SEISMIC EVALUATION OF INDONESIAN TRADITIONAL WOODEN STRUCTURES

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ABSTRACT: We report the progress of our research projects on the seismic evaluation of Indonesian traditional wooden structures. These structural members joint by the traditional method called Purus system. In the 2006 Central Java Earthquake, some traditional style buildings were completely destroyed. In this paper, the main findings on the seismic performance of the traditional style buildings with Purus system are as follows: (a) In Yogyakarta, Indonesia, we performed microtremor measurements for the traditional wooden structures. In case of structures without walls, the natural frequencies are recorded between 1.0Hz to 2.0Hz in spite of column’s height. (b) We performed experiments on the main frame of Indonesian wooden structures. In the teak wood frame, depending on the vertical load, the negative column is heaved upward. It is also found that the maximum strength was caused by the strength of Purus.

KEYWORDS: Indonesia, Traditional Wooden Structures, Joints, Static Cyclic Loading Test, Seismic Performance

1 INTRODUCTION

In Indonesia, many earthquakes have been occurred. The 2006 Central Java Earthquake (M6.3) damaged all over the city in Indonesia; more than 6 thousand people were dead, and more than 340 thousand houses were completely or partly collapsed. In Indonesia, there are traditional wooden structures. Some of them were collapsed in the 2006 Central Java Earthquake. These are generally unreinforced structures, and their seismic performance is poor. But some of them are used as assembly halls where many people gather in, so need to have the enough seismic performance. The traditional style structures have been constructed without considering their seismic performance. Accordingly, we try to acquire the seismic performance of the traditional wooden structures in Indonesia by the field survey and some experiments.

In this paper, we explain seismic characteristics of the frame of traditional style structures. The main plan toward this goal can be expressed as follows:

1. Through the field survey findings including microtremor measurements and some material tests, the method for the construction such as the detail of beam-column joints, vibration characteristics, and material properties is explained.

2. Conducting static cyclic loading tests for main frame specimens made of teak wood and cedar, the important seismic performance is observed: strength, the advance of the moment, the effect of material types and the form of joints applied.

2 CONSTRUCTION SYSTEMS

In this Chapter, we refer to column-to-beam construction systems of Indonesian traditional wooden structures. There is a style of Pendapa without walls and a style of Dalem with walls as Indonesian traditional wooden structures. In the 2006 Central Java Earthquake, some of them were completely destroyed. The structural members of these structures are generally made of teak wood. These structural members are jointed by the traditional methods called Purus system and Cathokan system. The details of joints are
characteristic of these structures.

Figure 1 depicts the detail of joints. **Purus system** is a lock device. A member processed as the end thin is inserted into the hole of other member. This end is called **Purus**.

As shown in Figure 1(a), the colored members (A, B, C) indicate the factors **Purus system** is composed of. First, the member (B) in the ridge direction is inserted into a column. The inserted member (B) is called **Sunduk Pamanjang**. Next, the member (C) in the span direction is inserted. The inserted member (C) is called **Sunduk Kili**.

**Cathokan system** is a device to prevent the beam from moving. Members processed as the depression are combined each other. Protruding column’s **Purus** inserted into the hole of the combined members, beams are fixed.

As shown in Figure 1(a), the colorless members (D, E) indicate the factors **Cathokan system** is composed of. First, the ridge direction beam (D) and the span direction beam (E) are combined. Next, **Purus** of the column (A) is inserted into the hole of the beams.

Figure 1(b) illustrates assembled joints. In this paper, we consider differences in seismic performance between **Sunduk Pamanjang** in the ridge direction and **Sunduk Kili** in the span direction.

### 3 FIELD SURVEY

In this Chapter, we report on the field survey in Yogyakarta, Indonesia. We explain about the district, the objects, the methods and the result of this field survey.

### Table 1: Object of Survey in Kotagede

<table>
<thead>
<tr>
<th>Structures</th>
<th>Style (*)</th>
<th>Collapsed Level (2006)</th>
<th>Built Year</th>
<th>Renovated Year</th>
<th>Movement Year</th>
<th>Height of Column (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jatmiko’s House</td>
<td>Pendapa</td>
<td>completely</td>
<td>about 1920</td>
<td>2006</td>
<td>-</td>
<td>2,500</td>
</tr>
<tr>
<td>Joglo UGM</td>
<td>Pendapa</td>
<td>completely</td>
<td>about 1930</td>
<td>2006</td>
<td>2007</td>
<td>3,110</td>
</tr>
<tr>
<td>UGM Center</td>
<td>Dalem</td>
<td>completely</td>
<td>about 1890</td>
<td>2006</td>
<td>-</td>
<td>3,500</td>
</tr>
<tr>
<td>Genbong’s House</td>
<td>Pendapa</td>
<td>completely</td>
<td>about 1775</td>
<td>1987, 1989, 2007</td>
<td>-</td>
<td>2,750</td>
</tr>
<tr>
<td>Mukadi’s House</td>
<td>Dalem</td>
<td>partly</td>
<td>about 1860</td>
<td>2007</td>
<td>-</td>
<td>3,600</td>
</tr>
<tr>
<td>Edy Priyanto’s House</td>
<td>Pendapa</td>
<td>completely</td>
<td>1900</td>
<td>2006</td>
<td>-</td>
<td>3,155</td>
</tr>
</tbody>
</table>

(*) **Pendapa** is without walls, and **Dalem** is with walls.

### Table 2: Result of Survey in Kotagede (2009.10.31)

<table>
<thead>
<tr>
<th>Structures</th>
<th>Span Direction Frequency (Hz)</th>
<th>Ridge Direction Frequency (Hz)</th>
<th>time</th>
<th>Temperature(°C) inside</th>
<th>Temperature(°C) outside</th>
<th>Humidity (%) inside</th>
<th>Humidity (%) outside</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jatmiko’s House</td>
<td>1.63</td>
<td>1.32</td>
<td>12:00</td>
<td>11</td>
<td>32.8</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Joglo UGM</td>
<td>1.66</td>
<td>1.56</td>
<td>13:30</td>
<td>11</td>
<td>31.7</td>
<td>33.4</td>
<td>51</td>
</tr>
<tr>
<td>UGM Center</td>
<td>6.10</td>
<td>6.90</td>
<td>13:30</td>
<td>13</td>
<td>31.4</td>
<td>33.4</td>
<td>55</td>
</tr>
<tr>
<td>Genbong’s House</td>
<td>1.17</td>
<td>1.33</td>
<td>14:45</td>
<td>11</td>
<td>31.7</td>
<td>32.2</td>
<td>52</td>
</tr>
<tr>
<td>Mukadi’s House</td>
<td>7.50</td>
<td>4.98</td>
<td>16:00</td>
<td>11</td>
<td>30.6</td>
<td>30.3</td>
<td>57</td>
</tr>
<tr>
<td>Edy Priyanto’s House</td>
<td>1.17</td>
<td>1.12</td>
<td>17:00</td>
<td>9</td>
<td>29.2</td>
<td>28.7</td>
<td>60</td>
</tr>
</tbody>
</table>
3.1 KOTAGADE DISTRICT
As shown in Tables 1 and 2, in this field survey, we target 6 structures in Kotagede district. Kotagede district is a residential area in Yogyakarta. The 6 structures are the traditional style structures. Table 1 says history of the structures such as the style of structure, the damaged level by the 2006 Central Java Earthquake, the built year, the renovated year, the movement year and the height of column. The height of the column is the length from the foundation stone to the top of the column. In the 2006 Central Java Earthquake, they were all collapsed except for Mukadi’s House. 4 structures are Pendapa style without walls, 2 ones are Dalem style with walls.

3.2 SURVEY METHODS
In this section, we present the methods of this field survey. We conduct microtremor measurements, some material tests, the hearing for residents about the method of the construction and the structure’s history. Concerning microtremor measurements, we measure the natural frequency of structures in the span direction and in the ridge direction, respectively. We also measure the water contents of all columns, temperature and humidity at the inside and the outside of structures. Finally, we study from residents about the details of joints, the renovated method and the structure’s history.

3.3 SURVEY RESULTS
Tables 1, 2 and Figures 2 to 4 say the survey results. The structures without walls recorded the 1st natural frequency within the range from 1.1Hz to 1.7Hz in both directions. As shown in Figure 2 (d), (e), (f), for instance, Edy Priyanto’s House is Pendapa style structures. Measurement points are shown in Figure 2 (a). As shown in Figure 2 (b), (c), this structure recorded one accurate peak of its natural frequency in both directions. On the other hand, the structures with walls recorded several times as much frequency as ones without walls. As shown in Figure 3 (d), (e), (f), for instance, Mukadi’s House is Dalem style structures. Measurement Points are shown in Figure 3 (a). As shown in Figure 3 (b), (c), this structure recorded some peaks of its natural frequency in both directions. It is considered to be caused by some walls.

Figure 4 shows the distribution of the natural frequency versus the height of the column. In case without walls, the natural frequencies range between 1.0Hz and 2.0Hz in spite of the height of the column. In the other case with walls, the natural frequencies are uneven however same height it may be. Water contents of all columns are about 11% on an average as shown in Table 2. The temperatures at the inside of structures are nearly equal to those at the outside of structures. The humidity is similar results.

3.4 FINDINGS
Observations from the survey results can be summarized in what follows.
• As indicated in Figure 4, in case without walls, the
natural frequencies are recorded in the range from 1.0Hz to 2.0Hz in spite of column’s height.

- As indicated in Figure 4, in case with walls, the natural frequencies are uneven however same height it may be. It is considered to be caused by the placement of some walls.
- As indicated in Table 2, water contents of all columns are about 11% on an average.

4 CYCLIC LOADING TEST

In this Chapter, we present the result of the experimental research projects conducted for studying the seismic characteristics of the main frame of Indonesian wooden structures under the cyclic loading. We explain about the test specimens, the loading conditions, the result and the discussion of these tests.

4.1 TEST SPECIMENS

We conduct experiments for 4 frame specimens without walls. The differences among the specimens are the plane of structure and/or kinds of timbers such as cedar and teak wood. Table 3 shows the classification of the test specimen type. Figure 5 depicts the schematic illustrations of the specimens. As shown in Figures 5 (a), (b), the specimens are comprised of 2 columns, a beam and either Sundak Pamanjang or Sundak Kili. The height and the displacement between columns of specimens are 2,710mm and 1,820mm, respectively. The size of the column section and the beam section are 120mm x 120mm, and 120mm x 85mm, respectively. The size of Sundak Pamanjang and Sundak Kili section is 80mm x
120mm. The specifications of each joint are depicted in Figures 5 (c) to (f).

The main physical characteristics out of material tests are as follows. The flexural strength of columns, Sundak Pamanjang and Sundak Kili, and the average of water content of the members were said in Table 4. The flexural strength of members was obtained by 3 point bending test.

### 4.2 LOADING CONDITIONS

Loading conditions are illustrated in Figure 6. Two foundation stones are set up on the wide-flange shape member established on the test bed. The specimen is placed on the foundation stones, and tenons of the column base are inserted into holes opened at the center of the foundation stone. The girder made of pine is put on the beam of the specimen, and is connected with the beam by bolts. The loading beam is set above girder. The hydraulic jack on the abutment test wall is connected to the loading beam. The weight is suspended by PC steel bars, the vertical load is given just above each column. The cyclic loading was applied to each specimen. Horizontal load was measured by a load cell attached to the jack. The cyclic loading was conducted by increasing the amplitude of the rotation angle $R = \frac{u}{L}$. Where, $u$ is the horizontal displacement of point A, and $L$ is the height of the column. As indicated in Figure 7, the

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**Table 3: Classification of Test Specimen Type**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Plane of Structure</th>
<th>Kind of Timber</th>
<th>Vertical load</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Ridge</td>
<td>Cedar</td>
<td>9.7</td>
</tr>
<tr>
<td>B</td>
<td>Span</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Ridge</td>
<td>Teak Wood</td>
<td>17.1</td>
</tr>
<tr>
<td>D</td>
<td>Ridge</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4: Classification of Test Specimen Type**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>A</th>
<th>B</th>
<th>C/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frexural Strength (N/mm²)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive Column</td>
<td>32</td>
<td>32</td>
<td>-</td>
</tr>
<tr>
<td>Negative Column</td>
<td>35</td>
<td>24</td>
<td>-</td>
</tr>
<tr>
<td>Sunduk Pamanjang</td>
<td>35</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sunduk Kili</td>
<td>-</td>
<td>43</td>
<td>-</td>
</tr>
<tr>
<td>Young’s Modulus (kN/mm²)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive Column</td>
<td>5.67</td>
<td>6.98</td>
<td>13.52</td>
</tr>
<tr>
<td>Negative Column</td>
<td>6.65</td>
<td>5.56</td>
<td>11.03</td>
</tr>
<tr>
<td>Sunduk Pamanjang</td>
<td>5.35</td>
<td>-</td>
<td>11.27</td>
</tr>
<tr>
<td>Sunduk Kili</td>
<td>-</td>
<td>5.86</td>
<td>-</td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>13.7</td>
<td>18.8</td>
<td>13.7</td>
</tr>
</tbody>
</table>
amplitude of $R$ is increasing as follows: 0.008, 0.01, 0.013, 0.02, 0.033, 0.05, 0.067, 0.1, 0.125, 0.167 (radian). In these tests, the loading direction when the jack is pushing is decided as positive, and the column of the positive direction is called a positive column.

4.3 TEST RESULTS

In this section, we present results of static cyclic loading tests for main frame specimens made of teak wood and cedar. In these tests, the important seismic performance is observed: strength, moment, the effect of material types and the form of joints applied.

4.3.1 Cedar Specimens

Figures 8 to 10 illustrate the test results of the specimens made of cedar. Specimen A recorded the maximum strength of 1.4kN at 0.067rad. After reaching the maximum strength, the restoring force declined and was 0kN at 0.14rad. Specimen B recorded the maximum strength of 0.81kN at 0.03rad. After reaching the maximum strength, the restoring force declined gentler than Specimen A and was 0kN at 0.14rad. Figure 9 shows the appearance in positive loading. In both specimens, the decline of their restoring force was due to the destruction of Purus. The destruction of Purus is shown in Figure 10. As shown in Figure 10 (a), Purus of Specimen A broke from the bottom to the hole of Purus. On the other hands, as shown in Figure 10 (a), Purus of Specimen B broke the bottom of the thinnest part of Purus. The maximum strength was also caused by the strength of Purus. The maximum strength of the ridge plane structure was 1.7 times as much as that of the span plane structure.

4.3.2 Teak Wood

Figure 11 to 13 illustrate the test results of the specimens.
made of teak wood.
Specimen C recorded the strength of 3.0kN at just before 0.05rad. But, as shown in Figure 12, it happened to heave the negative column upward, and the tenon of the column base was pulled out. So, increasing the vertical load from 9.7kN to 17.1kN, the same specimen was reloaded as Specimen D.
Specimen D recorded the maximum strength of 3.0kN at 0.067rad. After reaching the maximum strength, the restoring force declined brittlely and was 0kN at 0.15rad. In Specimen D, declining the restoring force was due to the destruction of Purus. The destruction of Purus is shown in Figure 13. The Purus broke by shear failure from the hole to the end of Purus. Therefore, the maximum strength was also caused by the strength of Purus.
As compared with the frames of ridge plane, the maximum strength of teak wood frame (Spec. D) was 2.1 times as much as that of cedar frame (Spec. A).
In Specimen D, the skeleton curve is steeper slope than that of specimens made of cedar.

4.4 ADVANCE OF MOMENT
In this section, we discuss the advance of the moment of the Indonesian traditional wooden frame based on the result of the former section.
Figure 14 illustrates the advance of the moment at 0.01, 0.03, 0.067, 0.1rad. The moment of Specimen C and D is scaled down one fifth of that of Specimen A and B.
Considering cedar frames, in the positive columns, Sundak Pamanjang and Sundak Kili, the moment of Specimen A was nearly even with Specimen B at every radian. On the other hands, in the negative column, the moment of Specimen A was higher than that of Specimen B. But, because of broken Purus, after 0.067rad, the moment of the column became around zero below the Sundak joint.
Considering teak wood frameworks, at the columns below Sundak Pamajang, the moment of Specimen C and D are several times as much as that of Specimen A. After 0.067rad, the moment of the negative column in Specimen D was dropped down because of broken Purus. On the other hands, at the columns above Sundak
Pamajang, the moment of Specimen A and D were reversed direction.

4.5 FINDINGS

Observations from the experiments can be summarized in what follows.

- Declining the restoring force was followed with the destruction of Purus.
- The difference in destruction of Purus was caused by the form of Purus and the kind of timbers. In the cedar frames, Purus of the ridge plane broke from the bottom to the hole of Purus, on the other hands, Purus of the span plane broke the bottom of the thinnest part of Purus. In teak wood, the Purus broke by shear failure from the hole to the end of Purus.
- The maximum strength was caused by the strength of Purus. As compared with the cedar frames, the maximum strength of the ridge plane was 1.6 times as much as that of the span plane. As compared with the ridge planes, the maximum strength of the teak wood frame was 2.3 times as much as that of the cedar frame.
- In the teak wood frame, depending on the vertical load, the negative column is heaved upward.
- The shape of Purus influenced on the moment of the negative column before destroyed Purus. The moment of the span plane was smaller than that of the ridge plane.
- The kind of timbers provided the difference in the scale of the moment. The moment of the teak wood frame was several times as much as the cedar frame.
5 CONCLUSIONS

We have reported the progress of our research project on the seismic rehabilitation of Indonesian traditional wooden structures. First, in Kotagede, Yogyakarta, we surveyed Indonesian traditional wooden structures. The main findings from the survey include:

a) In case without walls, the natural frequencies are recorded in the range from 1.0Hz to 2.0Hz in spite of column’s height. On the other hand, in case with walls, the natural frequencies are uneven however same height it may be.

b) The water contents of all columns are about 11% on an average. And, the temperatures and the humidity at the inside of structures are nearly equal to those at the outside of structures.

Next, we experiment on the main frame of Indonesian wooden structures under the cyclic loading. The main findings from the test include:

c) Declining the restoring force was followed with the destruction of Purus. The difference in destruction of Purus was caused by the form of Purus and the kind of timbers.

d) The maximum strength was caused by the strength of Purus. As compared with the cedar frames, the maximum strength of the ridge plane was 1.7 times as much as that of the span plane. As compared with the ridge planes, the maximum strength of the teak wood frame was 2.1 times as much as that of the cedar frame.

e) In the teak wood frame, depending on the vertical load, the negative column is heaved upward.

f) The shape of Purus influenced on the moment of the negative column before destroyed Purus. The moment of the span plane was smaller than that of the ridge plane.

g) The kind of timbers provided the difference in the scale of the moment. The moment of the teak wood frame was several times as much as that of the cedar frame.

Future topics of the research project include:

a) Based on the above-mentioned researches, we investigate base shear coefficient of Indonesian traditional wooden structures.
b) Based on the above-mentioned researches, we propose an effective method of the seismic reinforcement for Indonesian traditional wooden structures.
c) Based on the acceleration records during the Central Java Earthquake, analyzing Indonesian traditional wooden structures damaged by the earthquake, the tendency of the earthquake damage of the structures are studied.
d) Comparing the acceleration spectra with the performance-equivalent acceleration spectra, which is the inversion of the seismic performance of buildings into the response spectra as seismic design load, the seismic response is inspected.

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REFERENCES