Advanced Materials Research Vols. 133-134 (2010) pp 703-708

doi:10.4028/www.scientific.net/AMR.133-134.703

Hysteretic Behavior of Korean Traditional Wooden Frames

HONG Sung Gul[1, a], HONG Namhee K[2,b] and LEE Sun Young[3,c]

[1,3]Dept. of architecture, Seoul National Univ. , Seoul, Korea

[2]Dept. of Civil Engineering, Seoul National Univ. , Seoul, Korea

[a]sglhong@snu.ac.kr, [b]namheek@snu.ac.kr , [b]sunyoung0122@hanmail.net

Abstract The objective of this paper is to provide basic information on structural behavior of Korea traditional wooden frames under earthquake loading. One of prototype wooden frames for this study was chosen from a designated national treasure in Korea. A series of experimental work were prepared to investigate the behavior and hysteresis characteristics of traditional wooden frames under cyclic lateral loading. Three test specimens of a full scale were performed for cyclic hysteretic behaviors based on one static test specimen as a pilot test. The experimental observation showed stiffness degradations and slips after experiencing initial yield point and the first cycle at a new larger displacement due to inherent gaps in connections between columns and connection parts of beams and a gradual indentation of interfaces under pull and push. Addition of structural components such as an upper beam and clay-filled wall to the basic beam and columns increased the initial stiffness, strength and energy dissipation than those of basic frames. The behaviors of the wooden frames were simulated by DRAIN-2DX program for the dynamic analysis of an entire wooden frame system. Comparison between analysis models and the experimental behaviors showed that the behavior of wooden frames under consideration could be represented by a combination of link and truss elements. The maximum response of a wooden frame system under three earthquakes showed a safe behavior for a potential earthquake.

Keywords: Hysteretic behavior, rotational stiffness of joint, earthquake load, wooden frame

Introduction

Most traditional old wooden buildings of heritage in the world have been preserved since most of them may reflect unique cultural value of that area. The rational conservation methods for traditional old wooden buildings require knowledge of basic structural behavior because the most restoration techniques of deteriorated traditional old wooden buildings have been the state of art. Most deterioration of wooden building has been occurred by biological decay due to weathering and mechanical damage by earthquake and typhoon.

Unlike western architecture, in ancient oriental wooden architecture, the wall only defined an enclosure, and did not form a load bearing element. Buildings in East Asian have been supported by wooden frames for long time. Typical traditional wooden frames in East Asian involve lintel beams with mortise-tenon joints which support several brackets on the top of columns to transfer the vertical load due to mainly the weight of roof structure. The behavior of these connections is found to be semi-rigid. The technique of joint and construction in details have been changed. Brackets above columns are supposed to transfer gravity loads from roof systems to columns by haunch actions. Brackets, so called Dougong, are unique structural elements of interlocking wooden brackets, one of the most important elements in traditional East Asian architecture. It first appeared in buildings of the last centuries BC and evolved into a structural network that joined pillars and columns to the frame of the roof. Such wood bracket was widely used in the Spring and Autumn Period (770–476 BC) and developed into a complex set of interlocking parts by its peak in the Tang and Song periods.

The previous research on a simple wooden frame by Suh focused on the behavior of frame under lateral cyclic loads. Fujita et al performed dynamic test for various types of wooded frames including

mud plaster infill wall systems. They suggested analytical models in terms of bilinear and slip models for the mud plaster wall systems.

In this study full-scale wooden frames for test involving columns and a beam without an upper lintel above the beam and brackets are prepared. This study focuses on the lateral behaviour of wooden frame under lateral load. To main the focus on a typical behaviour of traditional wooden frames, a simple frame without unimportant components is prepared to minimize the number of components required for a whole system so that the other effects do not influence the structural behaviour of frame

Structure of Wooden Frames

Typical plans of wooded frames consist of exterior columns along the boundary of plan. From the point view of load paths the wooden frames have one way systems. Weight of roof tiles on inclined rafters are transferred via longitudinal members of a roof frame, so called purlins. Gravity loads on purlins then go to short columns on main cross beams in the short direction or extra beams. These cross main beams between two exterior columns in short directions transfer roof loads to column capitals through brackets. Number of bays in the long direction and number of purlins in the short direction represent the size of wooden frame buildings. In order to raise the slope of roofs or to increase the span length in the short direction of buildings, higher columns are located inside of the perimeter.

Experimental Program

One bay frame of full scale was selected from a typical wooden building in the longitudinal direction for the experimental programs in this study. Four test frames were fabricated by tenon-mortise connection to connect two columns and a beam. Two frames among them were prepared for simple static load and cyclic load, respectively. The third frame has an upper beam above the simple frame and the fourth has infill mud wall. Test set-up considers the support conditions at the bottom of columns and effects of roof loads on connection stiffness. Fig. 2 shows the test set-up for the first frame.

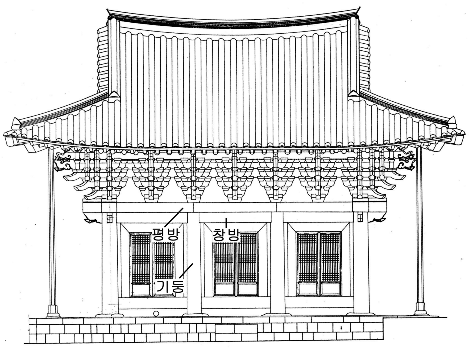

Figure 1: Example of structure for experimental program

The hinges at the bottoms simulate the support conditions for columns on natural stone foundation. The cables with turn buckle are supposed to generate compression forces on column capital which suppress the top of mortise-tenon connection and increase rotational resistance of connections. We prepared three types of frames for lateral behavior of wooden frames. The basic frame (CBS and CBD) consists of a lintel beams with two columns connected by mortise-tenon connection. Another frame is made by adding an upper beam above the basic frame. The final specimen is made by infilling a mud wall in the basic frame. Based on the experimental behavior hysteresis curves are simulated by using Drain-2DX.

The simple frame under monotonic lateral load showed elastic behavior in an initial stage. The initial stiffness relies on the depth of joint and friction forces between the surface of beam and its boundary inside of connection. As the columns incline, the main contact points with the boundary of

connection change as shown in Fig. 3. As a result the moment arm length for rotational stiffness is reduced.

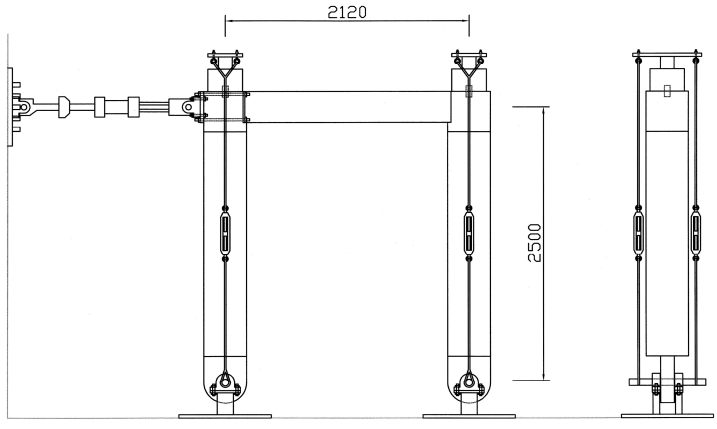

Figure 2: Test set-up for basic frame

From the load-displacement relationship, three different rotational resisting mechanisms can be identified. The relationship showed relatively higher stiffness in initial stage. The initial stiffness relies on the depth of joint and friction forces between the surface of beam and its boundary inside of connection. As the frame inclines in the second stage of behavior, the main contact points of top and bottom of beam with the boundary of connection change as shown in Fig. 3 resulting smaller arm length from the corner points. In other word the contact points at the top and bottom boundaries move to the corner points from A to a as well as from B to b in Fig. 3. In the third stage the beam pulls out of the joint and the vertical reaction increase due to contact between top and bottom faces of beam and column.

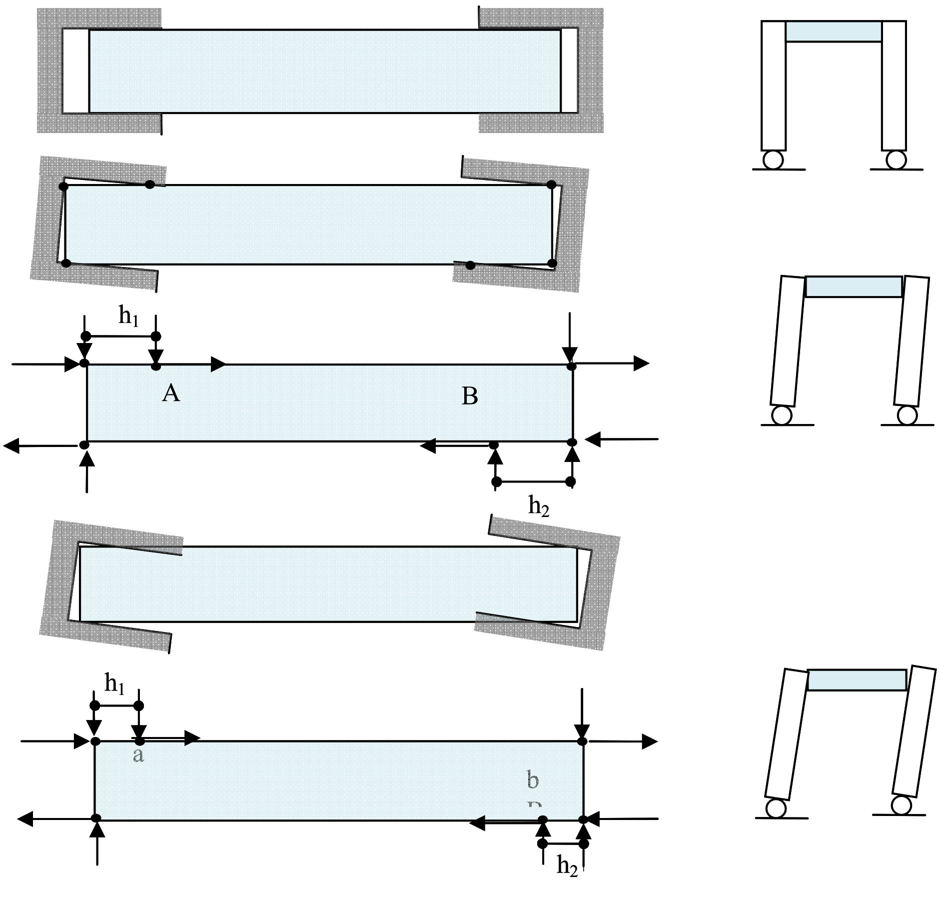

Figure 3: Change of contact points of joints when lateral loading

Test Results

Lateral load was applied at the level of beam and the load and the lateral displacement were measured. The rotational angle of joints was measured at the positions below the beam. After initial yielding the stiffness decreases up to 100 mm. The increase in stiffness after this point was observed. The second stage after yielding can be explained by the movement of rotation center of joint. The increase of stiffness relies on the friction at the interface between joint part of beam and columns.

Cyclic behavior of the basic frame was characterized by pinching phenomena between elastic region and post-yield stiffness. Form the maximum lateral displacement to the neural position the pinching effect prevails and the low stiffness was observed.

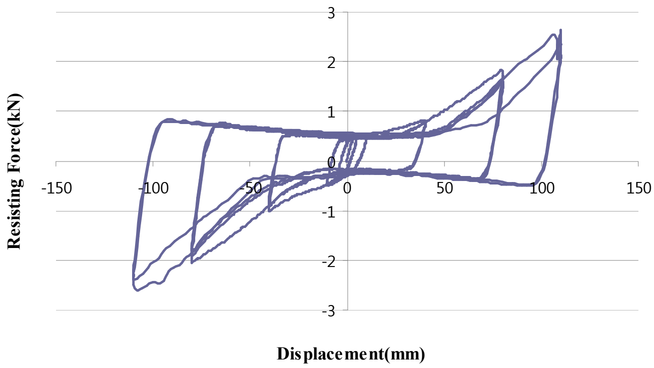

Figure 4: Cyclic behavior of basic frame

The second frame was prepared by adding an upper beam above the basic frame. The two beams were connected by pegs between the top face of the lintel beam and the bottom face of the upper beam. As the lateral displacement increase, the pull of lintel beam out of joint complex was resisted by friction between two beams. The secant stiffness of this frame was three or four times that of the basic frame without the upper beam. However, the degree of stiffness increase after 100 mm displacement was not significant because of large deformation of pegs between two beams. The equivalent damping ratio of this frame was about 10% and this value was lower than that of the basic frame.

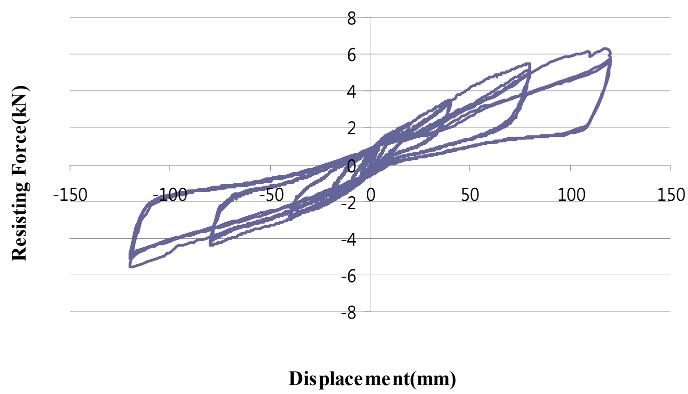

Figure 5: Hysteretic behavior of basic frame with upper beam

The third specimen was prepared by the basic frame with a.mud wall. The mud wall is not a structural component. The wall was built for enclosure for space. In the initial stage of loading the stiffness of the frame increased compared with other frames aforementioned. As the mud wall was separated from the columns in the large displacement excursion, the effectiveness of resistance decreased. In the mid displacement excursion the stiffness was increased by the strut action in the

wall. The crack pattern showed the vertical crack first due to the location of sub columns and the diagonal cracks by a diagonal strut action. As a result this frame has an increase in initial stiffness but pinching effect was observed after a peak point of each cycle.

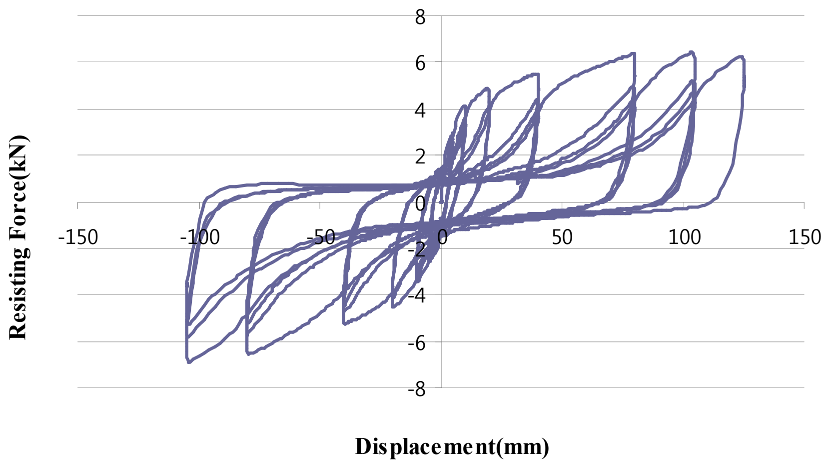

Figure 6: Hysteretic behavior of basic frame with mud wall

Simulation under Earthquake Loadings

To simulate the hysteresis curves of the experimental curves for the wooden frames, joint behavior is modeled by bilinear element and compression-tension element provided by DRAIN-2DX.. The bilinear element is able to represent the initial stiffness and the reduced stiffness after initial yielding by truss element and the compression-tension element is able to represent the stiffness in reloading stage with pinching behavior due to gap and friction of joints. The curves using the mechanical model and the experimental results are compared as shown in Fig. 7

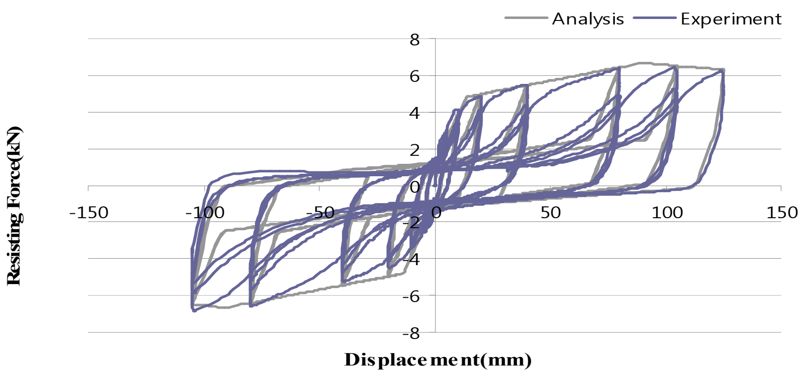

Figure 7: Comparison between experimental results and simulation

The maximum displacement of wooden frames having joints with mud walls under possible earthquake in Korea can be expected using the resulting joint models. The acceleration data from El-Centro and Kobe earthquake as well as Northridge earthquakes by scale down values for Korean Building Code are used to examine the earthquake hazard.

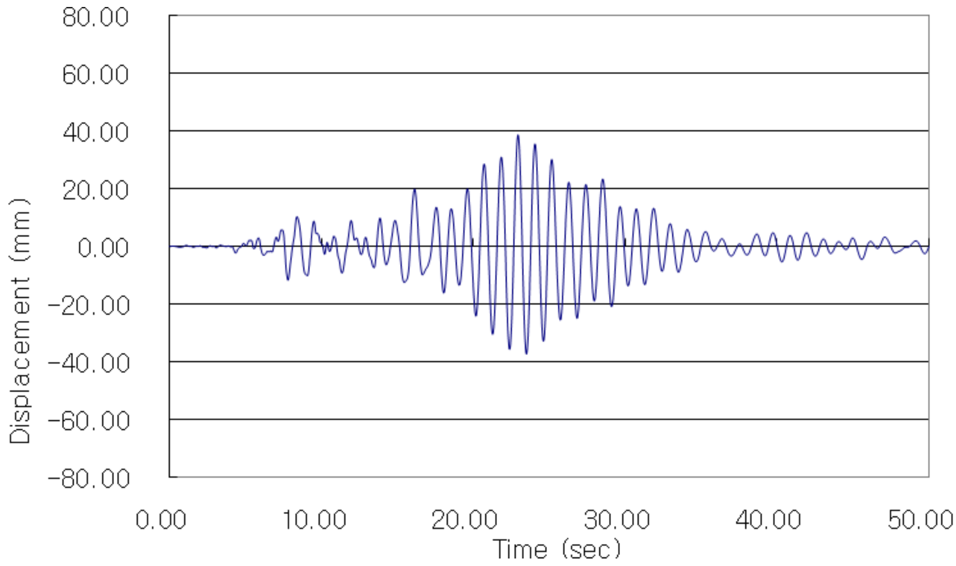

Figure 8: Time history of displacement at the top of columns under Northridge Earthquake

Conclusion

This study performed an experimental program for the structural behavior of basic traditional wooden frames under lateral loading. For investigation of seismic behavior of such wooden frames the simulation of cyclic behavior of joints was compared with the experimental results. Based on the experimental and analysis works in this study the following conclusions are made.

1) The lateral resistance of basic traditional wooded frames mainly relies on joint stiffness. The mud wall will contribute the initial stiffness but similar behavior of basic frames with upper beams after initial yielding.
2) The energy dissipation due to joint behavior is not so much because of slip between interfaces of beams and columns.

The simulation of hysteresis curves of wooden frames is able to expect dynamic behaviors of frames under earthquakes.

References

[1] Chang, W S, and Hsu, M F (2007). "Rotational performance of Nuki joints with gap II: the behaviour of butted Nuki joint and its comparison with continuous Nuki joint," The Japan Wood Research Society, 53: pp401-407.

[2] Chang, W S, Hsu, M F, and Komatsu, K (2006). "Rotational performance of Nuki joints with gap I: the behaviour of butted Nuki joint and its comparison with continuous Nuki joint," The Japan Wood Research Society, 52: pp58-62.

[3] Clough, R W, and Penzien J (1993). "*Dynamics of Structures*," McGraw-Hill, Inc., 730 pp.

[4] Dowrick, D J (1986). "Hysteresis Loops for Timber Structures," Bull of New Zealand Nat. Soc. of Earthquake Engrg, 19(20), 143-152.

[5] Seo, J, Choi, I, and Lee, J (1999). "Static and Cyclic Behavior of Wooden Frames with Tenon Joints under Lateral Load." *J. Struct. Engrg, ASCE*, 125(3), 344-349.

[6] Shiping, H (1991). "The Earthquake-resistant Properties of Chinese Traditional Architecture." *Earthquake Spectra*, 2 (3), 355-389