Investigation into the Architectural Design of a Traditional Japanese Wooden Pagoda

Yijie Zhang¹, Hesheng Tang*,² Songtao Xue³ and Yang Xun⁴

¹Post-Doctoral Fellow, Institute of Structural Engineering and Disaster Reduction, College of Civil Engineering, Tongji University, P.R. China
²Associate Professor, School of Architecture, Southwest Jiaotong University, P.R. China
³Associate Professor, Institute of Structural Engineering and Disaster Reduction, College of Civil Engineering, Tongji University, P.R. China
⁴Candidate of Ph.D. Program, Institute of Structural Engineering and Disaster Reduction, College of Civil Engineering, Tongji University, P.R. China

Abstract

Kiwarihou is a well-known traditional architectural design method for traditional Japanese wooden buildings. This article presents an investigation into the architectural design of a traditional Japanese wooden pagoda (three-storied pagoda in Joruriji temple) from the perspective of Kiwarihou. The pagoda in Joruriji temple was originally built around 1178, which was the right period for the emergence and development of Kiwarihou. Based on an extensive survey on the sizes of this pagoda, this paper explores the probable content of the Kiwarihou architectural design method. Investigative results showed that the sizes of nearly every aspect of this pagoda are either multiples or fractions of a specific length (the module). These encouraging results demonstrated that Kiwarihou had already been well developed during this three-storied pagoda period, and this three-storied pagoda is a typical example of Kiwarihou.

Keywords: Kiwarihou; three-storied pagoda; Joruriji temple; traditional architectural design

1. Introduction

Kiwarihou is an architectural design method of Japanese traditional wooden buildings. In this method, the sizes of a building are determined by multiples or fractions of a specific length (module). In general, the width between two adjoining rafters (from center to center) is designed as one module and the module is called Shi.

This method was said to have emerged during the Nara Period (645-780 AD), becoming full-blown in the Momoyama Period (1573-1674 AD). The three-storied pagoda in the Joruriji temple was established around 1178 AD, which fell between the two periods after Kiwarihou first emerged and before its popularity reached its peak. Thus the pagoda in Joruriji temple is a typical example of Kiwarihou. Developing an extensive investigation into the architectural design of this pagoda may help us to understand the development of Kiwarihou.

The most remarkable research on the architectural design of the pagoda appeared in 1968. In this study, Hamashima found that all of the bay widths were multiples of a specific length (Table 1.). The length is just 0.42 Kanejaku (K), which is to say in this pagoda 1 Shi = 0.42 K.

Moreover he found that the widths between two adjoining rafters on the first and second story were all 0.42 K, while the corresponding width on the third story was 0.4 K. Hamashima speculated that the whole bay width on the third story must have been determined as 20 times the Shi of the first story, with 22 rafters evenly arranged within this width. The calculation of Shi3 (the module on the third story) is:

\[ Shi3 = 20 \times 0.42 \text{ K} + 21 = 0.4 \text{ K} \]

On account of Hamashima's study, there are still two questions yet to be answered.

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Table 1. Bay Width of Pagoda in Joruriji Temple

<table>
<thead>
<tr>
<th>Story</th>
<th>Middle Bay Width (K)</th>
<th>Side Bay Width (K)</th>
<th>Whole Bay Width (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.2</td>
<td>2.94</td>
<td>10.08</td>
</tr>
<tr>
<td>2</td>
<td>3.36</td>
<td>2.94</td>
<td>9.24</td>
</tr>
<tr>
<td>3</td>
<td>2.815</td>
<td>2.815</td>
<td>8.445</td>
</tr>
</tbody>
</table>

(Received October 2, 2013; accepted March 2, 2015)
(1) Were other sizes of the pagoda besides the bay width determined by certain multiples or fractions of the Shi?

(2) Was the module on the third story determined as 0.4K from the original design or was it changed as 0.4K due to repair after its initial construction?

In order to answer these questions, the architectural design of the pagoda in the Joruriji temple will be fully investigated. This study will adopt the unit Shi, founded by Hamashima, to describe the sizes of the pagoda. If the results with the unit of Shi are all integers or certain ideal numerals, authors may speculate that this content could have been designed using Shi as a module.

This pagoda has been repaired four times since 1900. After the first modern repair in 1900, a set of measured drawings was obtained and published in a final report on this pagoda in 1967. The drawings and sizes published in the report are the basic data authors have adopted for this paper.

Analysis of the different sizes of the pagoda will stem from three aspects: the design of plan, section and bracket set.

2. Analysis on Design of Plan

Hamashima found that all the bay widths are some certain multiple of Shi (Table 1.). A similar phenomenon also appears in the depth of the eave.

The eave consists of two members: the base rafter and the flying rafter (Fig.1.). Consequently there are two types of depth of the eave: the depth of the base rafter (the horizontal distance from Gagyo to the end of base rafter, Fig.1.) and the depth of the whole eave (the horizontal distance from Gagyo to the end of the flying rafter, Fig.1.). The depths of the eave using units of K and Shi are illustrated in Table 2.

![Fig.1. Schematic Drawing of the Design of the Eave and Bracket Set in the Pagoda of Joruriji Temple (Unit: 1 Shi = 0.42 K)](image)

According to Table 2., both the depth of the base rafter and the whole eave are close to integer multiples of Shi. It may be inferred that the depths of the base rafter and the whole eave should have been designed as 6 Shi and 10 Shi, respectively.

![Table 2. Width of Eave in Pagoda of Joruriji Temple](image)

<table>
<thead>
<tr>
<th>Story</th>
<th>Depth of Base Rafter (K)</th>
<th>Depth of Base Rafter (Shi)</th>
<th>Depth of Whole Eave (K)</th>
<th>Depth of Whole Eave (Shi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.526</td>
<td>6</td>
<td>4.192</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>2.526</td>
<td>6</td>
<td>4.192</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>2.526</td>
<td>6</td>
<td>4.156</td>
<td>10</td>
</tr>
</tbody>
</table>

3. Analysis on Section Design

This analogous phenomenon also appears in this section design.

![Fig.2. Schematic Drawing of Design of Height (Cross Section of Pagoda in Joruriji Temple)](image)

When discussing the section design, it is necessary to introduce the construction of the Japanese multi-storied wooden pagoda.

Similar to Chinese pagodas, the Japanese multi-storied wooden pagoda consists of four parts: the pinnacle (Sorin in Japanese and Tacha in Chinese), the body, the foundation and the symbolic palace (Shariana in Japanese and Digong in Chinese, Fig.2.). Within those four parts the body is the most primary part of a pagoda.

The body of a multi-storied wooden pagoda largely consists of a multi-storied wooden framework. The framework on every story may further be divided into four parts: the basement (Hashiraban in Japanese and Pingzuo in Chinese), the column, the bracket set...
(Kumimono in Japanese and Dougong in Chinese) and the roof.

The section design includes two aspects: the entire height and the fractional height.

3.1 Design of Entire Height

The entire height of a pagoda $H_4$ consists of the following three sections: $H_1$, $H_2$, and $H_3$ (Fig. 2.).

- $H_1$: the height of the pagoda’s foundation
- $H_2$: the height of the pagoda’s body
- $H_3$: the height of the pagoda’s pinnacle
- $H_4 = H_1 + H_2 + H_3$

The entire heights of the pagoda with the units of $K$ and $Shi$ are illustrated in Table 3.

### Table 3. Entire Heights of Pagoda in Joruriji Temple

<table>
<thead>
<tr>
<th>Story</th>
<th>(K)</th>
<th>(Shi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>2.761</td>
<td>6.55</td>
</tr>
<tr>
<td>H2</td>
<td>33.6</td>
<td>80</td>
</tr>
<tr>
<td>H3</td>
<td>19.47</td>
<td>46.36</td>
</tr>
<tr>
<td>H4</td>
<td>55.83</td>
<td>132.9</td>
</tr>
</tbody>
</table>

According to Table 3, almost all of the entire heights of the pagoda were indivisible by the $Shi$; however, after numerous calculations it was found that almost every $H$ is divisible by one-third of $Shi$:

- $H_1 \div (Shi/3) = 2.761 \div (0.42/3) = 19.65\approx20$
- $H_2 \div (Shi/3) = 33.6 \div (0.42/3) = 240$
- $H_3 \div (Shi/3) = 19.47 \div (0.42/3) = 139\approx140$
- $H_4 \div (Shi/3) = 55.83 \div (0.42/3) = 399\approx400$

From this authors may infer that the entire height of the pagoda might have been designed using one-third of $Shi$ as a module or using $Shi$ as a module while reducing the height to one-third during construction.

3.2 Design of Fractional Height

The fractional height refers to the height of components on every story, such as the heights of the basement, the column, the bracket set and the roof on every story. Since there are many slanting members in the part of the bracket set and roof, the heights of these two parts could not be discussed separately (Fig. 2.). In this paper authors introduce a new concept of height between columns, $hj$. This refers to the height from the top of a column of a lower story to the bottom of the column on the next upper story. The height of the bracket set and roof may also be substituted by $hj$ (Fig. 2.).

The basement on every story of a Japanese multi-storied pagoda is made up of only one member: Hashiraban (H.B.), while Daiwa (D.W.) is a horizontal member on the top of columns only. There is no consensus on which part the H.B. and the D.W. should be calculated. Thus there are two types of fractional height: the height of the column ($h$) and the height between columns ($hj$). In order to analyze the design of the fractional height, authors have introduced some symbols here (Table 4.).

### Table 4. Symbols of Fractional Height of Pagoda in Joruriji Temple

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>hj</td>
<td>h</td>
<td>hj'</td>
<td>h'</td>
<td>hj''</td>
</tr>
<tr>
<td>1</td>
<td>h1</td>
<td>hj1</td>
<td>h'1</td>
<td>hj'1</td>
</tr>
<tr>
<td>2</td>
<td>h2</td>
<td>hj2</td>
<td>h'2</td>
<td>hj'2</td>
</tr>
<tr>
<td>3</td>
<td>h3</td>
<td>hj3</td>
<td>h'3</td>
<td>hj'3</td>
</tr>
</tbody>
</table>

1) Height of Column

The column heights every story with units of $K$ and $Shi$ are illustrated in Table 5.

The underlined data in Table 5. are ideal values. All the column heights including D.W. are ideal, while all the heights of columns excluding D.W. are less than perfect. It may be speculated that the $h$, including D.W., should have been determined using $Shi$ as a module. It also could be found that the heights of H.B. on the second and third stories are exactly equal to 1 $Shi$, so it is not possible to determine which part of the H.B. should have been calculated.

### Table 5. Column Height of Pagoda in Joruriji Temple

<table>
<thead>
<tr>
<th>Story</th>
<th>$h$ (K)</th>
<th>$h$ (Shi)</th>
<th>$h'$ (K)</th>
<th>$h'$ (Shi)</th>
<th>$h''$ (K)</th>
<th>$h''$ (Shi)</th>
<th>$h'''$ (K)</th>
<th>$h'''$ (Shi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.042</td>
<td>16.8</td>
<td>37.8</td>
<td>17.5</td>
<td>4.447</td>
<td>10.5</td>
<td>4.307</td>
<td>10.75</td>
</tr>
<tr>
<td>2</td>
<td>4.077</td>
<td>11.5</td>
<td>9.6</td>
<td>4.323</td>
<td>10.3</td>
<td>4.63</td>
<td>11.27</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.913</td>
<td>10.3</td>
<td>9.32</td>
<td>4.22</td>
<td>10.3</td>
<td>4.63</td>
<td>11.27</td>
<td></td>
</tr>
</tbody>
</table>

Note: There is no H.B. on the first story, so there is no datum for the last 4 columns of the Table on the first story.

2) Height between Columns

The height between columns with units of $K$ and $Shi$ are illustrated in Table 6.

### Table 6. Height between Columns of Pagoda in Joruriji Temple

<table>
<thead>
<tr>
<th>Story</th>
<th>$hj$</th>
<th>$hj'$</th>
<th>$hj''$</th>
<th>$hj'''$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.003</td>
<td>9.5</td>
<td>4.341</td>
<td>10.34</td>
</tr>
<tr>
<td>2</td>
<td>3.99</td>
<td>9.5</td>
<td>4.313</td>
<td>10.27</td>
</tr>
<tr>
<td>3</td>
<td>8.767</td>
<td>21.0</td>
<td>9.074</td>
<td>21.6</td>
</tr>
</tbody>
</table>

Note: There is no H.B. above the third story, so there is no datum for the last 4 columns of the Table on the third story.

The ideal data in Table 6. indicates that all the heights between columns ($hj$) excluding D.W. are divisible by either $Shi$ or 2 $Shi$, while all the heights between columns ($hj$) including D.W. are indivisible by either $Shi$ or 2 $Shi$. It may be inferred that the height between columns ($hj$) excluding D.W. could have been designed by using $Shi$ as a module.

Therefore all the $h$ (including D.W.) and $hj$ (excluding D.W.) could have been originally determined by taking $Shi$ as a module. Also, it may be inferred that the D.W. may have been calculated as part of the column and not part of the bracket set. This speculation coincides with Mingda Chen's conclusion in Pagoda of Fogongsi Temple.

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4. Analysis on Design of Bracket Set
The bracket set is the most important part of East Asian traditional wooden buildings. Due to their organic construction, bracket sets used to be the most important content of the module design method. The design of a bracket set has two aspects: height and depth of the bracket set (Fig.3).

4.1 Design of Height of Bracket Set
There are three types of height in the bracket sets: hk1, the height from the bottom of Daito to the top of Gagyo (Fig.3.).

The measured sizes of the height of bracket sets with different units of K and Shi are illustrated in Table 7.

All hk3 in Table 7 are seven multiples of Shi only. This is not accidental. It may have been designed by taking Shi as the module too (Fig.1.). Further, the deduction that the design content of the bracket set heights extends from the bottom of the Daito to the top of Gagyo coincides with the viewpoints of Guixiang Wang in 1982.

4.2 Design of Depth of Bracket Set
All of the depths of the bracket sets on the first and second stories are 2.1 K. This calculation is as follows:

2.1 K + Shi = 2.1 + 0.42 = 2.5.
Thus the depth of the bracket sets on these two stories is just 5 Shi. While the depth of the bracket set on the third story is 2.01 K, 2.01 + 0.42 = 4.8. The result is not perfect. Considering the module (the width between two adjoining rafters) on the third story is 0.4 K, that is to say, Shi = 0.4 K, if 2.01 K is divided by Shi, the result is exactly 5. Therefore, the depth of the bracket set on the third story is 5 Shi, also.

5. Results and Discussion
All the sizes illustrated in Table 8. are certain multiples or fractions of Shi. These phenomena should not be coincidental. Obviously, these sizes may have been determined by taking the Shi as a basic module (Fig.4.).

Table 7. Heights of Bracket Sets of Pagoda in Joruriji Temple

<table>
<thead>
<tr>
<th>Story</th>
</tr>
</thead>
<tbody>
<tr>
<td>hk1 (K)</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

Note: There is no Gawageta on the third story, so there is no datum of columns 4 and 5 concerning the third story.

Table 8. Conjecture of Architectural Design of Pagoda in Joruriji Temple (from Perspective of Kiwarihau)

<table>
<thead>
<tr>
<th>Content</th>
<th>Conjecture of Design (Unit: Shi or Shi3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan Bay Width</td>
<td>First story: Wm=10, Ws=7, W=24</td>
</tr>
<tr>
<td></td>
<td>Second story: Wm=8, Ws=7, W=22</td>
</tr>
<tr>
<td></td>
<td>Third story: Wm=Ws=7 Shi3, W=21 Shi3=20</td>
</tr>
<tr>
<td>Depth of Eave</td>
<td>First, second, third story: De=6, D=10</td>
</tr>
<tr>
<td>Section Entire height</td>
<td>H1=20 ÷ 3</td>
</tr>
<tr>
<td></td>
<td>H2=240 ÷ 3=80</td>
</tr>
<tr>
<td></td>
<td>H3=140 ÷ 3</td>
</tr>
<tr>
<td></td>
<td>H4=400 ÷ 3</td>
</tr>
<tr>
<td>Fractional Height h</td>
<td>hj1=17.5</td>
</tr>
<tr>
<td></td>
<td>hj2=11.5 (10.5)</td>
</tr>
<tr>
<td></td>
<td>hj3=11 (10)</td>
</tr>
<tr>
<td></td>
<td>hj=9.5 (10.5)</td>
</tr>
<tr>
<td></td>
<td>hj3=21</td>
</tr>
</tbody>
</table>
Shi first & second story: 5
Hashiraban
hk3=7

By Painting on Cross Section Real Measurement Painting in Ref. 7.

Fig.5. Construction of Bracket Set in Pagoda of Joruriji Temple
By Painting on Cross Section Real Measurement Painting in Ref. 7.

Authors have approached this question from the perspective of the structural features of the pagoda body.

According to part 4-2 in this paper, the depth of the bracket set on the third story has a close relationship with Shi3 = 0.4 K, therefore the bracket set on the third story should have been built at the same time with Shi3 = 0.4 K. If the conjecture is correct that Shi3 was changed from 0.42 K to 0.4 K afterwards, this repair should have involved the bracket set on the third story. Thus the survey on bracket sets in this pagoda may help us answer the second question raised in this paper.

Although the construction of the bracket set on the third story is a little different from that on the first and second stories (for example, both the first and second stories have Gawageta, while the third story does not, Fig.5), both of them show no essential differences in form or technology. As such, the bracket sets on every story were likely designed and built at the same time. That is to say Shi3 = 0.4 K and the bracket sets on every story are of the same age, and Shi3 = 0.4 K is likely to be original, or at least was carried on with the earliest design.

Overall, if authors examine the original design, the Shi3 was designed as 0.4 K, which is different from the Shi on the first and second stories (0.42 K); while the width of whole bay on the third story was determined as 20 Shi.

6. Conclusion
It can be seen that the domination of Shi in the architectural design of this pagoda is far beyond the scope of bay width. The Kiwarihou appearing in this building is more full-blown than the Kiwarihou (in this pagoda) that Hamashima discussed.

Acknowledgments
This study was supported by the Japan Foundation 2005, the National Natural Science Foundation of China (No. 51308395), and the National Science Foundation for Post-doctoral Scientists of China (No. 2013M531212).

References

Notes
1. The unit of data in the column of Conjecture of Design is Shi or Shi3. The data without any unit indicates the unit is Shi. The length of Shi is 0.42 K, while the length of Shi3 is 0.4 K.
2. De indicates the depth of the base rafter; D indicates the depth of the whole eave.
3. All the h refer to the height of the column with D.W.; the data of h outside the brackets indicate the height of column including H.B., while the data inside the brackets indicate the height of column excluding H.B.
4. All the hj refer to the height between columns in two adjoining stories excluding D.W.; the data of hj outside the brackets indicate the height of column including H.B., while the data inside the brackets indicate the hj including H.B.
6. Conclusion
It can be seen that the domination of Shi in the architectural design of this pagoda is far beyond the scope of bay width. The Kiwarihou appearing in this building is more full-blown than the Kiwarihou (in this pagoda) that Hamashima discussed.

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