The effect of friction joint and Gongpo (bracket set) as an energy dissipation in Korean traditional wooden structure

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ABSTRACT: The main objective of this paper is to investigate structural behavior of Korean traditional wooden structures. The main characteristics of traditional wooden structures in East Asian countries are considered as unique techniques of joint without fastener and relying on friction between components to transfer interaction forces.

As one of temple structures Bongjeong-sa built in the early stage of the tenth century first is considered as a typical example of Korean traditional wooden structures. It is classified as a national treasure in Korea. It was rebuilt several times for restoration. Its basic structural system consists of a column and lintel beam connected by friction joint and Gongpo (bracket set). The Gongpo system is a unique system of brackets placed on top of columns to provide additional support to beams or overhanging eaves.

A one-third scale model with the roof-dead load of 46,710 N is designed and prepared on a steel sliding table of 5 m by 4 m to perform a series of structural tests in a laboratory. Using this model the characteristics of lateral and twisting displacement on the top of columns of the frame and the dynamic effects of the Gongpo on the global behavior of whole systems are investigated. It is concluded that the friction joint of column-connecting beam serves as an energy dissipation device reducing the impact of earthquake, but the Gongpo is not efficient to dissipate the energy as we have guessed.

1 INTRODUCTION

The main building of Bongjeong-sa(temple) located in the Andong-city in Korea was built in the early stage of the tenth century first. It was rebuilt several times from first construction to now. In 1809, it was reconstructed on a large scale and a large part of the appearance of the present time (Fig. 1) is the result of that reconstruction. Until several years ago, the partial repair had been advancing for roof, decorative painting and wooden floor. The most recent total repair was performed in 2000 and it was classified as the national treasure of Korea [1].

The main building of Bongjeong-sa(temple) was composed by three frames in the front (13,312 mm) and the side (8,721 mm) (Fig. 2). The column is just placed on a foundation stone without the use of mechanical fasteners. The frame is composed by column and connecting beam. The connecting beams are connected by rake joints located over the columns, taking advantage of the reinforcement provided by the surrounding slot (Fig. 3). The architraves which are placed
bracket sets are located on column-connecting beam joints. All bracket sets, composed of *soro* (blocks) and *cheomcha* (arms), are located on architraves (Fig. 4). They are connected with one another by tie beam and the main role of those is the one interface columns with beams and the large percentage of the roof load about 2,500,000 N was transferred to foundation stone by those. The elevation of a structure was made up of the four building layers: base, columns and connecting beams, bracket sets and roof (Fig. 5).

In this research a dynamic test is performed to evaluate vibration characteristics of the main building of Bongjeong-sa (temple) in the laboratory. For this purpose, a one-third scale model with the roof-dead load of 46,710 N is designed and prepared on a steel sliding table of 5 m by 4 m. From the result of the vibration test, we evaluate natural frequency, transfer function between base layer and damping ratio of the building.

2 EXPERIMENTAL PROGRAM

2.1 Test model and sliding table

To perform vibration test at the laboratory, a one-third scale model of the main building which has the elements of 3119 was built. The dimensions of this test building are 2910 mm wide and 4450 mm long. To design this test model, Autodesk inventor 11 was used to draw whole elements. Although the soil walls, windows and doors exist between the columns, to exclude the effect of other variables other than the joints of columns and connecting beams, they were not contained in this test model. Also, the top part of roof was not contained in this test model and replaced by weight. Korean red pine was used to make test model
and it kept the percentage of moisture under 17%. The steel plate of 46,710 N was used to simulate the weight of roof (Figs 6–8).

To perform the vibration test, the steel sliding table of 5.5 m by 4.5 m was made. It was slid in the one-way direction on the LM guide and designed to be able to rotate to perform the test of orthogonal direction. It was slid in the hydraulic dynamic actuator.

2.2 The location of sensor

The location of the sensors to measure the acceleration and displacement are located in Figure 10–11. The total numbers of sensors are sixteen. Sensor points 1, 2, 11 and 12 are located on an architrave, the top of column and connecting layer, and measure the acceleration of Y-direction. Sensor points 3, 4, 9 and 10 are located on an architrave and measure the acceleration of X-direction. Sensors points 13 and 14 are located on steel sliding table and measure the acceleration of X-direction and the displacement of X-direction. Sensor points 15 and 16 are attached at architrave and measure the displacement of X-direction. Sensor points 5 and 6 are located on bracket set and measure the acceleration of X-direction. Sensor points 7 and 8 are located on the bracket set and measure the acceleration of X-direction.

3 VIBRATION TEST

3.1 Random vibration

It is actuated the sliding table as random signal which contains the frequency of from 1 Hz to 3 Hz to figure out the natural frequency of the test model. In process of the random vibration experiment, we observe that the natural frequency of test building changes according to the magnitude of vibration. To confirm the
Variation of natural frequency, the random vibration test was performed for the RMS amplitude of different kinds. The natural frequency of X-direction on the connecting beam, acceleration 3 in Figure 10, and the results of natural frequency are shown in Table 1. According to natural frequency results, the natural frequency of test building could confirm to change according to the magnitude of vibration amplitude. The variation of natural frequency could possible when weight or stiffness varied. In case of this test model, the weight did not change at all. So, we could suppose that the lateral stiffness of whole frame varied. The lateral stiffness of Korean traditional wooden structure is composed for the most part by the stiffness of column-connecting beam joints. The research result for joint stiffness shows that the stiffness of column-connecting beam joints is varied by restraint force and the magnitude of lateral displacement (Fig. 12). The stiffness of joints is the linear in the case of small displacement and changes if the displacement of joint is gradually enlarged. By this reason, the lateral stiffness of whole system changes according to the variation of joint displacement.

The accelerations and displacements are measured simultaneously during 180 seconds with a sampling frequency of 100 Hz. Then, stationary portions of records are selected to calculate the transfer function that could evaluate about the predominant frequency of the structure. To evaluate the variation of the predominant frequency according to the magnitude of vibration and the effect of vibration transmission between the layers, the transfer functions for acceleration between sliding table and architrave were calculated. The results of the calculation of transfer functions are shown in Figure 13.

The one of the main subjects of this research investigates the energy dissipation characteristics of Gongpo. To this end the transfer functions for acceleration between sliding table and Gongpo are calculated. The transfer functions of architrave and Gongpo are shown in Figure 14. We can confirm that the transfer functions of architrave are identical with the one of Gongpo. Therefore, we can confirm that the energy dissipation effect is in the joint of column and connecting beam and Gongpo do not perform the role of energy dissipation. Also, we can confirm that the predominant frequencies shift to the left according to the increase of

<table>
<thead>
<tr>
<th>The RMS amplitude of random signal (mm)</th>
<th>Natural frequency (Hz)</th>
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<tbody>
<tr>
<td>0.2</td>
<td>2.606</td>
</tr>
<tr>
<td>0.3</td>
<td>2.576</td>
</tr>
<tr>
<td>0.5</td>
<td>2.258</td>
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<tr>
<td>1</td>
<td>1.962</td>
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</table>

Figure 11. The sensor location on bracket.

Figure 12. Force-lateral displacement relationship of joint.

Figure 13. TF from ground acc. to connecting beam acc.
vibration amplitude and the value of transfer function become smaller in Figures 13 and 14.

3.2 Sine wave vibration

To confirm exactly the shift effect of predominant frequencies and the variation of transfer function value, sine waves that the amplitude changes from 0.2 mm to 2.5 mm were actuated and transfer function was calculated. The results of transfer function by sine waves are shown in Figure 15. In Figure 15, the predominant frequencies according to the amplitude of sliding table are shifted. If the amplitude of sliding table is larger than 1.0 mm, the transfer functions show similar values.

3.3 Impulse vibration

A free vibration experiment is performed to determine damping ratio and verify the variation of damping ratio by the magnitude of initial impact displacement. The initial impact displacements of 5, 10, 15, 20, 25, 30 mm are set to vibrate (Its duration time was 0.1 sec). The free vibration records of displacement at architrave, displacement 15 in Figure 10, presented in Figure 16. The damping ratios are calculated by the logarithmic decrement process and presented in Table 2. From table 2, we observe that if the impact displacement of sliding table larger than 10 mm, the damping ratio shows similar values a little bit more than 10%.

4 CONCLUSION

The energy dissipation effect is in the joints of columns and connecting beams but Gongpo do not show efficient energy dissipation. The predominant frequencies shifted to left according to the increase of vibration amplitude and the values of transfer functions became smaller. If the sine waves amplitude of sliding table are larger than 1.0 mm, the transfer functions shows similar values. If the impact displacement of sliding table is larger than 10 mm, the damping ratio shows similar values a little bit more than 10%.

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REFERENCES
