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Evaluation of geometrical characteristics of Korean pagodas

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ABSTRACT

One of the most popular monuments in Korean architectural heritage is multi-story stone pagoda. This study indicates detailed description and geometrical proportions of Korean pagodas. To evaluate geometrical characteristics of Korean pagodas, several cases were investigated and finally 60 of them with data that are more accessible were chosen. The pagodas are classified into different groups such as 3-story, 5-story and 7-story pagodas and different materials such as stone, wood and brick, though most of them are 3-story and stone monuments. The structure of pagodas is divided into four parts to evaluate geometrical features: base sty lobate, body, roof and head. This study has been focused on two sections, body and roof in detail. Using existing database, they were modelled in AutoCAD software to compare their proportions more accurately. Then the height, length and width of body part as well as the length and width of roof were investigated. According to the results, it is found that Pagoda structure follows a certain pattern with specific geometrical proportions.

1. INTRODUCTION

The purpose of this paper is to define different structural forms of pagodas, which are one form of stupas, and to evaluate proportions of these historical monuments in Korean ancient architecture.

In the fifth century BCE, the historic Buddha Sakyamuni died and was cremated, and the sarira found in his ashes were divided into eight portions. Stupas, which are dome-like structures similar to pre-Buddhist burial mounds in Northern India, were built over these relics. Stupas are defined as a symbol of insightful. With looking at stupa in clockwise direction it can be seen a respect for what the stupa contains and indicates (represents). The geometric and shape of the stupa was changed with spreading Buddhism throughout all Asia. In China, Korea, and Japan, the shape had been changed to multi-storeyed towers. The stories of the towers, or pagodas, became smaller in size with each story, and represented the branches of the tree of life and the

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terraces of the mythical mountain.

With the passing of time (year by year), the pagoda changed step by step in using from keeping Buddha's actual body parts building to a monument which believed to be symbolic of Buddha and a place of worship. In India the first pagoda was created like a semi-spherical tomb. In following eras, sty lobate (a flat sidewalk) was added to the base as a function of supporting and a sangryun (a long cylindrical metal ornament) was added to the pagoda's top and also a stone railing was added to surround the structure with beautiful form in design features, end in the pagoda shape most familiar these days (Chodzin and Kohn, 1998; Jo, 1995; Khan,1985).

2. SOUTH KOREA A SOURCE OF STONE PAGODAS

2.1 Historic Characterization of Korean Pagodas

People’s history, life, religion, etc. can be found in architectural heritages as a part of human culture. So, a society has an obligation in preserving this heritage safely to transfer it to next generations (Park et al., 2014).

A pagoda (called "tap" in Korean), which is a multi-story structure generally found at Buddhist temples, is considered the grave of Buddha. In china with entering Buddhism, the Indian-style semi-spherical tomb format was changed with a wooden pagoda in the shape of a pavilion. The Chinese style has then migrated to Korea and remained as a highly popular pagoda during the Three Kingdoms Period. Koreans used stone and created unique and unparalleled pagoda in the world which can introduce Korean history, culture, and religion (Park et al., 2014).

2.2 Structural Characterization of Korean Pagodas

To protect architectural heritages, one must consider natural disasters and hazards caused by social and environmental changes because most of them are always exposed outside. Even so, many masonry structures in architectural heritages have kept their structures intact for a long time despite numerous historic records of earthquakes. A great number of stone cultural heritages are well preserved in Korea, including unreinforced masonry structures that are seemingly weak during earthquakes (Antique Alive, 2015).

2.3 Korean Pagodas Classification

2.3.1. Material Classification

In India by using earth, then in China wood, pagodas were built as multi-story structures, which were spread to the three Kingdoms of Korea, and then Japan. The pagoda tradition was diverged in East Asia, with using bricks in China, in Korea using stone, and continuing to use wood in Japan. Korea has a plentiful supply of high-quality granite stone as the primary material, so they used granite to make unique and distinct pagodas tradition stone in compare with Chinese brick pagodas or Japanese wooden stone pagodas in comparison with Chinese brick pagodas or Japanese wooden pagodas. By entering Buddhism into Korea from China in the fourth century CE, the first pagodas were made of wood, like Chinese pagodas. After the sixth century, Koreans mostly built stone pagodas with using the granite from Korea's mountains. Nowadays Korea has more than 1,000 stone pagodas in different styles, mostly in the form of three-story stone pagoda (Lee, 1998).

a) High-quality granite b) Wood c) Dark gray brick

Fig. 1 Material classification (Antique Alive, 2015)

2.3.2. Number of stories classification

Three stories pagodas are more popular in Korea, among them, Seokgatap and Dabotap in Bulguksa Temple are the most renowned pagoda with the saddest legends but there are some pagodas with ten stories or more. Most of Korean pagodas has square architectural plan, although some have round plan or have six or eight sides (polygonal). In East Asia each story of pagoda has its own prominent skeleton roofline, and the whole structure is capped by a pillar and plate. The form of pagoda mainly is like a monument (Chodzin and Kohn, 1998; Jo, 1995; Khan, 1985).

a) Three-story b) Five-story c) Seven-story

Fig. 2 Classification of Korean pagodas according to number of stories (Park, 2008)

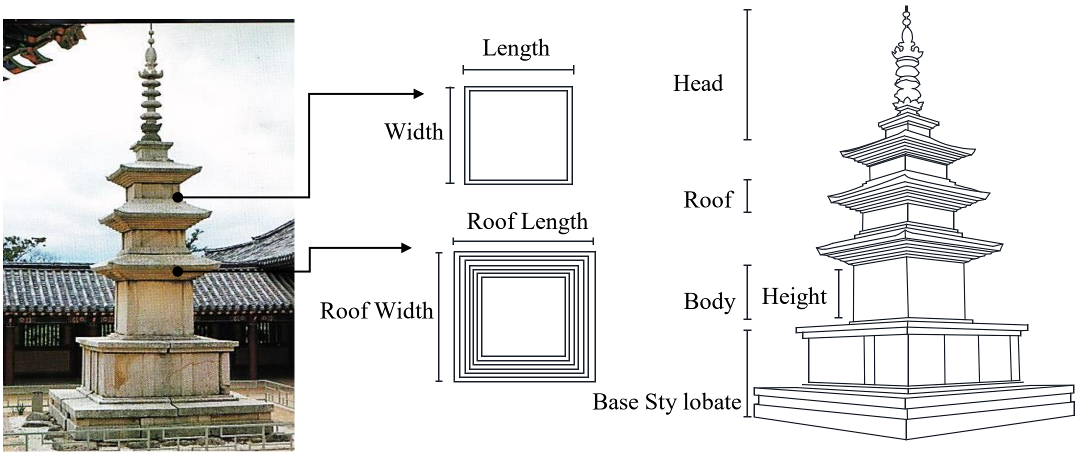
3. PROPORTION ASSESSMENT OF KOREAN PAGODA STRUCTURES

3.1 Description

In this study, to evaluate Korean pagoda structures' proportions, three types of pagodas are chosen, including three, five and seven-story pagodas. Among the large number of pagodas, 30 samples of 3-story pagodas, 22 samples of 5-story pagodas, and 8 samples of 7-story pagodas are investigated, and are modeled in AutoCAD 2017. Particularly, their dimensions and proportions are studied. Most of these 60 pagodas are stone pagodas and only a few are made of bricks, which are selected haphazardly.

3.2 Methodology

To obtain and compare geometrical proportions, a pagoda is divided into different parts for a 3-story stone masonry structure, Seokgatap (Fig. 3(a)). The pagoda stands 8.2 m high, directly across from Dabotap within the Bulguksa Temple complex in Gyeongju, Korea. It probably dates to around AD 751, when Bulguksa was completed. The pagoda consists of four main parts: base sty lobate, body, roof, and head (Fig. 3(b)). In this study due to the large variability of the base stylobate and head of pagodas, studies have been focused on bodies and roofs. The body has key dimensions of height, length, and width, and the roof has two key dimensions of length and width.



(a) (b)

Fig. 3 Seokgatap [left] element definition [right] (Park, 2008)

Various dimension ratios (proportions) are calculated from the first floor up to the last floor. The ratio equations are shown below:

$$\rho_h = \frac{H_i}{H_{i+1}} \quad (1)$$

where ρ_h is height ratio, and H_i & H_{i+1} are height of body at ith & i+1th floor, respectively.

$$\rho_l = \frac{L_i}{L_{i+1}} \quad (2)$$

where ρ_l is length ratio, and L_i & L_{i+1} are length of body at i^{th} & $i+1^{th}$ floor, respectively.

$$\rho_w = \frac{W_i}{W_{i+1}} \quad (3)$$

where ρ_w is width ratio, and W_i & W_{i+1} are width of body at i^{th} & $i+1^{th}$ floor, respectively.

$$\rho_{rl} = \frac{RL_i}{RL_{i+1}} \quad (4)$$

where ρ_{rl} is roof length ratio, and RL_i & RL_{i+1} are roof length at i^{th} & $i+1^{th}$ floor, respectively.

$$\rho_{rw} = \frac{RW_i}{RW_{i+1}} \quad (5)$$

Where ρ_{rw} is roof width ratio, and RW_i & RW_{i+1} are roof width at i^{th} & $i+1^{th}$ floor, respectively.

3.2.1 Three-story

Initially, the image data of 30 three-story pagodas were reproduced from pictures and three-dimensionally designed in AutoCAD software. Then the sizes and dimensions in specified sections were obtained. According to the above formulae, the dimension ratio was measured in different parts. By comparing these ratios, the ratio of 1.2 on average for all pagodas was obtained. The results are shown in Table 1. The first floor to second floor height ratio is much larger than the second floor to third floor height ratio because of the form and design of the three-story pagoda. However, regardless of the height of the first floor, the same ratio of about 1.2 in all other components (i.e., height, length, width, roof length, and roof width) of the pagoda was achieved except for the H_1/H_2.

Table 1 Average values of proportions for 30 three-story pagodas

Proportion		Average value for 30 three-story pagodas
Height ratio	H_1/H_2	2.87
	H_2/H_3	1.24
Length ratio	L_1/L_2	1.22
	L_2/L_3	1.25
Width ratio	W_1/W_2	1.20
	W_2/W_3	1.19
Roof length ratio	RL_1/RL_2	1.20
	RL_2/RL_3	1.21
Roof width ratio	RW_1/RW_2	1.10
	RW_2/RW_3	1.15

3.2.2 Five-story

In the same way as was done for three-story pagodas, all five-story pagodas were simulated by AutoCAD and the dimension ratio was measured in different parts. In Table 2 it can be seen that the first to second floor height ratio has the different value than other floors' ratios. This difference is only in height ratio, so in other parts such as length, width, roof length and roof width all components have similar ratios (about 1.5 ~ 2). According to the study, there is almost no difference between stone and brick pagodas in terms of proportions, and this proportion is likely to be used for aesthetic aspects, which means materials did not have substantial effects on the geometry of structures. The monuments appeared to be designed and built with different materials but in the same shape and proportions.

Table 2 Average values of proportions for 22 five-story pagodas

Proportion		Average value for 22 five-story pagodas
Height ratio	H_1/H_2	2.81
	H_2/H_3	1.21
	H_3/H_4	1.22
	H_4/H_5	1.20
Length ratio	L_1/L_2	1.17
	L_2/L_3	1.21
	L_3/L_4	1.18
	L_4/L_5	1.21
Width ratio	W_1/W_2	1.16
	W_2/W_3	1.13
	W_3/W_4	1.23
	W_4/W_5	1.11
Roof length ratio	RL_1/RL_2	1.14
	RL_2/RL_3	1.14
	RL_3/RL_4	1.13
	RL_4/RL_5	1.21
Roof width ratio	RW_1/RW_2	1.10
	RW_2/RW_3	1.15
	RW_3/RW_4	1.12
	RW_4/RW_5	1.14

3.2.3 Seven-story

For different sections of the seven-story stone pagodas, all ratios were obtained and shown in Table 3. As indicated, the first to second floor height ratio has also different values in comparison with other ratios. Based on the investigation of taller pagodas, it can be seen that the height of the first floor is less than that in other types (heights) of pagodas such as three-story or five-story pagodas. The value of the height ratio of the first to second floor has the lower value compared to the shorter pagodas. In Table 3, the comparative ratios of height, length, width, roof length and roof width of 8 seven-story pagodas are shown and it can be seen that the average value for all seven-story pagodas is close to 1.10.

Table 3 Average values of proportions for 8 seven-story pagodas

Proportion		Average value for 8 seven-story pagodas
Height ratio	H_1/H_2	1.92
	H_2/H_3	1.08
	H_3/H_4	1.16
	H_4/H_5	1.12
	H_5/H_6	1.07
	H_6/H_7	1.18
Length ratio	L_1/L_2	1.12
	L_2/L_3	1.06
	L_3/L_4	1.12
	L_4/L_5	1.11
	L_5/L_6	1.10
	L_6/L_7	1.18
Width ratio	W_1/W_2	1.07
	W_2/W_3	1.05
	W_3/W_4	1.09
	W_4/W_5	1.11
	W_5/W_6	1.06
	W_6/W_7	1.14
Roof length ratio	RL_1/RL_2	1.17
	RL_2/RL_3	1.08
	RL_3/RL_4	1.11
	RL_4/RL_5	1.06
	RL_5/RL_6	1.16
	RL_6/RL_7	1.15
Roof width ratio	RW_1/RW_2	1.04
	RW_2/RW_3	1.07
	RW_3/RW_4	1.06
	RW_4/RW_5	1.06
	RW_5/RW_6	1.09
	RW_6/RW_7	1.10

4. CONCLUSION

Masonry stone pagoda structures built in Korea are largely consisted of 3 parts: top part, body part and stylobate. The stylobate takes the role of foundation, and the reduction of stylobate’s bearing capacity may have a great influence on the safety of structures. In this study, specifically, the components of pagodas were classified into 4 main sections such as stylobate, body, roof and upper part head. Through investigation of a large number of pagodas in Korea, 60 pagodas (three-story, five-story and seven-story) were selected haphazardly from different parts of Korea, among which most of them were stone structures that are typical types of pagoda structures in Korea. The investigation of three-story, five-story and seven-story pagodas was carried out using AutoCAD to evaluate the geometrical properties of these ancient structures. According to the investigation of the thirty 3-story pagodas, many dimensional proportions at each floor were found to be close to the value of 1.2, except for the first to second floor height ratio. This means that the components of the floor are getting smaller as the story increases but with the same proportion. As can be seen in all types of pagodas, the first floor height above the base stylobate is larger than the height of other floors. When going forward from the three-story pagodas to the higher pagodas, the component's ratio is getting closer to the ratio of 1.1, and also the proportion for the higher floor is getting smaller. Therefore, in general it can be concluded that except the first to the second floor height ratio, the rest of the ratios is in between the values of 1.2 to 1.1 regardless the story number and height. This research proves that a very regular and accurate pattern was applied in making these stone and brick masonry structures that the architects and engineers of that era amazingly have used.

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