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A HISTORICAL STUDY ON MODULAR COORDINATION SYSTEM FOR BRICK MASONRY BUILDING IN JAPAN

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Abstract

This paper describes how the brick masonry techniques that were introduced from Europe and North America have been fused into and coordinated with traditional architectural techniques in modernization of Japanese architecture. Focusing on coordination with the dimensions of traditional wooden structures, the paper looks at previous survey results, reviews the literature, and reports the results of surveys using the proposed measurement method to paint a picture of the fervent introduction of overseas techniques and the smoothness with which they have been adapted and modified to contribute to the modernization of Japanese architecture.

Key Words

Japanese historical brick masonry building, Dimension, Module, Measurement

1 Introduction

Brick masonry buildings first began to appear in Japan around the middle of the 19th century, and quickly spread throughout the country over the next 70 years. However, because so many brick masonry buildings were destroyed by the Great Kanto Earthquake of 1923, laws were passed that all but prohibited the construction of new brick masonry buildings.

This paper examines brick masonry techniques that were introduced from Europe and North America during the early period of the modernization of Japanese architecture. Focusing on rigid size restrictions imposed by communities, it describes how directly imported techniques were modularly coordinated with traditional technical systems, and considers the phenomena during the modernization process and the ways in which brick masonry techniques were adapted for Japanese usage.

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2 Brick making techniques and the introduction of brick masonry buildings in Japan

2.1 Characteristics of brick masonry techniques in Japan

Because of Japan's relatively mild, wet climate and abundant forest resources, wood has been widely used in construction, especially in traditional structures. At one time, nearly all private houses and public buildings were made of wood.

In the mid-19th century, the pre-modern era when the country was closed to outside influences came to an abrupt end, and the new policy-makers started looking to the West for new culture and technology. Newly built residences of leaders, foreigners, etc., and public buildings were given a Western look, and an intensive effort was made to use brick masonry for the first time in Japan's history. The modernization of Japanese architecture began with the westernization of architectural styles and the use of hitherto unknown bricks as a building material.

In Japan, this new period is called the "Meiji jidai", or Meiji Era, which lasted from 1868 to 1912. The Meiji Era was an epochal period for the transformation of Japanese society into what it is today.

The construction of building using masonry methods had been part of European culture for thousands of years but had been almost unknown in Japan. The vast results of hundreds of years of architectural trial and error in the West had been eagerly absorbed by the Japanese in the course of a mere 50-60 years. Like other social phenomena, this rapid transformation in architecture represented the resrless spirit of the Meiji Era.

2.2 The evolution of brick making techniques and brick masonry buildings

The first thing that had to be investigated to establish this non-traditional architectural method in Japan was the production of bricks that could be used as construction materials.

Immediately before the opening of Japan, the great Western powers had contrived to attack the country, so the need was born in Japan to start production of cannons. Before cast iron cannons could be made, however, it was necessary to build furnaces that could process the iron. There was only one material known that could withstand the extremely high temperatures the furnaces required -- bricks. These bricks were not the traditional red variety but were white refractory bricks(fire bricks).

It was much more difficult to produce fire bricks than red building bricks. Therefore, Japanese technicians pored over Dutch manuals to gain the knowledge needed for cannon production. The first time that Japanese learned of the existence of bricks was probably through these Dutch manuals, the most popular of which was undoubtedly Huguenin's "Geschut Gieter," which was a volume on cannon production. The point to note here is that this work came with some illustrations including depictions of what appear to be construction bricks. Even during its isolationist period, Japan conducted trade, albeit slight, with the Netherlands via the port of Dejima. It was probably through this window to the world that the book was imported. (see Photo 1).

Photo 1: Nakaminato Refractory Furnace was built with bricks that were made using techniques described in a Dutch manual (built in 1855, restored in 1937).

The full-scale use of bricks for non-furnace purposes occurred a little bit after furnace construction, when the old shogunate in its waning days started building munitions plants. The Nagasaki Iron Works, begun in 1857, was the first Western-style factory in Japan. It was especially noteworthy for its use of trusses, construction of brick masonry buildings, and sintering of bricks for building materials, which was the first such production in Japan.

The man in charge of making Japan's first construction bricks is reputed to have been H. Hardes, a Dutch naval officer who was an instructor at the Nagasaki Naval Academy. Hardes came to Japan on the Yapan (later renamed the Kanrin-maru), a naval vessel which was built by the Dutch for the old shogunate. The bricks, which had metric measurements of 220×104×39 mm, were much thinner than later bricks. Although no architectural traces remain of the Nagasaki Iron Works, there is an example of similar architecture that is still extant-- the winch house of the Kosuge slip dock, at Kosuge in Nagasaki Prefecture. This building, which was used as a dry dock for ships, contained engines and turbines for raising ships out of water. It began operations on December 7, 1868 (see Photo 2).

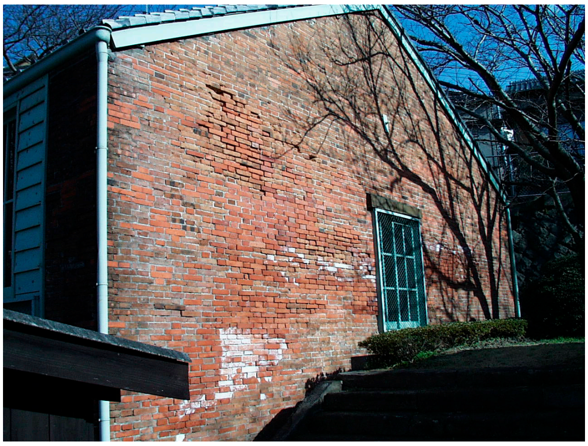

Photo 2: The winch house of the Kosuge slip dock (1868), one of the oldest brick masonry buildings in Japan. The bricks used in this building were manufactured under the direction of Dutch technicians.

3 Traditional Japanese measurement system

Today, Japan uses the metric system, and architectural blueprints, designs, and materials are based on the milli-meter (mm). However, this system has been used extensively only since 1966; before that, the traditional system was dominant.

The traditional system of measures in Japan is called the shakusun system adapted from China, it was based on the dimensions of the human body. In this system, 1 bu is equal to 3.03mm; 10 bu are equal to 1 sun, or 30.3 mm; and 10 sun are equal to 1 shaku, or 303mm. The smallest size was the rin, which is 1/10 of a bu, or 0.303mm. The most important dimension in a floor plan is 6 shakus, which are equal to 1 ken. In metric terms, 1 ken is equal to 1.818m.

A traditional material for flooring that is still used in Japanese construction is the tatami, whose dimensions have been standardized to equal 1/2 ken (0.909 m)×1 ken (1.818 m). The blueprints of the Tomioka Silk Mill drafted by French architects were based on units of 1.8 m because it was roughly equivalent to the traditional ken unit that Japanese construction workers were so familiar with.

In fact, there are still some dimensions used today that are based on conversions with old units. Despite the widespread use of the metric system, there are many cases in which architectural and land measurements are based on 90 cm units. In addition, building materials are often produced in dimensions based on 910 mm, which is nearly equal to the old 1/2 ken measurement.

4 Measurement system of bricks and brick masonry buildings

4.1 Standard dimensions of bricks in the early period

During the early period of modernization in Japan, it was necessary to have guidance from foreign technicians who were familiar with the brick-making technology and design and planning techniques that were being imported from the Europe and North America. It is likely that the technology that was transferred and the measurement system used were related to the nationality of the technician, and thus were inconsistent. However, most of the people who were involved with the actual construction were Japanese who were used to their own traditional system, so as we have already seen, it was natural for Western units to be converted into Japanese units. Over the years, brick dimensions gravitated toward the traditional units of measurement, that is, the shakusun.

In 1905, Shoemon Odaka presented a paper which stated that there were roughly 5 standard sizes of bricks that were being produced in Japan at the time. The most popular of these was the so-called "Tokyo style," which was 7 sun, 5 bu long, 3 sun, 6 bu wide, and 2 sun high. Converted into milli-meters, its dimensions were 227 mm× 109 mm×60.6 mm.

The way to confirm that these dimensions were used in the early stage of Japanese brick-making is through the Ginza Brick Street Project.

The man in charge of the Ginza Brick Street Project was one of the leaders of Japan's modernization, an Irish technician named Thomas Waters.

In his paper which was presented in 1895, Jintaro Takayama described standard sizes of bricks that were being used by various foreign countries at the time. These are listed in Table 1.

Table 1 Brick dimensions used in various countries in the 19th century

Country	Length×Width×Height (in milli-meters)
Germany	250×120×65
Great Britain A	236×115×76
B	254×124×76
C	229×109×65
Australia	305×150×67
France	220×106×54
Belgium	176× 85×45
Spain A	280×140×50
B	250×120×65
Netherlands	260×120×54
Italy	300×150×50
Sweden	250×120×65
Switzerland	250×120×65
USA	200×100×50
Mexico	260×130×65

The dimensions specified in the Ginza Street Project came to be known as the "Tokyo style," which eventually became the most widely used size of brick in Japan. Takayama noted that this size is closest to the "British C type," but the reasons for this similarity are not known.

It should be noted while there might be some geographical relationship with Waters' home country of Ireland, no such relation has ever been found.

4.2 Changes in Japanese brick dimensions

The following is an account of changes in brick dimensions in Japan

The history of bricks in Japan is a history of miniaturization. Bricklayers would hold a trowel for the mortar in their right hand, and one brick at a time in their left. For this reason, bricks had to be of a width that was easily graspable. Thus, the size of the hand was the deciding factor in the size of the bricks.

The bricks that were first brought to Japan in the mid-19th century were much harder to grasp than those seen today, because they had been made for the much larger hands of Westerners. Eventually, the size was modified to be less wide but thicker.

In the beginning, the size of the bricks depended on the type required for the particular building, so they were made to order, but this changed as a result of mass production that began in the early 20th century. As a result, by 1905, when Odaka presented his paper, bricks had begun to be produced in 5 standard sizes. These were the "Osaka style" of 7 sun 4 bu×3 sun 5 bu×1 sun 7 bu 5 rin (224×106×53 mm), the "Tokyo style" of 7 sun 5 bu×3 sun 6 bu×2 sun (227×109×60.6 mm), the "Sagyokyoku style" of 7 sun 5 bu×3 sun 6 bu×1 sun 8 bu 5 rin (227×109×56 mm), the "Sanyo style" of 7 sun 5 bu×3 sun 5 bu 5 rin×2 sun 3 bu (227×107×70 mm), and the "New Sanyo style" of 7 sun 2 bu×3 sun 4 bu 5 rin×1 sun 7 bu (218×105×52 mm).

As its name implies, the "Tokyo style" brick was first made in Tokyo. The "Sanyo style" was first made by the Sanyo Railway Company, had a height of 3 inches, including the

width of horizontal joints. The "Osaka style" was first produced in the provinces, especially the Osaka area. All of these bricks were larger but thinner than today's bricks.

The existence of such a large number of shapes and sizes in Japan's relatively small brick market (compared with the West) tells of the novelty of brick-making at the time and the complexity of the processes that occurred after the technology was introduced, and may give us an idea of the difficulties facing the modernization process during the Meiji Era.

After a while, there arose public demand for standardization. With bricks being narrower than today so that they could be easily grasped by bricklayers, especially women, there were calls for expressing shakusun lengths in metric units, so it was decided to standardize the width to 10 cm units, since there were no fractions involved. The width of joints was set at 1 cm, meaning the length would automatically be 21 cm. The best thickness was determined to be 6 cm. This was because thinner bricks would become deformed after the sintering process, while thicker bricks would make sintering more difficult.

As a result, in 1925 the Japanese Engineering Standards (JES) stipulated that the dimensions of normal bricks were to be 210 mm long × 100 mm wide × 60 mm thick. This represented the first national attempt to standardize brick sizes. The Japanese Industrial Standards (JIS) which were established after World War II maintained this shape and these dimensions (JIS R 1250, 1951)

5 Survey of module dimensions

5.1 Module dimensions

In Japan, survey research on module dimensions of a brick has been conducted by various researchers, including the present author. Information obtained therefrom was described in the previous chapter.

However, in order to gain a true picture of methods used for structuring brick buildings, the goal of design and construction techniques to achieve it, as well as the quality of the work, we must have an accurate understanding of the module dimensions and bonding patterns of brick walls. In other words, to understand the measuring system of bricks as an architectural structure, we need to pay close attention to the dimensions of wall materials used in masonry construction as well as the dimensions of the bricks themselves. However, there has been almost no such survey research conducted in Japan. The author is thus attempting to break ground in this area with the present study. For this purpose, the analysis involves a combination of unit brick size and joint width -- a combination which is called "brick module dimension."

5.2 Proposed method for measuring module dimensions

The measurement involves the use of steel tape to measure the position of the edges of bricks in 1 mm unit. As shown in Figure 1, there are three types of measurement courses: the stretcher course and header course in the horizontal direction, and the height course in the vertical direction.

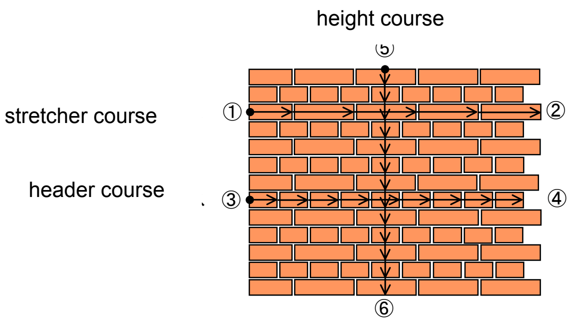

Figure 1 Measurement methods for brick walls

In the horizontal direction, the dimensions are measured about half way up the brick (stretcher course ①→②, header course ③→④), while in the vertical direction, measurements are taken of the central parts of the stretcher and header in such a way that the steel tape does not overlap with the vertical joints.

Using this measurement method, the authors surveyed about 380 surviving brick masonry buildings in Japan that were built from the mid-19th to mid-20th centuries.

5.3 Unit modules

The dimension module (M) is expressed as the product of the brick unit module (m) and the width of one joint (j).

M= m + j

The dimension module is set with the stretcher and header courses in the horizontal direction, and with the height course in the vertical direction.

Next, the minimum unit comprising the brick wall should be 1/4 the value of the horizontal stretcher dimension module (Uh). This value corresponds with 1/2 the header dimension module. For the vertical direction, the height dimension module is used as the unit module (Uv).

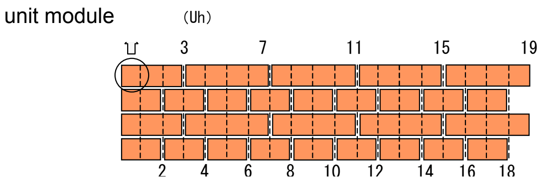

Figure 2 Unit module(horizontal direction)

Based on technical manuals of the time, the width of joints was determined to be 2-3 bu (6.06-9.09 mm), while the vertical and horizontal joints were 2 bu 5 rin (7.575 mm).

Combining this standard joint width with the dimensions of the most popular "Tokyo style" brick gives us a stretcher dimension module of 7.8 sun (236.3 mm), a header dimension module of 3.9 sun (118.2 mm), and a height dimension module of 2.25 sun (68.175 mm). In the horizontal direction, the stretcher dimension module (4Uh) becomes 7 sun 8 bu (236.3 mm), which is exactly twice the header dimension module of 3 sun 9 bu (118.2 mm). In the vertical direction, multiplying the unit module (Uv) of 2 sun 2 bu 5 rin (68.175 mm) by 4 (4Uv) gives us exactly 9 sun (272.2 mm).

6 Coordination with traditional measuring system for wooden structures

6.1 Dimensional relation between wooden and brick structures

While the walls of bricks structures consist of bricks stacked on top of one another, wooden materials are used to construct other features, such as columns, beams, floors, roofs and roof frames, ceilings, interior wall finish, fittings, doors and windows, and others. In addition, in the early days of modernization in Japan, a house built on a lot would likely be two structures, featuring a brick area for parlors, business dealings, etc., in the front, while the family living area in the rear would be a traditional wooden structure. These two types of structures would often be connected, meaning that the dimensions for materials, space, etc., would have to be coordinated.

6.2 Horizontal modules

When considering coordination for a traditional wooden house with an axis based on ken (1 ken = 6 shaku = 60 sun (1,818 mm)), it was easy to use a horizontal unit module (Uh) of 1/30 ken (= 2 sun (60.6 mm)). In other words, the whole number factors of the unit module (Uh) would have to be a modular coordination of the traditional architectural unit ken (1 ken = 6 shaku = 60 sun (1,818 mm)). Furthermore, since 30 could be divided by 2, 3, 5 and 6, this made it flexible for use in designs. At such time, the stretcher brick module (4Uh) was equal to 8 sun (242.4mm).

A nationwide survey of measurements conducted by the authors in Japan showed brick length to be 7.65 sun (231.8 mm) with vertical joint width of 0.35 sun (10.6 mm) in the stretcher course, and a brick header of 3.7 sun (112.11 mm) with vertical joint width of 0.3 sun (9.09 mm) in the header course. As a result, there are examples where the header brick module (4Uh) was rounded up to 8 sun (242.4 mm).

Even when the stretcher brick module (4Uh) was a little less, i.e., 7 sun 5 bu (227.25 mm), 8 bricks in the lengthwise direction (32Uh) would equal 1 ken = 6 shaku = 60 sun (1,818 mm)), making it easy to work with. In this example, brick length is 7.15 sun (216.65 mm) with vertical joint width of 0.35 sun (10.6 mm) in the stretcher course, and a brick header of 3.4 sun (103 mm) with vertical joint width of 0.35 sun (10.6 mm) in the header course. As a result, the stretcher brick module (4Uh) was rounded to 7.5 sun (227.25 mm).

On the other hand, when a whole number factor could not be coordinated with 1 ken, it was rounded using the shakusun system to produce a shakusun value that was a whole number factor. For example, when the previously mentioned stretcher brick module was 7.6 sun (236.3 mm), 5 bricks lined up end to end (20Uh) would be 39 sun (1181.7 mm), which was standardized for design and construction in the shakusun system.

6.3 Vertical modules

Next, let us examine the vertical unit module (Uv). The measurement surveys have shown that Uv is independent of Uh. It might have become necessary to coordinate Uv with Uh when the bricks were stacked vertically in a wall, or when the lintel of the opening was constructed of bricks. However, one seldom encounters examples like these in Japanese brick structures. There are a few cases of bricks stacked vertically in a design, but as far we can be discerned, there was no effort to coordinate Uv with Uh. The width of joints was set to allow for appropriate expansion and contraction.

The height of brick walls is usually not listed, even in blueprints, but the number of bricks is listed. In other words, at the design, construction, or estimation stage it was

shown as a whole-number factor value using the shakusun system for the vertical unit. It is said that the old-time bricklayers used terms such as "4 dan 9 sun," which meant 4Uv＝9 sun (272.7 mm). Thus, 1Uv＝2.25 sun (68.175 mm).

This is an example of combining the height of a Tokyo style brick (2 sun (60.6 mm)) with the width of lateral joints (0.25 sun (7.575 mm). About 1/3 of all the buildings surveyed by the authors were built with the 4Uv＝9 sun dimensions. However, relatively thin bricks were seen in many combinations of brick height and joint width, such as 1.95 sun (59.085 mm)/0.3 sun (9.09 mm), and 1.9 sun (57.57 mm)/0.35 sun (10.6mm) (see Photo 3).

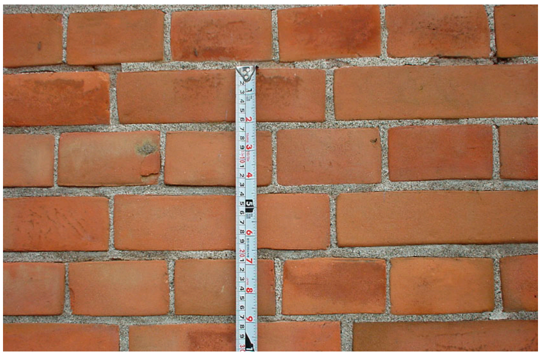

Photo 3 There were many cases of 4Uv = 9 sun (272.7 mm） in the vertical direction.

Besides 4Uv = 9 sun (272.7 mm), there were also fairly numerous examples of 5Uv = 11 sun (333.3 mm), 5Uv = 12 sun (363.6 mm), 6 Uv = 13 sun (393.9 mm), and 7Uv = 16 sun (484.8 mm). In all cases for factor numbers, the shakusun system was used to create whole number values. Furthermore, within the shakusun system there was the same kind of standardization for design, construction and estimation that there was seen in the horizontal direction.

7 Discussion

In the mid-19th century, Japan was undergoing a great social upheaval, and architecture was quickly being modernized. For the administrators of this new system, the intensive introduction of brick building techniques from the West was a symbol of how these changes affected the average Japanese. For the first time ever, Japanese came into contact with bricks as construction materials, brick-making technology, and brick buildings, and they began to master these techniques required for utilization.

At that time, foreign technicians were supervising the work, so some imported materials were used. Even Japanese-made bricks were manufactured using the technology, materials and dimensions that the supervisors had used in their respective home countries, so there was likely no compatibility with natural Japanese patterns, traditional architectural methods, or production systems for building materials, not to mention the spirit and psyche of the Japanese people. However, it wasn’t long before imported technologies and techniques were given a Japanese flavor.
Even in the complex measuring system, which was both traditionally and locally ingrained, there was a movement toward the traditional Japanese shakusun system for all brick modules, including the dimensions of the bricks themselves and the joint widths that were used with them. This provided a smooth fusion with existing wood construction techniques.

The modernization of Japan involved the intensive introduction of hitherto unknown technologies and systems from the outside. It was supported by the strong Japanese

spirit of accepting new ideas and methods and incorporating them into the traditional technological system.

The present paper has discussed the introduction and fusion of brick masonry in Japan and its role in modernization of Japanese architectures based on the results of measurements taken of brick masonry buildings that are still extant in Japan, as well as an examination of survey reviews and other literature. For the first time in Japan, the authors have developed and tested a brick dimension module and associated measurement and analytical methods. The results indicated that in the unit modules, it was extremely effective to set a stretcher module of 1/4 (= 1/2 of the header module). The brick masonry technique using this unit module was applicable to Dutch bond, American bond (consisting of a few stretcher courses interspersed with a header course), English bond (in which “queen closers” are inserted at the ends of walls), Flemish bond (consisting of alternating stretcher and header modules on a layer), a header (German) bond, stretcher bond, and an irregular bond which featured some header modules between stretcher modules.

Furthermore, it was revealed that the brick module used at that time could be estimated by applying the value of a factor of measured unit modules to the shakusun system. The use of this system may help to reveal hitherto unknown aspects of brick masonry technology in Japan. At the same time, we may be able to better understand some of the factors involved in the modernization of Japan.

8 Conclusions

On September 1, 1923, a major earthquake struck the Kanto region of Japan, including the capital Tokyo. Because of the concentration of both population and buildings in this area, the Magnitude 7.9 quake caused the death or loss of more than 100,000 people. Surveys taken at the time showed that many brick masonry buildings were destroyed. However, closer examination of the damage shows that the brick masonry buildings which were designed and constructed under the strict guidelines derived from the lessons of the 1891 quake were unharmed.

Thus, the problem lay in the brick buildings which had not been reinforced against earthquakes. Nevertheless, the building code that was revised after the quake effectively prohibited the construction of brick masonry buildings. The history of brick masonry buildings - from 1850 to 1923 - was therefore a very short one, and the brick buildings that survive today are protected as valuable historical and cultural assets.

At the same time, another look is being taken at the construction of new brick buildings because of their unsurpassed durability, beauty, and environmental compatibility. In April 2003, the Japanese national building code was revised to include regulations on reinforced masonry structures. We can anticipate that this revision will give birth to a new generation of brick buildings in Japan that are highly resistant to earthquakes.

The authors hope that the results of the present surveys will be used to preserve historical brick structures as cultural assets, assist in their rehabilitation, and provide fundamental knowledge for the development of new reinforced masonry structures in Japan.