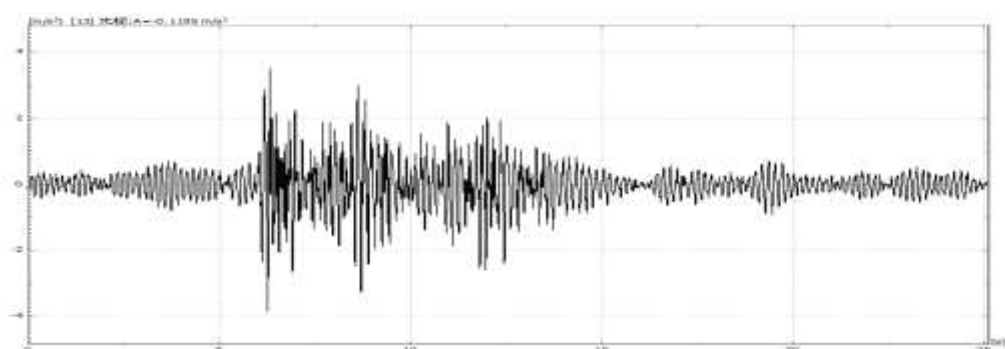


Figure 6. Acceleration response at the top floor in the *y*-direction.

3.3.3 *Discussion*

It can be found that the strain and acceleration responses in the *x* direction are greater than the ones in the *y* direction. The main reasons why they are stiffer in the *x*-axis than in the *y*-axis are the differences of beam span and cross-section, and connection's friction.

4 CONCLUSIONS

In shaking table tests, the model is still in elastic state and does not suffer damage. It shows this type of structure has good entirety and stability. In *x* and *y* directions of the model frame, the basic natural vibration frequency is 6 Hz and 4 Hz, and corresponding damping ratio is 8.736% and 11.427%, respectively. Compared to the rigid frame, the present structure has a lower natural vibration frequency and a higher damping ratio. Through the shaking table test, the strain, acceleration and displacement responses are obtained. It can demonstrate that the characteristics of seismic response of frame with semi-rigid joints and the frame have good seismic performance.

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