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Research on Technique "Banzhu" Used in Traditional Dwellings in China from the Perspective of Formwork

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Topic: T1.3. Studies of traditional techniques and materials

Abstract
In China, "Banzhu" refers to the traditional construction technique using formworks and ramming for buildings. Based on a literature review and oral testimonies of builders, this paper describes the areas where Banzhu was the dominant building technique in ancient China. This paper provides a classified study of this technique from the perspective of formworks, according to the unit arrangement and fixed approaches, in order to show the characteristics and distribution of different variations. It is found that all kinds of formworks need to comply with the basic requirements of blocking the earth, controlling the wall section, and fixing themselves, and the reasons for variations are the requirements for wall quality, height, and labor availability.

Keywords: *Banzhu; Formwork; Rammed earth; China.*

1. Introduction

"Banzhu（版筑）" is one of the traditional construction techniques widely used in ancient China. It refers to the use of formworks and ramming to form a structure with a certain strength. From the Shang Dynasty (about 1600 BC - 1046 BC), it was widely used in building walls (Du, 2005), and continues to be used today because of its simple operation and easy availability of materials.

In China, the material of Banzhu is mainly earth, and the research on it is mostly subordinate to the concept of rammed earth and earthen architecture, which makes more emphasis on materials while ignoring the most fundamental content under the definition of this technique - formwork. The natural and social conditions in various regions have given birth to different types of dwellings, resulting in different types of Banzhu techniques, and the formworks used are also different (Fig.1).

Discovering the wisdom and rationality in it is of great significance to inheriting and developing these traditional techniques. Although the technique was once used in most areas of China, this paper concentrates on areas where Banzhu was the dominant building technique in the ancient period (before AD.1840). The research method consists of oral testimonies of builders in typical

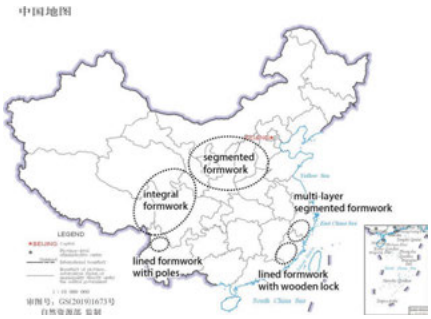

Fig. 1 The classification and distribution of Banzhu. (Own elaboration based on the map of China, bzdt.ch.mnr.gov.cn)

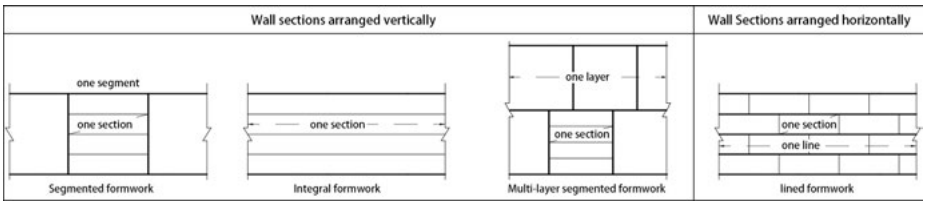

Fig.2. The classification of formworks (author)

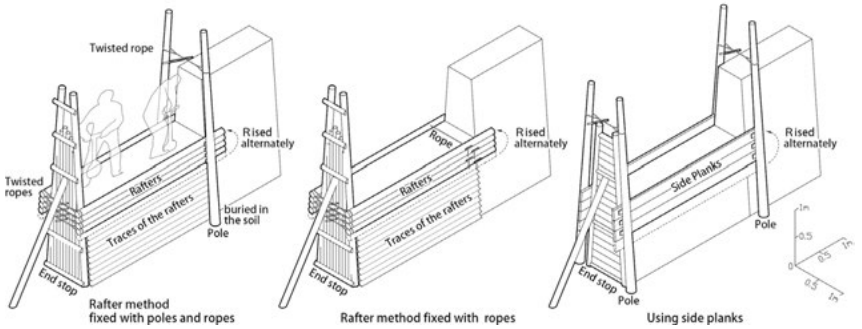

Fig.3. The segmented formworks (author)

areas to confirm the basic techniques and a literature review to make sure the variations and distribution.

The walls built by Banzhu are often divided into multiple units, which are separately rammed. One part of the wall corresponding to a side plank is called one "Ban (版)" which means one wall section and can be arranged vertically and horizontally (Fig.2).

When wall sections are arranged vertically, they can be divided into segmented formwork, integral formwork, and multi-layer segmented formwork. Segmented formwork means dividing the wall into several segments, and a segment of the wall is formed by stacking several wall sections vertically; extending one segment to the whole wall is the integral formwork; superimposing the method of segmented formwork forms the multi-layer segmented formwork. When wall sections are arranged horizontally, only have one kind of division, namely lined formwork. It means each section is spliced horizontally until completing a circle of the wall called one line. Different unit divisions affect the use of formwork, including the way of moving and fixing.

2. The segmented formworks

In the segmented formwork, wooden poles are used on both sides of the wall to fix the side planks or directly fix them with ropes, and end stops are used to control the wall cross-section and are located at the end of each segment of the wall.

In the Loess Plateau area, "rafters(椽)" — thin logs — are used instead of planks, which is called the "rafter method (椽筑法) ". When a segment is being constructed, the side rafters are fixed on both sides of the end stop using poles or ropes (Fig.3, 4).

Fig.4. Rafter method used in Shanxi (Source: Zhang, 2017)

The shape and size of the end stops are determined by the cross-section of the wall which usually is a trapezoid with a small top and a large bottom. This shape was probably inherited from the earthen city walls because of similar construction methods and distribution areas. The city walls originated from mounded earth, giving them the initial shape of a trapezoid. The shape of walls lowers the center of gravity making them more stable and allows the foot of the wall, which is the most vulnerable part, to withstand more erosion. The end stop is framed with wooden sticks and then filled with other simple materials such as thinner sticks. The rougher the trace left by the end stop, the better the connection between the two segments.

The side rafters are stacked and placed on both sides of the end stop. One rafter corresponds to one ramming layer. After the height of one side rafter is rammed, the next one is placed. From about the fourth rafter, the bottom rafters can be pulled out and placed on the top, and the rafters can be raised alternately up to the desired height. The unmoved rafters protect the newly rammed earth wall. The end of rafters near the end stop is tightened with ropes. The end near the built earth wall can be fixed with a pair of poles or ropes. Using poles, the upper end is tightened with a twisted rope, and the lower end is buried in the soil. Wooden wedges are placed between the rafters and the poles to adjust the spacing of the rafters and to facilitate their removal. Using rope, the inner rope is rammed into the earth wall, and the outer rope is cut to remove the side rafters. The unevenness of the side rafters and the inclined sides of the wall just solve the self-weight of the rafters, so that no other support is needed at the bottom.

In the Loess Plateau, the rafters are similar in size, about 10cm in diameter and 3m long, forming segments about 2.6m long and less than 3m high. (Zhang,2017; Lu, 2015).

The method of using side planks is similar to that of side rafters, constructed in segments, fixed by poles on both ends, and raised alternately. To prevent the side planks from sliding down, wooden braces are sometimes added below them.

Using rafters to replace planks is a simplified way of building. Almost all of the formwork is made of rod-shaped materials, which are easier to obtain and process than planks. These rafters can be used to build a roof after the walls are finished. However, the rafter method also has obvious shortcomings. The gaps between the rafters are not rammed, resulting in poor wall surface quality. The inclined sides limit the height of the wall and increase the floor space.

In addition, two rafters can be spliced at the middle poles to extend the length of one segment (Regional Feature Library in Anding, 2017), which can reduce the movement of the whole formwork, speed up the construction, and reduce the wall joints.

3. The integral formworks

By splicing the side planks, the length of one segment is extended to the overall length of the wall including corners, forming the integral formwork (Fig.5). It facilitates simultaneous ramming and allowed the building of rows of wall sections without vertical joints. The work efficiency is improved in the case of abundant manpower and the integrality is improved. This method is mainly distributed to Tibetan areas in Tibet, Sichuan, Yunnan, and Qinghai provinces.

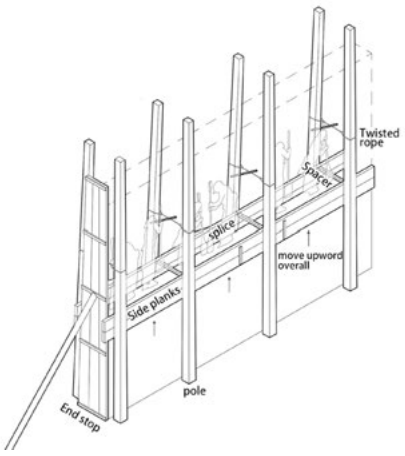

Fig.5 The integral formwork (author)

In integral formwork, side planks are still fixed by poles, and the end stop is fixed at the end of the wall. But, the side planks are generally larger. In the east of Qinghai, it is 45cm high and 4.5m long (Zhang,2016); in Tibet, it is 30cm high and about 5m long (Muya, 2009). Due to the large height of the side planks, a wooden spacer is placed between the two opposite planks to avoid falling inwards under the pressure exerted by the poles. At the same time, the distance between side planks is controlled to form a slightly trapezoidal section of the wall. Each time a section is finished, the entire side planks are pushed up (Fig.6).

Fig.6 People were pushing up side planks of the integral formwork (Source: Shu, 2016, https://www.poco.cn/works/detail_id5245000)

The height of the poles depends on the height of the wall. Taking buildings in Qinghai as an example, the height of the buildings there is generally three-story, so the height of the poles is also increased accordingly, about 12m or more, and the diameter is about 15cm, and the distance between poles is 1~1.5m or so (Jing, 2013). During construction, after the foundation wall is completed, all the poles are erected, which is convenient for construction. The inside surface of the wall is often kept vertical, and the outside is slightly inclined, so the poles are also vertical on the inside and inclined on the outside.

The scenes of Tibetan construction are often very grand, with many people building together at the same time. In this labor scene, the action of ramming is accompanied by the singing, forming a rough dance (Muya, 2009).

Sometimes due to the influence of the internal wooden structure, the construction of earth walls needs to be alternated with wooden structures. In Diqing Tibetan Autonomous Prefecture, Yunnan province, dwellings are usually two to three stories, with rammed earth walls outside and wooden structures inside (Fig.7). After the foundation is completed, the walls are first built to the height of one story, then need to be dried for a few days to increase strength, at the same time, the internal wood structures are assembled. The walls and wood structures of the second story are built the same way, and so on for three or four stories (Zhao, 2018).

The poles were erected differently in this area. The inner poles, which are slightly higher than one story, need to be removed when the wooden structure is being constructed and erected again after it. The poles on the first floor are buried underground, and on the second and third floors are fixed in the gaps between the wooden beams and the earth wall. There also are beams tied between the outer poles to stabilize them and serve as ladders.

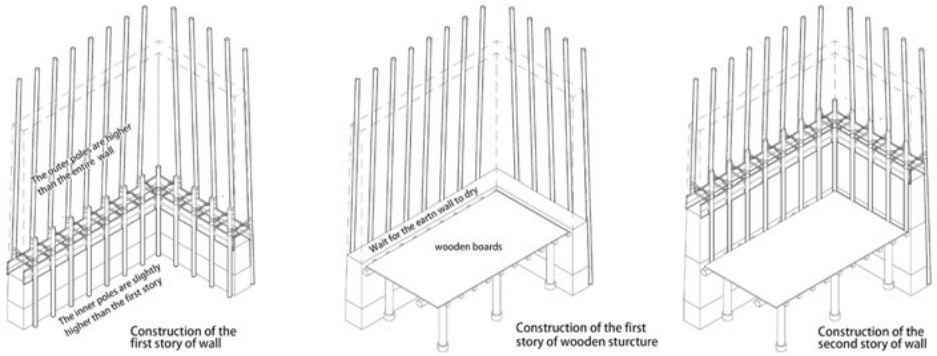

Fig.7 The integral formwork in Deqin, Yunnan province (author)

4. The multi-layer segmented formworks

Multi-layer segmented formwork is used to build higher walls. During construction, the entire wall is divided into several layers (unequal to the height of the building story, but related), and the height of formwork is not the overall wall height, but the height of one layer. In the scope of each layer, it is similar to segmented construction, but it needs to solve the support problem because poles are raised. This method is mostly distributed in the northeast of Fujian and the southwest of Zhejiang province. The outer walls of the buildings there are 2 to 3 stories high, most of them are enclosure walls, and the internal wooden structures are load-bearing.

The wall here is almost vertical, so the end stops are in the rectangle. Two pairs of side planks are generally used and raised alternately (Fig.8). The dimensions of the side planks and the end stops are different in different regions. The length of the side planks in northern Fujian is about 4~4.5m and the height of the end stop is about 4.5m (Wu, 2019). In Zhejiang, it is much smaller. The length of the side planks is only 1.2~1.5m, and the height of the end stop is about 1.7m.

The side planks are fixed by the poles, and the poles need to be supported by putlogs. in northern Fujian, bamboo tubes whose length is equal to the width of the wall are pre-buried 30cm below the top surface of the first layer. When ramming the second layer, wooden putlogs are inserted into the bamboo tubes and hung the two ends out of the wall. Then simple wooden boards are laid on the putlogs and the poles are placed on them. The upper ends of the poles still use twisted ropes, and the lower ends are fixed with ropes or iron wires through the wall where small bamboo tubes are also embedded to facilitate pulling out them. In the Zhejiang area, poles are directly fixed with putlogs, the poles are slotted at the end and ride on putlogs, and wooden wedges are used to fasten them (Fig. 9). One end of the putlogs is slightly larger than another to facilitate putting out by tapping the end.

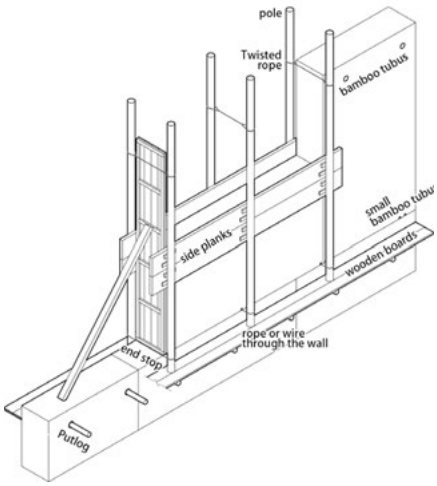

Fig.8 The formwork used in northern Fujian (author)

Fig.9 The formwork in southern Zhejiang (author,2019)

The segments of the upper and lower layers should be staggered to avoid straight joints. But this stagger is small, usually, only one wall thick, formed by intersections at corners. Layers and segments need to be connected by uneven surfaces and concaves shaped by the sharp end of the rammer, or pre-buried woods (Zhang,2015). Between segments, bamboo tubes and wooden sticks are embedded to connect each other in some regions.

During construction, the earth wall was first constructed followed by the wooden structure, but the two were not completely separated, combined with wooden pins or stringers at the top. Such weak connections make the wall have a certain stability, in the meantime, avoid problems caused by different shrinkage of different materials.

The walls here are amazing in the ratio of height to width. In northeastern Fujian, the bottom width is 0.5~0.6m and the height is about 10m. They are not load-bearing walls, and the need for multi-story buildings makes them thin and light, while also meeting the needs of thermal insulation and defense. The joints left by the construction can also be regarded as reserved expansion joints to protect the interior of the wall from cracks. The construction of each section maintains the speed of segmented formwork, while the height is increased through putlogs.

5 The lined formworks

The lined formwork means that the whole formwork moves horizontally after tamping each section and completing a circle of the wall is as one line. The modules are small, the formwork is light, the operation is flexible, and the quality of the single section and the integrity of the whole wall is guaranteed, making the method common in the world.

The formwork is generally composed of two side planks and an end stop with the same height of side planks, which can be fixed in a variety of ways.

5.1 The formworks with putlogs and wooden ribs

With the end stop, one end of the side planks can be mortised with the end stop and another end fixed with putlog below them and a pair of wooden ribs outside. Putlogs are placed on notches cut on the top of a previously built wall and protruded slightly over the wall. A hole is made at the protruding end to fit the wooden ribs preventing them from spreading out. (Fig.10). The end stop can be omitted, another set of putlog and ribs is placed at the position of the end stop, and a space is added to prevent side planks from tilting inward.

This method is used in various regions, and there is no centralized distribution area. However, the size of the template varies in different regions. In the Daliang Mountain of Sichuan, the side planks is about 2m long, 0.33m high, and the end stop is about 0.5m wide (Lu, 2015). The size of the formwork in Tibet is larger, and two doors are directly used as side planks, with a length of 2m and a height of 1m. The diameter of the putlogs is 15cm and of the poles is 13cm (Muya, 2009).

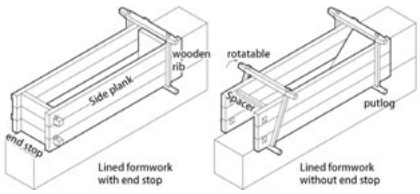

Fig.10 Two kinds of lined formworks fixed with putlogs and wooden ribs (author)

5.2 The formworks with wooden locks

In southern Fujian, where Tulou is commonly distributed, the side planks are fixed at the open end with a wooden lock. The wooden lock is generally composed of two vertical wooden bars and two horizontal wooden bars. The vertical bars are curved inside and fixed in the middle with a horizontal bar. Another horizontal stick is pressed down from the top to open the vertical sticks to both sides by taking advantage of their curved sides (Fig.11,12). As a result, the bottom of vertical sticks is tightened inward due to leverage. There are also putlogs under the side planks, but much thinner, to support the weight of the side planks and people standing on them when ramming and to mark the thickness of the wall when placing planks (Lin, 1995).

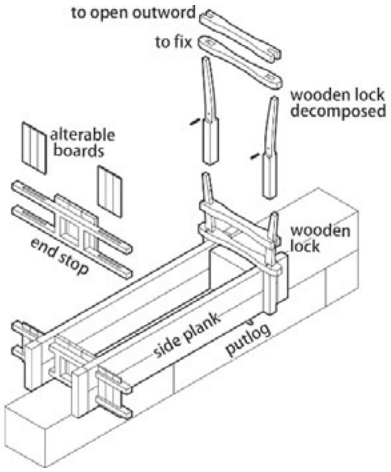

Fig.11 The formwork with a wooden lock (author)

In some areas, the putlogs will be replaced with bamboo wedges to avoid the holes (Huang, 2009). The end stops here are slightly different from the other methods. Because the height of Tulou is mostly 3 to 5 floors, and some walls can reach more than 20m, each story of the wall is gradually thinned in a stepped shape from inside to stabilize the wall. To adapt to the different thicknesses, the end stops are made in a frame structure to adjust the width by increasing or decreasing the wooden boards in the middle. However, if the wall is too thick, reaching more than 1.5m, two walls should be built along both sides of the wall firstly, and then fill in the middle to prevent the end stops and the wooden locks from being too large.

Fig.12 The formwork used in Tulou (Source: Chen, 2016, www.163.com/dy/article/E9GLU3K10521AJ1J.html)

5.3 The formworks with poles

Poles are rarely used to fix lined formwork since every time the formwork is moved, the poles have to be re-installed, which undoubtedly increases the workload. This method is only seen in the Jianchuan area of Yunnan. Dwellings are two-story high with load-bearing wooden structures inside, and earthen walls outside.

The side planks are about 4m long, 0.4m high and 7cm thick, fixed by three pairs of vertical poles. Inclined poles are used below them to prevent slipping. After tamping one section, move the formwork horizontally to the next, and reinstall all the poles (fig.13).

Using poles eliminates the holes caused by the putlogs and reduces the weak points of the wall. In addition, the installation of the side planks also breaks the restrictions of the putlogs. It can be used diagonally, and the triangular hypotenuse is directly rammed at the gable.

In the meantime, the formwork here has another feature, no end stop is used, except for the first line, corners, and ends of the wall. Therefore, each section is intersected by inclined planes, which enhances the connection between them. This advantage is also reflected in the corners and where the partition and exterior walls meet.

Jianchuan is an earthquake-prone region, and the anti-seismic requirements result in the use of poles, no use of end stops, and diagonal ramming.

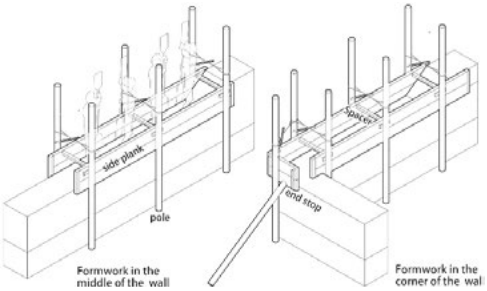

Fig.13 The formworks used in Jianchuan (author)

In addition, the rammed earth wall is also closely integrated with its internal wooden structure to be stable mutually.

6. Conclusions

The combination of wall sections is affected by multiple factors, such as the height of the wall, the quality requirements, and the manpower. The way that the sections are stacked vertically, similar to the rammed layer, may be applied earlier than that arranged horizontally. Furthermore, the rafter method is more simplified, which may have

existed long before people could handle finely processed wood, and with the improvement of processing tools, it gradually evolved into a convenient and suitable thickness of the wooden planks. The integral formwork can improve efficiency while achieving the best integrity if there is sufficient manpower. The multi-layer segmented formwork has both the quickness of segmentation in the meantime solving the problem of construction of the high wall. The method of lined formwork has the characteristics of flexible operation of small units and closer horizontal connection.

From loose earth to stabled walls, formworks play an indispensable role in shaping. The side planks are used to block the earth. The end stops limit the spacing between side planks and determine the thickness and walls cross-section, and this function can be replaced by spacers. The fixing methods such as tensed by ropes, erecting poles, using putlogs and wooden ribs, and wooden locks are mainly used to resist the lateral pressure during tamping and prevent the side planks from being stretched out. Fixing with ropes directly is only found in the rafter method. Erecting poles is widely used, and it is buried if it is on the ground or supported and fixed by putlogs if not. In the latter case, the problem of high walls can be solved, and the poles can be reduced to wooden ribs, making the whole formwork more compacted. The use of wooden locks can fix the side planks from the top, reduce the diameter of the putlogs, and even make them replaced with bamboo wedges, reducing or eliminating the impact of the holes on the wall.

These traditional technologies, which once created wonderful architectures, are being rapidly lost under the impact of modern technology. With the rise of green, low-carbon, and vernacular architecture, they have become a hot spot for architects. If we understand them more precisely and comprehensively, the more chances we have to develop their strengths and potential.

Funding

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