Investigation into the Architectural Design of a Traditional Japanese Wooden Pagoda

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Investigation into the Architectural Design of a Traditional Japanese Wooden Pagoda

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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)[1]. The three-storied pagoda in the *Joruriji* temple was established around 1178 AD[2], 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*.

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The most remarkable research on the architectural design of the pagoda appeared in 1968[3]. 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)[4], which is to say in this pagoda 1 *Shi*= 0.42 K.

Table 1. Bay Width of Pagoda in *Joruriji* Temple

Story	Middle Bay Width		Side Bay Width		Whole Bay Width	
	(K)	(*Shi*)	(K)	(*Shi*)	(K)	(*Shi*)
1	4.2	10	2.94	7	10.08	24
2	3.36	8	2.94	7	9.24	22
3	2.815	20/3	2.815	20/3	8.445	20

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 *Shi*3 (the module on the third story) is:

$$Shi3 = 20 \times 0.42\ K \div 21 = 0.4\ K$$

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

(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[5]. 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.

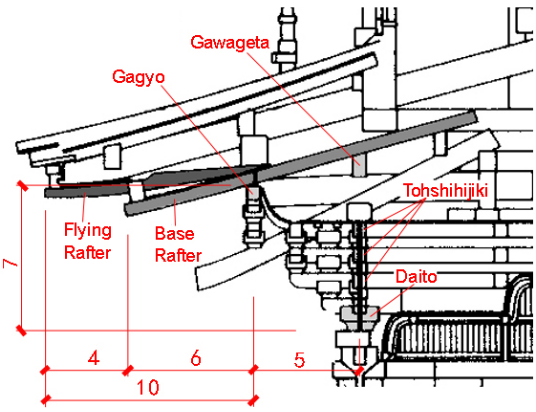

Fig.1. Schematic Drawing of the Design of the Eave and Bracket Set in the Pagoda of *Joruriji* Temple (Unit: 1 *Shi* = 0.42 K)
By Painting on the Cross Section Real Measurement Painting in Ref. 7.

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

Story	Depth of Base Rafter		Depth of Whole Eave	
	(K)	(*Shi*)	(K)	(*Shi*)
1	2.526	6	4.192	10
2	2.526	6	4.192	10
3	2.526	6	4.156	10

3. Analysis on Section Design

This analogous phenomenon also appears in this section design.

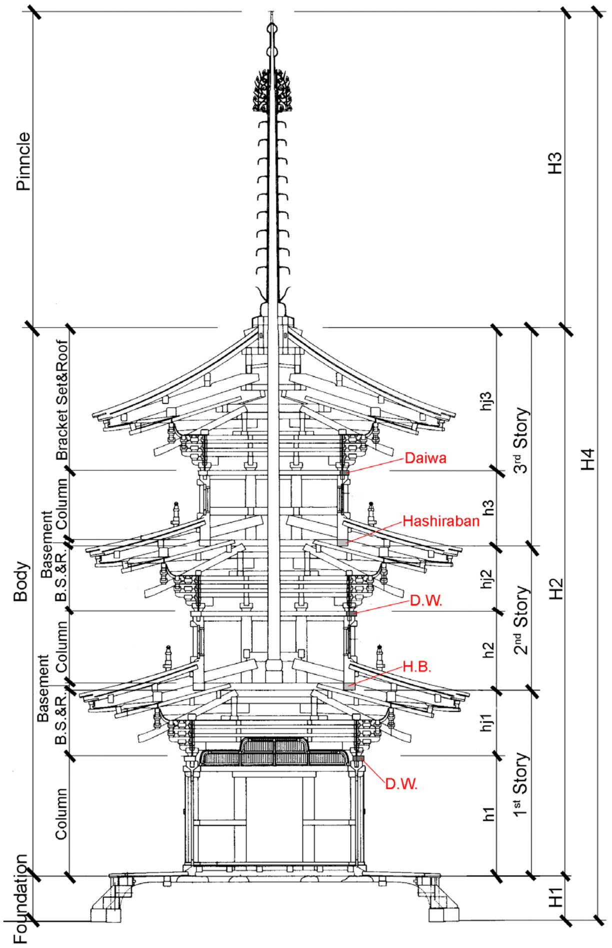

Fig.2. Schematic Drawing of Design of Height
(Cross Section of Pagoda in *Joruriji* Temple)
By Painting on Cross Section Real Measurement Painting in Ref. 7.

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[6].

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 H4 consists of the following three sections: H1, H2, and H3 (Fig.2.).

H1: the height of the pagoda's foundation

H2: the height of the pagoda's body

H3: the height of the pagoda's pinnacle

$H4 = H1 + H2 + H3$

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

E.H.	(K)	(*Shi*)
H1	2.761	6.55
H2	33.6	80
H3	19.47	46.36
H4	55.83	132.9

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*:

$H1 \div (Shi/3) = 2.761 \div (0.42/3) = 19.65 \approx 20$

$H2 \div (Shi/3) = 33.6 \div (0.42/3) = 240$

$H3 \div (Shi/3) = 19.47 \div (0.42/3) = 139 \approx 140$

$H4 \div (Shi/3) = 55.83 \div (0.42/3) = 399 \approx 400$

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

Story	Excludes H.B.& D.W.		Excludes H.B., Includes D.W.		Includes H.B., Excludes D.W.		Includes H.B.& D.W.	
	h	hj	h'	hj′	h″	hj″	h‴	hj‴
1	h1	hj1	h'1	hj'1	h"1	hj"1	h'"1	hj'"1
2	h2	hj2	h'2	hj'2	h"2	hj"2	h'"2	hj'"2
3	h3	hj3	h'3	hj'3	h"3	hj"3	h'"3	hj'"3

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 considered as 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

Story	h		h'		h"		h'"	
	(K)	(*Shi*)	(K)	(*Shi*)	(K)	(*Shi*)	(K)	(*Shi*)
1	7.042	16.8	7.38	17.5	—	—	—	—
2	4.077	9.7	4.4	10.5	4.507	10.75	4.83	11.5
3	3.913	9.32	4.22	10	4.323	10.3	4.63	11

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

Story	hj		hj'		hj"		hj'"	
	(K)	(*Shi*)	(K)	(*Shi*)	(K)	(*Shi*)	(K)	(*Shi*)
1	4.003	9.5	4.341	10.34	4.433	10.5	4.771	11.36
2	3.99	9.5	4.313	10.27	4.44	10.5	4.723	11.25
3	8.767	21.0	9.074	21.6	—	—	—	—

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*[7].

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 *Gawageta*;

hk2, the height from the bottom of *Daito* to the top of the uppermost *Tohshihijiki*;

hk3, the height from the bottom of *Daito* to the top of *Gagyo* (Fig.3.).

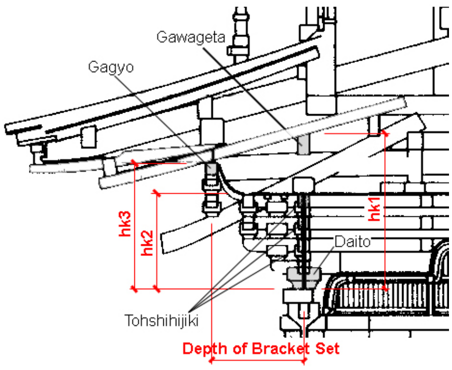

Fig.3. Design Contents of Bracket Set in the Pagoda of *Joruriji* Temple By Painting on Cross Section Real Measurement Painting in Ref. 7.

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

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

Story	hk1		hk2		hk3	
	(K)	(*Shi*)	(K)	(*Shi*)	(K)	(*Shi*)
1	2.18	5.2	3.498	8.3	2.959	7
2	2.18	5.2	3.498	8.3	2.959	7
3	2.18	5.2	—	—	2.959	7

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

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[8].

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[9]. This calculation is as follows:

2.1 K ÷ *Shi* = 2.1 ÷ 0.42 = 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[10], 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*3 = 0.4 K, if 2.01 K is divided by *Shi*3, the result is exactly 5. Therefore, the depth of the bracket set on the third story is 5 *Shi*3, 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.).

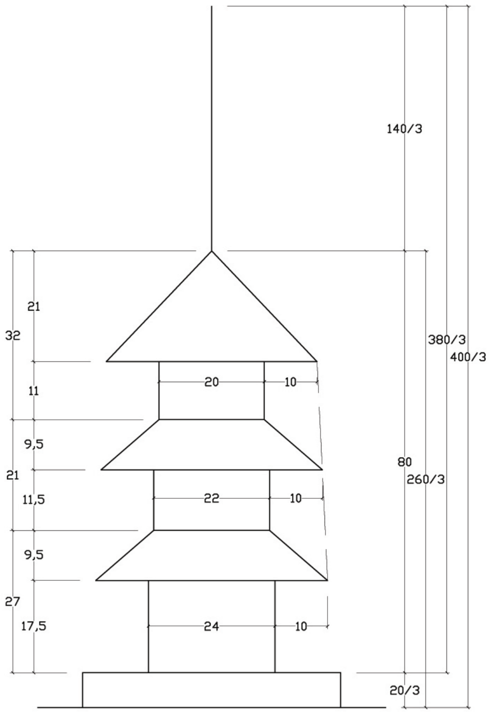

Fig.4. Conjecture of Architectural Design of Pagoda in *Joruriji* Temple, Unit: *Shi* = 0.42 K

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

Content			Conjecture of Design (Unit: *Shi* or *Shi*3)
Plan	Bay Width		First story: Wm=10, Ws=7, W=24 Second story: Wm=8, Ws=7, W=22 Third story: Wm=Ws=7 *Shi*3, W=21 *Shi*3=20
	Depth of Eave		First, second, third story: De=6, D=10
Section	Entire height		H1=20 ÷ 3 H2=240 ÷ 3=80 H3=140 ÷ 3 H4=400 ÷ 3
	Fractional Height	h	h1=17.5 h2=11.5 (10.5) h3=11 (10)
		hj	hj1=hj2=9.5 (10.5) hj3=21

Bracket Set	Height	hk3=7
	Depth	First & second story: 5 Third story: 5 *Shi*3

Note: 1. The unit of data in the column of Conjecture of Design is *Shi* or *Shi*3. The data without any unit indicates the unit is *Shi*. The length of *Shi* is 0.42 K, while the length of *Shi*3 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. including: 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 hj excluding H.B., while the data inside the brackets indicate the hj including H.B.

As the first question raised in the paper has been addressed, authors would like to move on to the second one below.

Hamashima noticed that the *Shi* on the third story (*Shi*3 = 0.4 K) of the pagoda is different from those of the first and second story (*Shi* = 0.42 K). It is natural to ask whether *Shi*3 = 0.4 K was the original design or if it was changed from 0.42 K to 0.4 K in subsequent repairs.

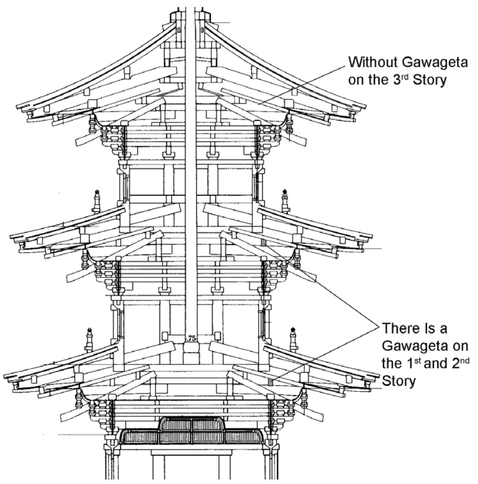

Fig.5. Construction of Bracket Set in Pagoda of *Joruriji* Temple By Painting on Cross Section Real Measurement Painting in Ref. 7.

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 *Shi*3 = 0.4 K, therefore the bracket set on the third story should have been built at the same time with *Shi*3 = 0.4 K. If the conjecture is correct that *Shi*3 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 *Shi*3 = 0.4 K and the bracket sets on every story are of the same age, and *Shi*3 = 0.4 K is likely be original, or at least was carried on with the earliest design.

Overall, if authors examine the original design, the *Shi*3 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

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Notes

1 Ref. 11, 373.

2 According to *Joruriji Nagarekiji* (current articles of *Joruriji* temple, the only historic document of the *Joruriji* temple, formed in 1350), the pagoda had been moved from Kyoto to *Joruriji* temple in 1178, while the year of establishment remains unknown. Compared with the pagoda in *Ichijoji* temple (founded in 1171), the pagoda in the *Joruriji* temple is supposed to have been established not far from 1178. (Ref. 15, 24-56)

3 Ref. 3.

4 *Kanejaku* is the Japanese current "foot", 1 *Kanejaku* = 0.303 m.

5 Ref. 7.

6 There is no part of basement (*Hashiraban* in Japanese and *Pingzuo* in Chinese) in the framework of the first story.

7 Ref. 1, 37.

8 Ref. 12.

9 Ref. 7.

10 Ref. 7.

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