Review

Transplantation and Adaptation: Research on Reinforced Concrete Structures in Modern Nanjing (1909–1949)

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Abstract: Modern Nanjing experienced a boom in the construction industry. As an advanced material and construction system, reinforced concrete structure was also imported during this period. This paper presents the brief historical background and structural adaptability of reinforced concrete buildings in modern Nanjing. Reinforced concrete was used in industrial buildings in the districts along the Yangtze River in the early 20th century, and in public buildings along Zhongshan Road after 1927. Western-style reinforced concrete buildings used both pure frame structure system and mixed structure with a reinforced concrete frame, brick masonry and timber roof trusses. The Chinese Renaissance buildings used roof structures with different shapes and materials on the main reinforced concrete structure. Based on the study of existing modern reinforced concrete buildings in Nanjing, this paper classifies and compares different types of structures, and indicates that the selection of structures was the adaptive result of comprehensive trade-offs between structural performance, space availability and economy. This research implies the transplantation and adaptation of reinforced concrete structures in modern Nanjing and lays a fundamental structural foundation for the conservation of this architectural heritage.

Keywords: reinforced concrete; cement; pure frame; mixed structure; roof trusses

1. Introduction

With the opening of coastal cities in China after 1840, British and other Western architectural styles were imported. The colonial veranda style, the pure British and French styles, and the international style gradually appeared in the concessions, and spread to the Chinese controlled districts and neighboring cities [1–3]. Along with the influx of architectural styles, architectural technologies were also imported. Colonies and concessions, such as Hong Kong and Shanghai, began to use reinforced concrete structures as they could withstand both gravity and lateral loads and were used in Britain and France [4–7]. Shanghai completed its first reinforced concrete building in 1908 and adopted the London-based building codes, known as Rules with respect to reinforced concrete building in 1915 [8]. As a city close to Shanghai, Nanjing was directly influenced by the architectural trends in Shanghai. In Nanjing, reinforced concrete structures were used in industrial buildings in Xiguan and Pukou districts at the beginning of the 20th century, and in public buildings along Zhongshan Road after 1927 (Figure 1).

As the main component of concrete, cement gradually ceased to rely on imports after 1911 [9] (p. 53), but it was still more expensive than bricks and other traditional building materials. Our earlier research showed that the construction techniques of detached housing, which were mainly from Britain, were often modified by Chinese craftsmen to make them simpler, cheaper and more suitable for Chinese tastes [10]. This phenomenon also occurred in modern reinforced concrete structures. Pure reinforced concrete frame
structures were relatively rare in Nanjing, while mixed structures that combined the advantages of reinforced concrete frames, brick masonry, timber and steel roof trusses were more common in Western style buildings. In addition, Chinese Renaissance buildings, originally promoted by foreign architects and popular with Chinese officials, combined both Western architectural composition and Chinese decorations. Reinforced concrete frames were often used as the main structural elements, but the most distinctive roof sections also had the flexibility to choose Chinese or Western timber trusses, reinforced concrete trusses and steel trusses, depending on different needs.

Figure 1. The areas where reinforced concrete buildings were distributed in modern Nanjing.

Wang Yanmou traces the history of cement in China [9] (pp. 37–114), and Chen Liang and Xu Biyu introduce the development of Nanjing’s modern industrial buildings and their construction technologies [11,12]. Terunobu Fujimori, Liu Yishi, Gregory Bracken examine the spread of Western architectural styles in China [1–3]. According to their research, the colonial veranda style architecture from South Asia was the first foreign style introduced into China, but after 1920, the pure Western styles were directly imported from Europe and America due to their closer connections with China. Cody, Nancy and Atkin studied the process by which Western architects created Chinese Renaissance buildings by applying the Beaux-Arts system and traditional Chinese architecture [13]. Cody also describes the dilemma of American architects in modern Shanghai and the lack of materials, technologies and skilled construction workers in their projects [14]. Tang Fang explores the building regulations of the public concession in Shanghai [8]. Changxue Shu demonstrates the influence of British Victorian technology of common brickwork on buildings in Shanghai by comparing modern brickwork in two locations [15]. Yiting Pan describes the conflict and compromise between British architects and Chinese builders in Hong Kong, Together
with James Campbell, Pan also examines the importation of Western timber, carpentry, construction tools, and machines in Chinese Treaty Ports [6,7]. The studies by Cody, Shu, Pan and Campbell show that imported architecture and technology were more or less redesigned to suit local technological levels, economic conditions and cultural traditions in China. All the above literature helps us to understand the complicated modernization of Chinese architecture.

Based on a study of the remaining reinforced concrete buildings in Nanjing, this article classifies and compares different types of structures and points out that the reinforced concrete buildings in modern Nanjing have the characteristics of cheap and flexible, which absorbed the advantages of reinforced concrete frames, and other kinds of structures. In the following, Section 2 introduces the general history of cement and reinforced concrete buildings in Nanjing. Section 3 examines two types of reinforced concrete structures of the Western style buildings, one is the pure frame structure and the other is the flexible mixed structure. Section 4 analyses the characteristics and application range of different roof trusses in the Chinese Renaissance buildings. Section 5 is the conclusion that summarizes the whole article and indicates that the technical characteristics of reinforced concrete buildings should be preserved for the future.

2. Brief History

2.1. Cement: From Import Dependence to Local Substitution

Modern concrete is a composite material consisting of cement, fine and coarse aggregate, with cement playing the key role. Portland cement was invented in Britain in 1824 and became widely used in the construction industry in Europe and North America at the end of the 19th century [16]. In China, cement was no longer mainly imported but mainly produced locally.

Mainland China began building cement plants in Tangshan, Guangzhou, and Hubei in 1889. Both equipment and technology were imported from European countries such as Britain, Germany, Denmark, etc. At first, foreign experts were hired as technical consultants, later returning students became the main technical force. Nevertheless, before 1911, China’s cement supply was still dependent on imports from Japan, colonial Hong Kong and Macau. By 1911, the total production of the three largest cement plants reached 100,000 tons, which was equivalent to the amount of imported cement at that time [9] (p. 60). The domestic cement had the same quality as the imported cement, plus, it had the advantages of stable production, low price and convenient transport. Therefore, domestic cement displaced imported cement and dominated the domestic market after 1920. For example, the specifications for the famous Sun Yat-sen Mausoleum clearly stated that the building company had to choose either Ma brand cement, produced by Tangshan Qixin Cement Plant, or Taishan brand produced by Nanjing Chinese Cement Plant [17].

The period from 1911 to 1937 was the golden age of domestic cement and also the most prosperous period of Nanjing’s construction industry. It is true that the Qixin Cement Plant, located in Tangshan, was the first and largest cement manufacturer whose products were sold throughout China. However, with the establishment of local factories in eastern China, such as the Shanghai Huashang Cement Plant (1920), the Nanjing Chinese Cement Plant (1921) and the Nanjing Jiangnan Cement Plant (1934), the Qixin Cement Plant’s market share was divided. Local cement plants in Shanghai and Nanjing quickly dominated the construction market in East China.

During this time, Chinese concrete construction technology was also localized. After a short period of learning from foreign engineers, Chinese builders in Shanghai quickly mastered all the technology. These Shanghai builders brought their experience to Nanjing, so that the main reinforced concrete projects in Nanjing were built by Chinese builders. In terms of specifications, building codes for reinforced concrete in major Chinese cities were formulated after the late 1920s. Nanjing issued its building regulations in 1933, which stipulated that the volume ratio of cement, sand and gravel in concrete should not be less than 1:2:4 [18]. However, Chinese architects and engineers at the time were so
optimistic about the earthquake-resistant properties of reinforced concrete that they did not include a seismic design component in either the building codes or the actual construction projects [19]. Fortunately, there has not been a major earthquake in the major cities of eastern China for hundreds of years, and none of these buildings collapsed.

With the outbreak of the Second Sino-Japanese War, China’s cement plants suffered heavy losses and declined sharply or even stopped production after 1937. At that time, the East China market was dominated by Japanese cement brands and later, after the war by American cement brands [9] (pp. 51–114).

2.2. The Development of Reinforced Concrete Buildings in Modern Nanjing

The opening of Xiaguan Port in 1899 and the establishment of the Nationalist Government in 1927 were two prominent events in the history of Nanjing’s modern development. Modern construction activities in Nanjing are closely linked to these two events.

With the opening of the port, many industrial and commercial buildings sprang up in the Xiaguan and Pukou districts along the Yangtze River, after capital poured into Nanjing in the early 20th century. Brick-wood structures and Western styles were the main choice of buildings during this period [11]. In 1909, reinforced concrete frame structure was first used in six factory buildings of the Puzhen Machinery Plant, a Sino-British railway repair company. Remarkably, this building was completed only one year after the first reinforced concrete frame structure in Shanghai, the Shanghai Telephone Tower. Eight years later, the International Export Company (Kiangsu), a meat and egg processing factory founded by British businessmen, also adopted the reinforced concrete structure for its expansion project.

In 1927, Nanjing was selected as the capital of the Nationalist Government and witnessed a golden age of economic development and urban construction in the following decade [20]. Both the districts along the Yangtze River and the newly created district along Zhongshan Road developed into prosperous areas. Along the Yangtze River, reinforced concrete was mainly used for the construction of factory buildings with large spans, such as the Chinese Cement Factory in 1927. The smaller industrial buildings also utilized reinforced concrete, but their frame structures were usually combined with brick walls and roof trusses made of wood or steel. The public buildings along Zhongshan Road were mainly built for the government. Most of them were built of reinforced concrete although there were different styles and functions.

During the Japanese occupation from 1937 to 1945, the construction industry in Nanjing declined rapidly. The construction industry was dominated by repairs and few new buildings were built during the brief post-war recovery from 1945 to 1949. But after that, Nanjing was once again enveloped in the shadow of civil war.

3. Flexible Combination: Pure Frame and Mixed Structures in Western-Style Reinforced Concrete Buildings

3.1. Pure Frame and Mixed Structures

Reinforced concrete frame structure was very popular in Europe and America in the early 20th century. Although many Chinese architects favored this structure system, it was still relatively rare in modern Nanjing.

Portland cement was used primarily as a cheap substitute for reconstructed stone. By integrating steel and concrete, the French engineer François Hennebique invented the system of reinforced concrete frame structure at the end of the 19th century. It was proven that concrete with reinforcing bars could not only resist compression, but also had excellent tensile strength. From this point on, reinforced concrete frame structure became popular in France, Britain and America [21]. Reinforced concrete was adopted as the basic material for this structure, the frame of which consisted of beams, columns, floor slabs and other components that support the building’s entire load. In terms of mechanical status, the beam transferred the load of the floor or roof to the column and the column transferred the
load to the foundation, while the walls in this structure existed only as a self-supporting enclosing element.

According to some Chinese architects, this structure resembled the traditional Chinese timber structure, which was also supported by frames instead of walls. For this reason, they vehemently advocated this reinforced concrete frame structure [22,23]. However, due to the high price and complicated technology, reinforced concrete frame structure was mainly used in large-scale public buildings and industrial buildings. A typical case is the International Export Company (Kiangsu) factory in Nanjing (Figure 2). The frames were reinforced in the 1990s with enlarged members that, enclosed the original reinforced concrete material.

Figure 2. The structure of the International Export Company (Kiangsu)’s factory.

As an alternative structure, the mixed structure was popular for public buildings of medium size and industrial buildings of medium span in modern Nanjing because of its cheap price and flexibility [24]. This structure mainly used brick masonry and reinforced concrete frame to bear the load of the building, and sometimes other materials were also used as structural members, such as timber floor slabs, timber or steel roof trusses. According to our investigation, this type of building mainly used brick walls on the exterior wall and reinforced concrete frames on the interior, timber or steel roof trusses were often used for the roof structure, and timber floor slabs were sometimes used for the floor. A typical case is the former Senate of the Nanjing Provisional Government in the 1920s, which used reinforced concrete frames, load-bearing brick walls, timber floor slabs and timber roof trusses (Figure 3). This building was reinforced with steel cladding in the 2010s, so the original material can still be seen.

3.2. The Performance Differences between Pure Frame and Mixed Structure

In this article, the performance differences between a reinforced concrete pure frame and a mixed structure are evaluated by selecting one frame at a time (Figure 4). The schematic diagram of the mixed structure is based on the former Senate of Nanjing Provisional Government. The outer load-bearing structure, interior structure and roof truss are masonry, reinforced concrete frame and Western timber truss respectively. In the structure schematic diagram of the frame-only structure, the masonry and timber truss are replaced by reinforced concrete columns and trusses.
The Structural Mechanics Solver (version V2.0), a computer software for structural mechanics analysis and calculations, is used here. Its functions include solving the geometric composition of planar bar structures (systems), internal forces and displacements of statically determinate and statically indeterminate structures, the lines of influence, natural frequencies and mode shapes of free vibrations, and elastic stability. With this solver, the static or dynamic mode of the mechanism for the geometrically variable system can be displayed, the internal force diagram and displacement diagram of the structure can be drawn, the modal shapes of free vibration and the instability modes of elastic stability analysis can be displayed statically or dynamically, the influence line diagram of the structure can be drawn. In structural mechanics, the joints of cast-in-place concrete structures are usually simplified as rigid joints because the rotational capacity of the joints is limited by the beams and columns connected to them. However, the joint between the masonry wall and the beam is simplified as a hinged joint because the surrounding structural members have a limited effect on the rotational capacity of the joint. The connection between the superstructure and the foundation is usually simplified as a rigid connection.

The thickness of the brick masonry is 240 mm, and the size of the frame column is $b \times h = 200 \times 200 \text{ mm}$. $E_C$ is the elastic modulus of concrete, $E_W$ is the elastic modulus of masonry, $f$ is the strength of normal sintered brick. $E_W = 1600f$. The beams and columns all have rectangular cross-sections, so their moment of inertia should be measured by formula: $I = bh^3/12$, where $b$ is the width of the cross section and $h$ is the height of the cross section. By inputting the specific dimensions of the beams, columns, and walls, their respective moment of inertia $I_B$, $I_C$, and $I_W$ can be obtained, and therefore the bending...
stiffness of each component $E_CI_B$, $E_CI_C$, $E_WI_W$ can also be obtained. Inputting these data into a structural mechanics solver and applying the same horizontal force (10 kN) to both structures, their structural deformations can be compared. When subjected to a horizontal force, the response of the structure is usually linear in the early stage, i.e., the horizontal load is proportional to the horizontal displacement of the structure. The stiffness, used to measure the structure’s ability to resist deformation is the force required to produce one unit of horizontal displacement. When the horizontal load exceeds a certain limit, the horizontal force required to produce one unit of displacement decreases, i.e., the stiffness decreases. 10 kN ensures that the horizontal load and the horizontal displacement of the structure are linear, so that the stiffness of the structure can be determined.

As can be seen in the Structural Mechanics Solver (Figure 5), the displacement of node 18 in the upper part of the mixed structure is calculated to be 4.153 mm, while in the pure frame structure it is 3.509 mm. The stiffness of the mixed structure is 2.40 kN/mm, which is 84% of the pure frame structure (2.84 kN/mm).

\[ \text{Figure 5. The displacement of the mixed structure (left) and the pure reinforced concrete structure (right).} \]

### 3.3. Results and Discussions

Although the mechanical performance of the pure reinforced concrete frame is better, the mixed structures are not too far behind. Compared to the pure frame structure, the mixed structure has a slightly lower ability to resist lateral displacements, but the decrease is limited. The stiffness of the mixed structure reaches 84% of the pure frame structure.

The economic advantages of the mixed structure were obvious, as it used inexpensive materials and sophisticated techniques to replace expensive steel and cement. Reinforced concrete was used only in the interior beam-column system, while exterior walls supported the load with brick masonry, and the floors were filled with timbers within the unit grid delineated by the reinforced concrete beam-column frames.

Although the pure frame structure had greater adaptability in terms of space, the mixed structure was also very flexible in terms of internal space allocation. The pure frame structure allowed for a variety of space layouts, especially with great potential to the exterior expansion, because the external facades could be easily replaced, reflecting its advantages in the process of adaptive reuse. However, for an administrative building with relatively stable functions, the mixed structure was flexible enough, as it also used frames in the central part that can be freely subdivided within the constraints of the exterior walls.

In summary, although the pure reinforced concrete frame structure had a slight advantage in terms of mechanical performance and spatial flexibility, it was more frequently used in construction projects with foreign investment in modern Nanjing due to its high cost and complex technology. The mixed structure, with its economic advantages and reasonable performance in terms of mechanical performance and spatial flexibility, found wider application in modern Nanjing.
4. The Adaptation of Chinese Renaissance Buildings: A Multitude of Roof Trusses on Reinforced Concrete Bodies

4.1. Roof Trusses with Different Forms and Materials

Chinese Renaissance architecture is a mixed architectural type that originated in modern China. Chinese timber structure architecture originated in the Neolithic period, along with agricultural means of production. It was the choice of advanced technology and social consciousness at that time and has been spread to modern times. Even though some brick structure buildings appeared later, they could not shake the mainstream of timber structure [25]. When new materials replaced old materials, there was a transition phase, in which the expressions of the old materials were often reflected in the new materials [26]. For example, the Chinese masonry stupa imitated timber structure for a long time [27]. Chinese Renaissance architecture also showed this transitional character—in the era of reinforced concrete as an advanced structural choice, it still insisted on the ornamentation of the traditional Chinese timber structure.

This type of building generally used reinforced concrete structures, Beaux-Arts composition and Western equipment to efficiently meet the requirements of modern functions, but at the same time used traditional Chinese interior and exterior decorations to satisfy the aesthetic taste of the owners. These buildings began as mission schools and hospitals that attempted to integrate Chinese culture, and were later accepted by the top echelons of the Nationalist government to demonstrate the cultural identity of the emerging nation-state [28]. Henry Murphy, a pioneer of this type of architectural exploration, put forward the theory of new wine in old wineskins to explain the combination of reinforced concrete structures and traditional Chinese decorative patterns [14].

Although the main part of the building was a reinforced concrete frame structure, the roof section, characteristic of Chinese Renaissance buildings was treated differently. In the case of the Sun Yat-sen Mausoleum, Western style reinforced concrete trusses were used to imitate the roof shape of classical Chinese palaces. The concert hall of the former Nanking Women’s University was designed by Henry Murphy, who greatly admired the classical Chinese style, and used the Chinese-style timber roof trusses. The former residence of the Chairman of the Nationalist Government, located near the Sun Yat-sen Mausoleum, was built with Western style timber trusses, as the Chinese architects felt that the stability of the Western triangular truss was much better than that of the traditional Chinese parallelogram truss. The Huangpu Hall of the Lizhi Club was a more complex construction, utilizing steel roof trusses to cover the huge area of the hall (Table 1).

4.2. Comparative Analysis of Roof Trusses with Different Forms and Materials

4.2.1. The Chinese and Western Timber Roof Trusses

In this article, the structural characteristics of the Chinese and Western timber roof trusses are compared under the same conditions of a 9-meter span and a 5 kN/m load. The elastic modulus of timber is \( E = 1 \times 10^4 \text{ N/mm}^2 \), the cross-sectional moment of inertia is \( I = bh^3/12 \) (\( b \) and \( h \) are the width and height of each section respectively), when both have rectangular cross-sections. The compressive stiffness \( EA \) and bending stiffness \( EI \) of each member are calculated and then entered into a structural mechanics solver to generate axial force diagrams, shear force diagrams, and bending moment diagrams for both types of trusses (Figure 6). By comparing these diagrams, the mechanical performance of the two trusses can be evaluated.

4.2.2. The Western Timber and Reinforced Concrete Roof Trusses

The load-bearing capacities of roof trusses made of wood and reinforced concrete with the same cross-section are compared under the same load. Timber and concrete share a similar compressive strength. For example, the design value for the longitudinal compressive strength of TC17 timber is 16 MPa, and the design value for the compressive strength of C30 concrete is 14.3 MPa. Therefore, the internal forces of timber and reinforced concrete roof trusses are also similar for the same section and loading (Figure 7). It is
important to note that the density of reinforced concrete (about 2400 kg/m\(^3\)) is almost 5 times higher than that of timber (about 500 kg/m\(^3\)), which results in a significantly higher dead weight of the reinforced concrete roof truss. This should also be taken into account when choosing the material for roof trusses.

**Table 1. Structures of the Chinese Renaissance buildings.**

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<tr>
<th>Building</th>
<th>Structure</th>
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<th>Roof Structural Form</th>
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<td>The Sun Yat-sen Mausoleum</td>
<td>Reinforced concrete frames;</td>
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<td></td>
<td>Reinforced concrete roof trusses</td>
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<td>The Concert Hall of the former Jinling Women’s University</td>
<td>Reinforced concrete frames;</td>
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<td>Chinese-style timber roof trusses</td>
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<td>The former residence of the chairman of the Nationalist Government</td>
<td>Reinforced concrete frames;</td>
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<td>Western-style timber roof trusses</td>
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<td>The Huangpu Hall of the Lizhi Club</td>
<td>Reinforced concrete frames;</td>
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<td>Brick walls;</td>
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<td>Steel roof trusses</td>
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4.2.3. The Steel, Timber and Reinforced Concrete in Long-Span Roof Trusses

Steel has a very high strength. For example, the design compressive strength of Q235 steel is 215 MPa, which is much higher than that of timber (16 MPa) and concrete (14.3 MPa). In this article, the axial force and bending moment diagrams of the steel roof truss with a span of 18 metres under a load of 20 kN/m are calculated by the structural mechanics simulator (Figure 8). It can be seen that the maximum axial force of the beam occurs in the bottom chord at 98 kN. If the beam is designed based on the magnitude of the axial force, the cross-sectional area of steel would be 455 mm\(^2\) according to the following formula.

\[
A \geq \frac{F_N}{\sigma} = 98 \times \frac{10^4}{215} = 455 \text{ mm}^2
\]
(\(F_N\) is the axial force of the member, \(\sigma\) is the design strength value of the material).

If a concrete section reinforced with four 1-inch-diameter HPB300 steel bars is adopted, the cross-sectional area should be increased to 6470 mm\(^2\).

\[
A \geq F_N - 4 \times 5.06 \times 270 / \sigma = 111 \times 10^3 / 14.3 = 6470 \text{ mm}^2
\]

As for TC17 wood, the required cross-sectional area must be at least 6125 mm\(^2\).

\[
A \geq F_N / \sigma = 98 \times 10^3 / 16 = 6125 \text{ mm}^2
\]

It is obvious that the material strength of steel is significantly higher than that of timber or concrete. In steel-reinforced concrete and timber trusses, the required cross-sectional areas are too large to meet the load-bearing requirements. Therefore, the steel truss is the best choice for a large span roof.

Figure 6. The comparison between the Chinese (left) and western (right) timber roof trusses, the axial force diagrams (top), shear force diagrams (middle) and bending moment diagrams (bottom).
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(such as schools, offices and official residences) to be economical, while reinforced concrete roof truss is weaker than that of the Western style roof truss for the same span length. It carries higher peak internal forces, with an axial force of 61,761 N, a shear force of 65,496 N, and bending moment of 3,835,817 N·mm, compared to the axial force of 27,614 N, shear force of 4568 N, and a bending moment of 2,730,010 N·mm in the Western timber roof truss.

The design values of longitudinal compressive strength of timber and concrete are very close, so the mechanical performance of timber and reinforced concrete roof trusses is similar. The advantages of timber truss are its low cost, light dead weight, simple techniques, and prefabrication, but its corrosion resistance and fire resistance are poor. In comparison, the advantages of reinforced concrete truss are its good corrosion resistance and fire resistance, but its disadvantages are high cost, heavy dead weight and complex technology. In general, timber roof trusses were more commonly used in civil buildings (such as schools, offices and official residences) to be economical, while reinforced concrete roof trusses were more used in memorial buildings (such as Sun Yat-sen Mausoleum) to be durable.

With its high strength (13–15 times that of wood and concrete), the steel truss spans long distances, and non-solid web section shapes such as I-shaped sections can be used to reduce the required cross-sectional area. Therefore, steel trusses were generally used where the roof span was large and high load-bearing capacity was required.

Figure 7. The axial force diagram (left) and the bending moment diagram (right) of the reinforced concrete roof truss.

Figure 8. The axial force diagram (top) and the bending moment diagram (bottom) of the steel roof truss.

4.3. Results and Discussions

Due to the absence of diagonal connections, the mechanical performance of the Chinese roof truss is weaker than that of the Western style roof truss for the same span length. It carries higher peak internal forces, with an axial force of 61,761 N, a shear force of 65,496 N, and bending moment of 3,835,817 N·mm, compared to the axial force of 27,614 N, shear force of 4568 N, and a bending moment of 2,730,010 N·mm in the Western timber roof truss.

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5. Conclusions

In modern Nanjing, reinforced concrete buildings emerged in the early 20th century and reached their peak during the rule of the Nationalist Government from 1927 to 1937, during which time, various local materials replaced imported materials and gradually dominated the local construction markets. Western-style buildings used both pure reinforced concrete frame structure and mixed structures, with the choice of structures being the adaptive result of a comprehensive balance between structural performance, space availability and economy. In the foreign investment projects, the pure reinforced concrete structure was preferred due to its excellent structural and spatial capacities. In other projects, where economy was more important, a mixture of reinforced concrete frame, brick masonry, timber roof trusses, etc. was chosen to achieve a balance between economic and structural performance, which became more and more popula. In Chinese Renaissance buildings, the main part happened to be reinforced concrete construction. As for the most prominent roof part of the general civil buildings, although the Chinese timber truss has a long history, the Western timber truss was preferred because of its better structural performance. In the monumental buildings with high durability requirements, roof trusses made of reinforced concrete were the right choice. Steel roof trusses were the best choice roofs with large spans due to their high strength and small cross-section.

Among Nanjing’s modern architectural heritages, reinforced concrete buildings make up the vast majority of public and industrial buildings, and most of them are still in use. Since 2006, many buildings have been included in the list of outstanding modern historical buildings in Nanjing (Nanjing Planning Bureau 2006), but only 20% are well preserved, and more reinforced concrete buildings are still waiting to be protected [29]. The structural technologies mentioned in this article have both high historical and scientific value. They not only represented the high level of structural technology in Nanjing, but also witnessed the development of modern construction technology at that time. Therefore, not only the space and appearance, but also the structural features should be carefully preserved in present and future practice. The original structural technologies should not be arbitrarily replaced by contemporary substitutes.

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References


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