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ON-SITE TESTING AND EVALUATION OF A RELOCATED AND RECONSTRUCTED HISTORICAL TIMBER BUILDING

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ABSTRACT

This paper presents the results of an on-site static and dynamic testing program of a historical timber frame that was relocated and reconstructed recently in Shanghai city. The static loading tests considered wood beam members of various quality, dimension and positions within the wood post-and-beam frame. The dynamic loading tests considered three principle directions and the influence of static loading. It was found that the static and dynamic behaviour of the frame was significantly affected by the construction quality of timber connections. Significant variation of test results was observed due to the loose connections as well as the external disturbance, such as wind. It was also found that for such reconstructed wood frames, the presence of static loading can help improve the structural integrity and mechanical properties.

Keywords: *Timber construction, Relocation and reconstruction, On-site testing, Construction quality and evaluation*

1. INTRODUCTION

China has a long history of using wood as the major construction material. In the past, wood has been widely used in residential constructions of China due to its easy availability and manufacturability. The garden structure of Jiangsu province of China is one of the most famous examples. With the rising urbanization, some of the historical timber structures need to be torn down while they may be favoured in some other cities with special city planning emphasizing on traditional architectural culture. In such case, building relocation and reconstruction is a desirable choice to preserve the social and cultural values of the existing historical timber buildings [1]. However, very few research work related to this topic can be found in literature [2-4].

The research work presented in this study was a part of a construction project in Shanghai city, which was aimed at demonstrating the traditional residential constructions of China and combining the traditional construction techniques with modern exhibition centres, shopping malls and featured hotels. The major characteristics of the constructions were to use the structural frames of the traditional wood residential buildings, which consisted of 90 buildings sampled throughout the country of China, as the internal components of the new constructions, mostly as non-loading carrying members and for decoration purposes, and a series of reinforced concrete shear walls and roof diaphragms at the perimeters of the buildings as the load carrying components.

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Although the wood frames reconstructed from the traditional residential buildings were only subjected to self-weight and construction loads, which were only present during the construction period, it is important to investigate the structural behavior of so-reconstructed wood frames and provide reference for similar relocation reconstruction projects, in which the wood frames may be subjected to larger and more complicated loads.

Aiming at that purpose, the authors conducted a series of on-site static and dynamic tests to evaluate the structural behavior of individual members as well as an entire frame in the principle directions. Considering the nature of variation of wood material, similar tests were replicated on different members with the geometric and physical information (position of the individual members, dimension and degradation status, etc.) taken into account to achieve a more reasonable understanding of such reconstruction projects.

2. EXPERIMENTAL STUDY

2.1. Test setup

Both the static and dynamic loading tests were conducted based on a reconstructed wood post-and-beam frame. The reinforced concrete shear walls and diaphragms were not constructed yet, so that the test results could reflect the structural behavior of the wood frame itself. The static tests considered three beams with both ends connected to columns by means of mortise-tenon connection. The beams were of different spans, surface appearance (as in correspondence to different material degradation) and positions within the frame (edge span and intermediate spans). Fig. 1 shows the tested wood frame and the positions of the three beams, which were demonstrated in the plan view of the wood frame.

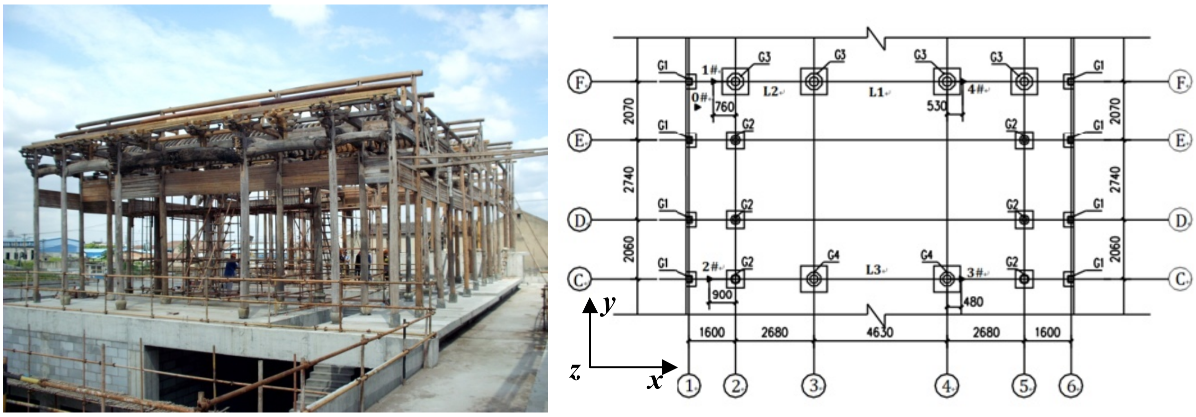


Fig. 1 Structural appearance and layout in plan view (*L*1, *L*2 and *L*3 are for the tested beams and ▲ for acceleration measurements of dynamic tests)

The dynamic tests were conducted by using the ambient excitation, for which the wind may dominates since the frame was located nearby the Yangzi river. The data were measured by use of accelerometers that were located symmetrically in the frame and nearby the beams under static loading tests. Four accelerometers were used, the position of which are illustrated in Fig. 1.

2.2. Loading methods and procedures of static test

The static loading was applied in steps: for each step of loading, a certain amount of packed cement (the weight is known as 50 kg per pack) was put into steel lifting cages. The lifting cages were connected to the tested beam via steel cables that were wrapped around the beam at prescribed positions, as shown in Fig. 2. Beams 1 and 3 were of relatively large span (4630 mm) and therefore two lifting cages were used and connected at the third points of the beam, respectively; whereas beam 2 was of a smaller span (2680) and only one lifting cage was used and hanged at the midspan node of the beam. For all the three beams, a total cement weight of 150 kg per lifting cage (the weight of the lifting cage itself is ignored) was applied in three steps.

The static testing results mainly consisted of the beam deflection at the midspan node and both member ends. The deflections were measured by dial gauge and manually recorded after each step of loading. Before reading the data, the beams were loaded for 2~3 minutes so that the deflection became stable. The dial gauges were fixed to steel pipes of the scaffold by means of magnetic bases.

Fig. 2 Steel lifting cage and cable connection position of beams under static loading

2.3. Loading methods and procedures of dynamic test

Since the building was nearby the Yangzi River where wind was relatively strong, the dynamic tests were simply based on the ambient wind excitation. The tests considered the influence of static loading and measured the structural responses along the *x*, *y* and *z* axes, as defined in Fig. 1, of the frame with and without the static loading.

Fig. 3 Lance piezoelectric type accelerometers for measurement of acceleration

The structural acceleration responses were recorded by use of Lance (LC0132T) piezoelectric type accelerometers and processed by a SVSA signal acquisition instrument, which can convert the piezoelectric data for structural analysis purpose. The accelerometers were placed on the top surface of prescribed beam members and were oriented to measure the accelerations in the three directions as mentioned earlier [5], as shown in Fig. 3.

The acceleration measurements were collected by the signal acquisition instrument at a time period of 20 seconds. For each combination of the static loading (with or without) and direction of acceleration, three measurements were made to mitigate the variation of the test results.

3. TEST RESULTS

3.1. Static test results

The test results of the three beams (number as #1, #2 and #3, respectively) are listed in tabs. 1, 2 and 3, respectively, in which the first measurement was done with no loading applied. The corresponding data were used to describe the initial readings of the dial meters. Consequently, the second, third and fourth measurements were corresponding to a weight of 50 kg, 100 kg, and 150 kg per lifting cage.

Table 1 Static testing results of beam #1 (corresponding to L1 in Fig. 1)

Measurements	Applied load (kg)		Beam deflection measurement (mm)		
	Load per lifting cage	Total load	Left end	Midspan	Right end
First	0	0	1.98	0.68	0.95
Second	50	100	1.82	1.92	1.25
Third	100	200	2.10	2.10	1.35
Fourth	150	300	1.90	2.30	1.50

Table 2 Static testing results of beam #2 (corresponding to L2 in Fig. 1)

Measurements	Applied load (kg)		Beam deflection measurement (mm)		
	Load per lifting cage	Total load	Left end	Midspan	Right end
First	0	0	0.75	3.49	2.75
Second	50	100	0.80	3.50	2.80
Third	100	200	0.88	3.57	2.80
Fourth	150	300	1.10	3.65	2.82

Table 3 Static testing results of beam #3 (corresponding to L3 in Fig. 1)

Measurements	Applied load (kg)		Beam deflection measurement (mm)		
	Load per lifting cage	Total load	Left end	Midspan	Right end
First	0	0	2.24	0.57	1.40
Second	50	100	2.37	86	1.47
Third	100	200	2.50	1.25	1.62
Fourth	150	300	2.75	1.60	2.00

The test results were then processed to establish the relationship between the applied load and the midspan deflection. To get rid of the initial reading of the dial meters, the second, third and fourth readings were adjusted by subtracting those of the first reading. In addition, to get rid of the influence of rigid body movement of the tested beams, which is possibly caused by the loose contact between the wood in the connection area, the readings corresponding to the beam end measurements were subtracted from those of the midspan node to evaluate the relative midspan deflection. The so-established load and midspan deflection relationships of the three beams are shown in Fig. 4.

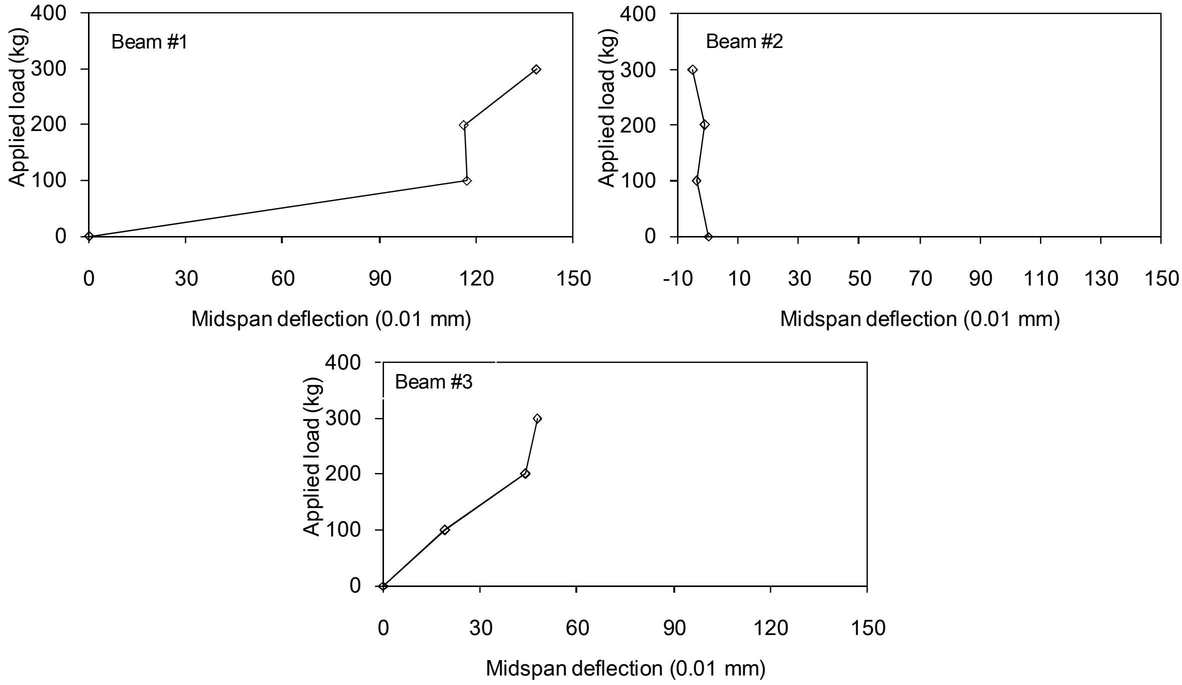
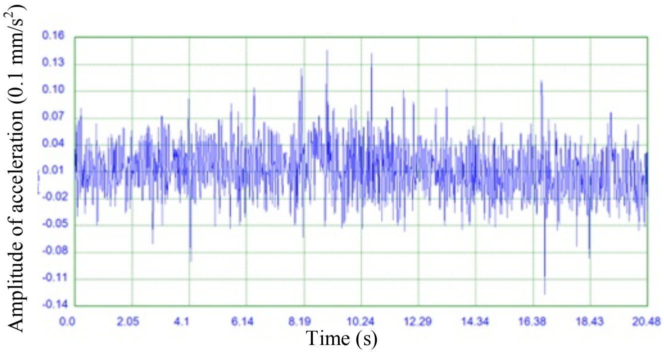


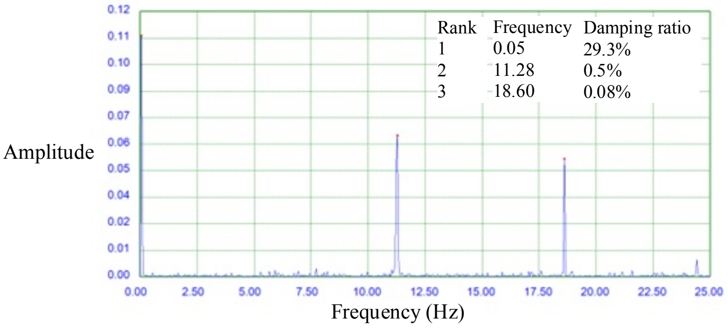
Fig. 4 Applied load and midspan deflection of beams for static loading tests

3.2. Dynamic test results

The dynamic test results mainly consisted of the acceleration readings measured along the *y* and *x* axes in the plan and the *z* axis of the frame. The original data of measuring point 1 is shown in Fig. 5 for demonstration purpose. These original data were then used for evaluation of the natural frequencies and damping ratios of the frame in the three directions. The evaluation diagram of damping ratio based on the acceleration results of measuring point 1 is also shown in Fig. 5. More detailed results of all four measuring points are listed in Tabs. 4 and 5, respectively.



a) Distribution of acceleration in time domain based on results of measuring point 1



b) Distribution of acceleration in frequency domain based on results of measuring point 1

Fig. 5 Evaluation of natural frequency and damping ratio based on results of point 1

Table 4 Dynamic testing results of natural frequencies of the frame (Hz)

Static loading	Direction (axis)	Measuring points			
		1	2	3	4
NO	*z*	11.47	15.45	1.27	0.98
	y	10.64	1.44	1.81	1.03
	x	10.94	5.91	1.76	1.22
YES	*z*	11.33	18.41	1.40	1.40
	y	11.33	11.38	1.44	1.59
	x	11.28	19.31	1.66	6.38

Table 5 Dynamic testing results of damping ratios of the frame

Static loading	Direction	Measuring points			
		1	2	3	4
NO	*z*	0.13	0.13	3.21	1.91
	y	0.15	1.45	2.06	4.00
	x	0.16	0.28	1.03	4.10
YES	*z*	0.46	0.43	1.39	1.37
	y	0.13	0.86	3.36	1.77
	x	0.35	0.12	0.95	0.54

4. DISCUSSION

The static test results shown in Tabs. 1, 3 and 3 and Fig. 4 indicated significant variation and erroneous data, which can be caused by external disturbance and the difficulty in on-site testing of reconstructed wood frames. The relationship between the applied load and midspan deflection of the tested beams exhibited significant fluctuation. This can be caused by the loose contact among the connected members at the both ends of the tested beams. The results of beam #2 were significantly affected by the stiffness of the frame, which was quite low since the post-and-beam system was merely supported by limited number of temporary bracings, and the testing technicians stayed on the scaffold during the testing period and may have introduced certain error into the deflection readings. The original objective of the static testing was to compare the test results with a simply supported beam to evaluate the contribution of the connections between it and other neighbouring members; however, this was biased by the aforementioned factors.

Compared to the static testing results, the dynamic tests provided more information about the structural properties, including the natural frequency and damping ratio of the frame. Comparing the results with and without the static loading, it can be seen that the difference between the dynamic responses in the three principle axes decreases with the static loading while the natural frequencies in all the three axes increases. This indicates that the presence of the static loading improved the structural integrity of the wood frame, which also implies that the reconstructed wood frame is insufficient in connection stiffness.

Based on the static and dynamic test results, it is evident that for reconstructed timber structures, the timber connections were disassembled and reconstructed. During the reconstruction process, the loose contact within the connection area can significantly impair the effective connection stiffness and affect the structural integrity. Thus, special attention should be paid to reconstruction and quality control of timber connections during the relocation and reconstruction projects of timber structures, especially those with significant material degradation and performance deterioration.

5. CONCLUSIONS

This paper presents the results of an on-site static and dynamic testing program of a relocated and reconstructed historical timber frame. The static and dynamic loading tests indicated that the static and dynamic behaviour of the frame can be significantly affected by the construction quality of timber connections. Significant variation of test results was observed due to the loose connections as well as the external disturbance, such as wind. It was also found that the presence of static loading can help improve the structural integrity and stiffness of the tested frame. The test results indicate that special attention should be paid to reconstruction of timber connections as they can significantly impair the structural integrity and mechanical properties of such reconstructed timber structures.

ACKNOLEDGEMENTS

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