

# Revelations of Integrated Development of Design and Structure in Japanese High-Rise Building

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**Abstract.** Developments and applications of the integrated design and structure technology in Japan's high-rise buildings are studied in this paper. Two samples of milestone projects are outlined to illustrate the design pattern of technology before art in the construction of Japan's high-rise buildings.

**Keywords:** high-rise building, integrated development, technology before art.

## 1. Introduction

In the modern society, the city is highly urbanized, which results in a shortage of land in the urban area. The construction of high-rise buildings turns to be the main subject in the word's architecture development and research field nowadays because of its small footprint and high-volume rate. The architecture and the structure are the two most closely related professions in the design of high-rise buildings and the architectural design and the structural design are the two most important aspects in the process of the building design. In the design procedures, the architect and the structural engineers must cooperate with each other so as to create a safe, reliable, applicable, economic and aesthetic building. That is to say, the thirty spokes unite in the one nave, but it is on the empty space for the axle that the use of the wheel depends. Clay is fashioned into vessels; but it is on their empty hollowness, that their use depends. The door and windows are cut out from the walls to form an apartment, but it is on the empty space within that its use depends. Therefore, what has a positive existence serves for profitable adaptation, and what has not that for actual usefulness. It is just like a pottery maker makes containers by pinching the soil, which is a procedure to create a vacant space from soil. To meet different needs in our daily life, different designs of the soil is required to create various vacant spaces in different nature, and the structure of the container is closely related to the procedure of pinch [1].

## 2. The Development of High-Rise Buildings in Japan

Traditional wooden architecture in the ancient Japan is very similar with those in China. Most of them are low-rise buildings with one or two storey. The highest bidders are the Himeji Castle and the Five-storey pagoda in the monastery [2] (Figure 1). The famous Himeji Castle has a total of 5 stories with a height of 31.49 meters measured from the southern ground. The buildings of more than 10 stories can be found only after the introduction of western building techniques after the Meiji Restoration.

To meet the psychological needs of overlooking for ordinary people, a building in wooden structure with a height of 32m, named "Overview of Mount Fuji", was built in 1887 in the Mount Fuji. Actually, in the late 19th century, all of those so-called high-rise buildings were closely related with overlooking sightseeing. Following the "Overview of Mount Fuji", several masonry towers were built in the Osaka, Tokyo.

Severe damages occurred in the 1891 Great Mino-Owari Earthquake revealed the weaknesses of non-earthquake-resistant in the western brick buildings. Technology and steel reinforced concrete structures are

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soon introduced to Japan. The Mitsui Banking Corporation is Japan's firstly civil built in steel structure. It was built in 1902 by Yokogawa, who returned from the United States after his investigations.

After the Second World War, Japan entered the rapid economic growth period since the 1950s. Along with the abolish of the height restriction in 1964, the Kasumigaseki Building (Figure 2) was completed in April 1968 by the Mitsui Real Estate Development, which is regarded as Japan's first modern high-rise building since it is the milestone building with a height of over 100 meters. Japan has become another hot spot in the high-rise building construction after the USA. This was also Japan's first blossom period in the construction of high-rise buildings.

After the 1980s, Japan's high-rise buildings blossomed into maturity, during which a stable development of high-rise buildings can be found in Japan along with the continuing prosperity in Japanese economy. In the 1990s, the Yokohama tower in Yokohama (the Stubbins, the Mitsubishi, completed in 1993) was the tallest building in Japan. This high-rise building has 70 stories above the ground and 4 stories under the ground with a total height of 296 meters, it was ranked No.25 in the tallest building list in the world.

Nowadays, hundreds of high-rise buildings taller than 100 meters can be found in Japan, they have become a big attraction in the modern cities of Japan. Ultrahigh-rise buildings group in Tokyo, Nishi-Shinjuku, Otemachi and Osaka OBP (Osaka Business Park), have already become a symbol of the modern metropolis. Furthermore, based on the advanced seismic structure technology, construction technology, materials technology and construction techniques, designs of ultrahigh-rise building with a height of more than 800m, 150-storey have also been launched in Japan's construction industry..A problem should be studied from several aspects, the development in the structure and material has played a big role in the development of high-rise buildings in Japan.

### **3. The Development of Structure in the High-Rise Buildings in Japan**

Japan is one of the earthquake-prone countries, the structure itself must be ensured to have sufficient strength, stiffness and ductility so as to achieve the purpose of alleviating the damage in the earthquake disasters. Japan pays a great attention to the development of technology. A lot of money has been invested into the research and development of building technology each year by the government as well as construction companies. Up to \$2.37 billion is used in the technology research in 1994. As the high-rise building construction is highly technical, the high-rise building construction in Japan is prepared firstly from the technical aspects. The construction industry associations and building societies has repeatedly commissioned by the Japanese Ministry of Construction to carry out researches in the structure of high-rise buildings, including the construction, disaster prevention, equipment and construction research. These studies not only lay a solid theoretical foundation for the future construction of a large number of high-rise buildings, promote the modernization of related technical fields, but also establish the conviction of “technology first” in the design concept. Therefore, the development pattern of technology before art is established in the high-rise building construction in Japan. Considering the earthquakes, the building's structure design has always been dominated by the seismic design method [3].

From the point view of structural materials, Japan has experienced the timber, the masonry, the brick, the reinforced concrete and the steel construction periods. From the aspect of structure design, Japan has gone through the brick, the frame, the giant steel, and so on. Concerning the quakeproof research, the Japanese scholars has made great achievements since the 1980s, a relatively complete technical system is formed, particularly in the seismic research [4]. Generally speaking, the design concept of structural design followed by art design so as to realize the purpose of quakeproof as well as well-looking. In this background, a number of high-rise and ultrahigh-rise buildings have built recently or under construction in Japan by following this principle.

### **4. The Integration of Design and Structure in Japanese High-Rise Buildings**

The high-rise building construction is highly technical, thus the high-rise building construction in Japan was prepared firstly from the technical aspects. Furthermore, the conviction of “technology first” is established in the design concept. Therefore, the development pattern of technology before art is taken in the

high-rise building constructions in Japan. Nevertheless, the architectural design and the structural design are often out of joint due to various causes in the constructions of high-rise buildings in our country, leading to a lot of security risks in the building. Comparing with the modern Japanese architecture, there is an obvious backward in the construction techniques and construction-quality in the domestic buildings. Superficial and clumsy design techniques are always found exaggerated form in many buildings, it is hard to find some great association between the art and technology. the building space and the shape of the blindly processed due to the fact that lots of architect are lack of technical knowledge in the structure, ultimately resulting in the loss of those wonderful creation tools. Therefore, the study of the integration of architectural design and structural design in Japanese high-rise buildings plays a very important significance in China, especially in this earthquake-prone period.

## 5. Samples

Two samples of Japanese high-rise buildings are illustrated in the following to explain the integration of architectural and structural design.

Sample 1: The Tokyo Sugunami Garden City (Figure 3) is located in Tokyo's Sugunami Ward. It is invested jointly by the Japan Energy Corporation and the Mitsui Co., Ltd., and is designed and constructed by the Takenaka Corporation. The construction was started in June 1998 and was completed in October 2000. The Tokyo Sugunami Garden City consists of one ultrahigh-rise building and other three low-rise buildings, the main part of the building has a total of 30 storey (28 storey above ground, two storey underground), with a height of 93.1 meters. It was the highest building which applied the base isolation technology in Japan. Isolation bearings and dampers were applied in the building's base isolation system. Two types of isolation bearings were used, including a high-strength rubber seismic isolation bearings and ordinary rubber bearings. And the vibration dampers use a U-shaped lead damper [5].



Fig.1: Tokyo Sugunami Garden City

In the design of this building, the designers complied with the rules in the structural design firstly, appropriate processing are then carried out in the external physical structure in line with the structural design, the main attention is focused on the structural design. Concerning the specific structural design details, laminated technology is used in the ordinary rubber bearing, which is made of the thin film and thin sheet of rubber by overlapping layers. This type of rubber bearing has a great stiffness in the vertical direction, which enable to withstand large vertical loads; while it is also very soft in the horizontal direction, making the period of the building longer, which can isolated the seismic from the upper part of the building effectively to mitigate the motion of the building when the earthquake occurs. The high-strength rubber bearings are new products joint developed by the Takenaka Corporation and Stonebridge Corporation, the hardness and strength of rubber bearings are greatly improved by adding carbon and some other materials into the rubber. The high-strength rubber bearings are usually arranged around the structure to resist the pillars' pull forces caused by earthquakes. The U-shaped lead damper is produced by the Mitsubishi Materials, which can

rapidly reduce the vibration of structures by arranging them in the foundation beam. Base-isolation system is set up between the bottom and the foundation, it consists of 16 high-strength rubber bearings in five different types with a diameter of around 110 ~ 150 cm arranged around the building, and another 14 general rubber bearings arranged in the central of the building, plus a total of 99 U-shaped lead dampers arranged in the foundation beam. The rubber bearings and U-shaped lead dampers can effectively isolate the buildings above the foundation with the seismic motions, which will reduce the left and right swing of the building during earthquakes, giving us a sense of security. The building itself as well as the life, health, and properties of people will be safeguarded during the earthquake because of this base isolation technology. Complying with the internal functions, horizontal long windows, vertical long windows as well as grille details formed a rich facade of the building, leading us to imagine the soft wind in Japan.

Sample 2: Invested by the Sumitomo Realty & Development, the construction of the Sumitomo Building (Figure 4) was completed in March 1974. It is also well-known under the nickname of Bill or Triangle. The Shinjuku Sumitomo Building, raises 52 stories and 210.3 meters in height, has a construction area of 177,466.54 square meters. As part of the big urban revitalization, a large number of ultrahigh-rise buildings were built on the site of the Yodobashi Shinjuku West Exit water plant, including the Tokyo Metropolitan Government Building. To avoid the awkward situation of face to face between the windows and walls, the Shinjuku Sumitomo Building adopted a triangle design to the buildings in this city of skyscrapers, it has a unique flat shape and an empty chamber in the center, which enable us to enjoy the landscapes from the windows and enable the central part of building to collect natural light efficiently. The tube structure is applied in this Japan's first high-rise building with a height of more than 200m, making a very good use of this unique flat shape. For the design purpose, ground motion intensity is set according to the evaluation of speed of ground motion during earthquake, for the common facilities, it is a pioneer in the implementation of existing codes to the seismic design requirements by using the artificial seismic wave.



Fig.2 Shinjuku Sumitomo Building

The structural system with a "rigid truss frame plus shear week" is applied in the Shinjuku Sumitomo Building. The main structure is composed of closed plane frames, which are called triangle or hexagonal frame tubes. There is a distance of 3m among the frame tube columns. Not only in the shear stiffness, but also the bending stiffness and torsion rigidity, large-scale welded H-section are used in the best position of frame tubes of beams and columns. The name of frame-tube structure is due to the fact that there is a small hole in the wall of tube, 85% of the horizontal force is bear by the frame tube. The shear truss is supported by a series of "X"-shaped steel from the top to the bottom, which are very prominent in the building's facade, it is very essential to withstand the horizontal force, although it is true that the structure will not bring any good external appearing. Among the four-storey underground, the lowest two layers are constructed with the reinforced concrete structures, while encased steel truss-concrete composite frame are used for the other two layers, all the storey stand above the ground floor was made of steel frame structure. In some other samples, such as the Shinjuku Mitsui building and the Keio Plaza Hotel, reinforced concrete structures are used for the entire three storey underground, the lowest two layers above ground are constructed with the encased steel

truss-concrete composite frame, the other parts of the buildings are in steel frame structures. The guiding principles and design characteristics mentioned above are well demonstrated by the listed samples.

In the development of the new city center in the southern Kyoto, a comprehensive survey of the stratum was carried out by the Architecture Centre and the southern Kyoto, not only limited to the local region, but also a much wider areas for the anti-seismic purpose. In accordance with the priority of construction planning, the cross-section stratum of the four blocks on the north Kyoto were also studied. The Committee was set up by experts from various science and engineering disciplines, including the earthquake, geology, soil, structural engineering, and so on. Academic researches and discussions were launched by experts from their particular areas, including the measurement of elastic wave through the explosive experiments in the depth of 150m underground, the physical examination in the depth of 165m are carried out by the use of crop survey drilling, testing and drilling through the wall, the soil samples are obtained in depth of 80m and 140m for three-axis dynamic tests. These studies will provide indispensable information for the study of seismic design and construction of high-rise buildings. According to the seismic design requirements, it will be safe for the life, health and properties of people even if an earthquake happened in the same level of the Great Kanto Earthquake. Furthermore, in the evaluation of seismic performance, based on the seismic ground motions of the design purposes, initial investigations and researches are performed to obtain the fundamental feedbacks.

## 6. Conclusion

A building is much more like a human being. The construction corresponds to the appearance, size, and temperament. The structure corresponds to the bones, endurance, and life. While the electrical, plumbing and heating, ventilation and other construction equipments correspond to the nervous, context and organs. It is not a good building if there is not a good structure, and a good structure dates back to a good construction [6]. On one hand, the building structural system provides us with basic technical support to meet specific functional requirements. It also forms the shape of the original frame. On the other hand, new functional requirements ask for new structures, which stimulates the creation of new structures, for instance, the long-span construction and the high-rise buildings possess of their specific development backgrounds. Is there any new functional requirement from our human beings? This might be the opportunity to create a new type of architecture and structure.

Along with the rapid development of the city, there are a lot of requirements in the design and construction of high-rise buildings. It is very effective and meaningful to study the integration of architectural and structural design in Japan's high-rise buildings, especially for improving the design quality during the current seismically period of China. The significance is greatly enhanced due to the special economic and construction status of the high-rise buildings. Nevertheless, it is a great challenge for this study due to the prejudice of some architects and the cross-disciplinary nature in building design. Fortunately, a growing number of theorists and architects have begun to pay their attentions to this work.

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