The structural system and analysis of timber construction
built in Tianning pagoda, China

MA Renle
Professor
Department of Building Engineering, Tongji University
Shanghai, China

HE Minjuan, PhD
Professor
Department of Building Engineering, Tongji University
Shanghai, China

LI Hui        FENG Li
Lecturer     Engineer
Department of Building Engineering, Tongji University
Shanghai, China

Summary

The Tianning Pagoda located in Changzhou Jiangsu is being rebuilt. It is octagonal with 13 stories and 153.79 meters in height. The pagoda is the style of the Tang and Song Dynasty. Its main structural system is steel frame. In order to follow the Chinese tradition of wood construction of temples, a wood hall is being built in the 1st floor of the pagoda. The wood hall covers over 1300 m². Chinese Dou-gong style is adopted. A few horizontal steel braces are added between wood columns in order that the structure has enough whole rigidity and stability. This paper will introduce the hall system, connection and structural analysis etc.

Keywords: Tianning Pagoda, Structural system, Connection construction

1. Introduction

Located in the city of Changzhou China, the Tianning Temple was built 1300 years ago. Because there are a lot of magnificent buildings with large space in the Temple, the Tianning Temple was No.1 Buddhist Temple in Southeast China. Tianning Temple had been destroyed and rebuilt for five times within 1300 years. From 2002, the Tianning temple began to rebuild. The Tianning Pagoda which is built in the Temple is 153.79m in height with 13 stories. The architectural area is 27000 m². Because of its height and its area, the pagoda will be the highest and largest pagoda in China. It will link Chinese historical culture and modern architecture together (Bing Huizhong, 2004). And it also will be a sightseeing place for local and foreign visitors.

The main load bearing system of this pagoda is a steel structural system. The pagoda is decorated with a lot of wood members and bronze. But in Chinese traditional opinion, the main hall of Buddhist temple should be built in wood. Therefore, at the first floor of this pagoda, a wooden hall is built. Most horizontal loads and vertical self weight in this hall are borne by the timber beams and columns. A few timber columns are connected to the continuous pagoda frame columns. So a few loads are transferred to the frame. In order to meet the requirements of whole structural rigidity and stability, a few braceings are added between the timber columns. In this paper, the structural system of this timber hall is introduced, the connection construction in the wood hall is presented, the analysis method and the load bearing capacity of the timber structure are recommended.
2. **Structural system**

The elevation of the pagoda is shown in figure 1. For the whole height in 153.79 meters, the bottom 21 meters is concrete and the upper parts are steel frame. The steel frame is installed upon the bottom concrete frame and transfer all the upper weight, wind load and earthquake action etc. to the bottom concrete structure.

The wooden hall at first floor is larger than the upper floors. The wooden roof extends to the outer of the pagoda. The plan arrangement of the wooden hall at first floor is shown as figure 2. Its section A-A is shown in figure 3.
As shown in figure 3, the round columns are wooden. Their diameters are 600 mm. These wood columns are only one floor in height. The black elements are concrete columns and shearwalls. Concrete columns will be extended to 21m in height. And then steel columns will be installed on them. Wood beams connect with columns by Dougong (a kind of corbel). Wooden beams and flying-rafters form the roof of main hall. The upper floor supports on the whole frame columns by steel beams.

In order to ensure the rigidity and integrity of this timber hall, some horizontal braceings are added upon the wood ceiling shown in figure 4 and 5.

![Figure 4 Position of bracings and link beam](image4.png)

**Figure 4 Position of bracings and link beam**

![Figure 5 Plan B-B of bracings](image5.png)

**Figure 5 Plan B-B of bracings**

As shown in figure 2, concrete columns and timber columns need to be work together. In this case, the link beams between different material columns should be rigid enough. At the same time it needs to be convenient that the connection between the end of beam and the side of column. To solve the rigidity of beam and the convenience of connection, steel box beam is designed as this link beam. Wood is used to decorate out steel beam as shown in figure 6. One end of steel beam insert into timber column and the other end of this beam is welded on the steel plate which is embedded on the surface of concrete column.

![Figure 6 Link beam](image6.png)

**Figure 6 Link beam**

### 3. Structural design

Wood used in this timber hall is Manglletia fordiana Oliv. which is imported from Burma. Its Modulus of elasticity $E$ is 7040 N/mm$^2$, bending resistance strength $f_m$ is 93.3 N/mm$^2$, compression
resistance strength parallel to grain $f_c$ is 43.2 N/mm$^2$ and compression resistance strength perpendicular to grain $f_{cp}$ is 11.1 N/mm$^2$ respectively when the moisture content is 12%.

Main loads considered are dead load, roof live load and wind load. Dead load includes the weight of roof, beams, columns, bracings, connections such as Dougong and finishing materials. Roof live load means examination load on roof. Because the timber construction is only one floor in height, earthquake action is not the controlling load.

All beams are looked as simple beams or continuous beams. Columns are simply supported ones. According to calculation method of static analysis, forces in all elements can be got. Based on these inner forces in elements, the strength, rigidity and stability of timber elements can be checked upon the timber code (GB50005, 2003). Most timber beams are connected with timber columns by tenon. In this case, the section on element should be considered weaken by connection.

4. Conclusions

Timber structure is a kind of traditional construction in China. Because of the lack of wood resource decades before, timber construction buildings were limited strictly. It results that our engineers are not familiar with the design and building technique of timber construction. Wood science research in China is also far behind the other countries. For lack of experience, there is no enough design guidance in our timber design code and manuals.

In fact, timber structure design is just like the other structures’ such as steel concrete ones. From the basic design principle and methods, timber structural system can be formed. Based on the structural system, structural static and dynamic analysis can be conducted. Just like other structural system, integrity, rigidity and stability are very important, so enough bracing system is need.

For a structure, skillful application of different material is very important. This design of tianning pagoda proves that timber combined with concrete and steel can result a wonderful hybrid construction. Whole steel frame is benefit for the wind resistance and seismic resistance of the high-rising structure. Concrete bottom structure is rigid enough and links the upper structure and foundation together. Timber hall inherits the Chinese traditional culture. It is very important for a engineer to synthetically apply all material, structure, culture, art and aesthetics together.

5. References
