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The brief analysis on the structure and material selection of high-rise and super high-rise buildings

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Abstract. The main factors that influence the structure and material selection of high-rise and super high-rise buildings are as follow: functional requirements, Structural force, economic elements and constructional level etc. Starting from the meaning of structural type selection of high-rise and super-high-rise buildings, this paper mainly discusses the influencing factors in structural type selection and material selection, which can be used for reference in future structural design.

1. Introduction

With the progress of social-economic development and the enhancement of comprehensive national strength, China's urban architectures are primarily high-rise and super high-rise buildings [1].

1.1 The definition of high-rise and super high-rise buildings

As stipulated in China, the housing buildings with more than 10 floors (including the 10th floor) or the height more than 28m as well as the other types of high rising civil concrete structure higher than 24m can be defined as the high-rise buildings. Internationally, the high-rise buildings with the height more than 100m or 30 floors is stipulated as super high-rise buildings. While, in Japan and France, the building higher than 60m is regulated as super-high buildings. According to America's terms, the buildings over 152m (500 feet) are generally considered as the skyscrapers and in accordance with the new standards of Council on Tall Buildings and Urban Habitat, buildings only higher than 300m can be listed as super high-rise buildings[2~4].

1.2 Developing conditions of building structures of high-rise and super high-rise at home and abroad

1.2.1 The developing status of building structures at abroad

After the World War of the last century, most countries has suffered from the double strike of economic and natural disasters. While during the process of their city reconstruction, they have built up massive high-rise buildings by their diligence and wisdom. In 1931, the 102-story 381m Empire State Building stood in New York. Then New York World Trade Center and Willis Tower completed the construction. Willis Tower, the 113-storeyed and 443m building completed in 1974, has become the landmark building that transcended the Empire State Building. The emergence of the super high-rise buildings has enhanced the technological revolution in architecture. With the development of science and technology, the world has constructed a mass of high rising buildings. For instance, the

Petronas Twin Towers, an 88-storeyed 453m building that located in Kuala Lumpur, Malaysia and built in 1998 once was the tallest skyscraper in the world and is still the tallest twin tower in the world. Now the tallest building in the world is the 162-floor 828m Burj Khalifa Tower. Burj Khalifa means "the supreme leader of the Islamic world" in the ancient Arab world and the title of Arab rulers [4~6].

1.2.2 The developing status of building structures at home
Since the new China was founded, China's high-rise buildings have ushered in a spurt of development owing to the economic development, the enhancement of comprehensive national strength and the minds' opening up. In 1977, the Baiyun Hotel in Guangzhou broke the 100m record; in 1995, the 81-storeyed 385.95m Diwang Building completed construction; in 2004, the 106-storey, 509m Taipei 101 building sprang up and kept the record of "the world's tallest building" during December 31, 2004 to January 4, 2010; in 2008, The 104-floor, 460m-high Shanghai World Financial Center completed and in 2014, the 128-storeyed (118 floors are above ground, 5 floors are podium building, and 5 floors are basement) , 632m-high Shanghai Tower ranked the second tallest building in the world[3].

1.3 The definition and the necessity of structure selection

1.3.1 The definition of structure selection
Structural selection is the connection between various actual needs and the lectotype design as well as the overall planning of type selection design objectives and controls. In architectural design, the key link of the spatial organization and architectural modeling is to select the best structural scheme, namely, the structure selection of architecture [7].

1.3.2 The necessity and meanings of structure selection
With the development of the society, people require more on the safety, economy, aesthetics and comfort of buildings. Due to the high-rise building has more influence on the function, appearance and social life of the city, people has higher demands on high-rise building. This requirement has been integrated into people's daily life and involved in the whole process of the building including designing, constructing, managing, using, maintaining, reconstructing, reinforcing and scrapping etc.; meanwhile, it influences many aspects including the urban society, owners and users, politics, economy, relevant technical specifications and so on. During the design of architectural schemes, these requirements would impact the structural selection of buildings.

Generally, the structural design of the building can be divided into three stages: structural selection, structural topology design and structural component design. Each stage is very important to building's structure that a tiny unwise decision would increase the construction difficulty and the costs or even dissatisfy the demands of design specification. These three stages are continuous which highlights the importance of the early decision making. An unreasonable structure selection will affect all decisions of topology design and component design and finally lead to the irrational structure design. Therefore, structural selection is extremely important that a suitable structural selection can not only improve the using function of the building, but also promote the building safer, more economical and more artistic[6~8].

2. The structure and material selection of high-rise and super high-rise buildings

2.1 structure characteristics of high-rise and super high-rise buildings

2.1.1 The controlling effects of horizontal load
The horizontal load refers to the building bearing the capacity from the horizontal direction. The most common horizontal load in architecture are wind and seismic loads which play a decisive role in structural design. Under the forces of horizontal load, the horizontal displacement of high-rise and super high-rise buildings would be extended [9].

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2.1.2 High strict requirement of Lateral displacement

Generally, high-rise building design has strict requirements on lateral displacement which ensures the safety of the buildings for the reason that the lateral displacement protects the building from the fracture by the large-scale swing in the strong wind [10].

2.1.3 The obvious effect of the ductility

The ductility refers to the plastic deformation capacity of building that reached the yield strength to meet the requirements of structural strength's stiffness and stability. Compared with multistoried buildings, high-rise building with high heights and large flexibility requires large ductility to guarantee stiffness of the building. Therefore, ductility becomes an important control objective in structural design [11].

2.2 The factors that influences the structure selection of high-rise and super-high-rise building

Influenced by the urban space and environment, all-round consideration for the factors should be taken to ensure the feasibility and reasonability of the structure selection during the designing and constructing period of the high-rise and super high-rise buildings[12] .

2.2.1 The influence of the building's function on the structure selection

The building function is determined when the architectural schematic design is formulated. The structural design of the building should be carried out according to the building's function which is the basic influencing factor. Structure selection should be based on the function requirement of the building sites, for instance, when designing the hotel or the entertainment venue, the structure should meet the function of hotel or the entertainment venue instead of the structure of residential or commercial sites [13].

2.2.2 The influence of building structural materials on structural selection

With the development of science and technology, the emergence of new structural materials brings new structural patterns and thus promotes the bold changes of architectural patterns which inevitably brings huge influence to the structure selection of building. Along with the development of the steel and iron materials, and compared with reinforced concrete, steel structure materials have obvious advantages such as light weight and high quality whose high strength to weight ratio is more than 5 times as reinforced concrete. If the gravity of the high-rise and super-high rise buildings is too high, it would bring impacts on the design, construction, material transportation, structure earthquake-resistance Capability and structural technical and economic indexes of the buildings. Therefore, it is necessary to select the materials that can reduce the dead weight of the building and meanwhile the weight reduction could decrease the baseload and the effect of the earthquake so as to reduce the cost of foundational and structural engineering. Therefore, rational building structural materials should be chosen and the selection of the structural types should maximum the material performances [14].

2.2.3 The influence of construction technology on structure selection

The construction technology controls the structure types of the building which means the structure selection of the building should conform to the current construction technology. The structure selection should be practical and practicable. If the structure types are advanced and novel that exceed the existing construction conditions and construction technology, it would bring great difficulties to the construction and the quality of the construction [13].

2.2.4 The influence of economic factors on structure selection

Economic factors influence the type selection of building structure, especially for high-rise and super high-rise buildings. For example, the cost would increase compared with the normal buildings in scale, construction duration, labor and materials and meanwhile the capital management will be more

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complex as well. Hence, the project cost should be full in consideration when selecting the structural types. Before the construction implementing, the project should be budgeted and the corresponding architectural design could be adopted only after the budget is approved by the investor. If the budget is higher than investors' estimate, the design need be further optimized [12].

2.2.5 The influence of structural design theory's development on structural type selection

The development of the building's function, type, and height as well as space utilization promotes the development and innovation of building's structural type, material, composition and structural system. The application of computer technology accelerates the development and innovation of structural design theory. The development of structural design theory makes the original reinforced concrete structure unable to meet the structural needs of high-rise buildings. The emergence of structural systems such as frame, shear wall, frame-shear wall, and tube structure and so on diversifies the structural selection of buildings [7].

2.2.6 The influence of construction site on structure selection

The construction site could influence the rationality of structural force of high-rise or super high-rise buildings, and thus affect the structural selection. The rationality of structural force means the following functions: effective wind resistance, reliable earthquake resistance, clear force-transferring path, reasonable force distribution and failure mechanism. The construction site's conditions differ the basic wind pressure and at the same time the fortification intensity. When the condition permits, the selection of construction sites should be in accordance with the relevant data such as engineering geology and seismic activity during the selection of the structural system. According to the requirements of the project, the construction site should be comprehensively evaluated based on the relevant regulations to choose the site favorably wind resistant and earthquake resistant. When the objective conditions do not permit for the selection of the construction sites, the structural type should be carefully selected to ensure the structural stress rationality [14, 15].

2.3 The common structural types and material selection of high-rise and super-high-rise buildings

2.3.1 The frame system and material selection

Under the forces of horizontal load, frame system keeps the house with small lateral resisting stiffness and large horizontal displacement which therefore is called the flexible structure system. The main advantage of the frame structure is to provide with the large interior space and flexible layout, which is suitable for the buildings such as the multi-floor and high-rise office buildings, hotels, hospitals, schools and multi- floor factory workshops and so on. During the non-seismic areas, the frame structure generally can be built up to 15 floors generally and up to 20 floors at most. When the building is with multi-layers, the pier moment would be large caused by horizontal load, which could lead to the section size unreasonable and meanwhile bring the difficulties to the architectural design and worsen the economy condition as well. Generally, the concrete grade should be exceeded over C20. During the anti-seismic design period, the first anti-seismic grade frame beam-column and its nodes of concrete grade should not be lower than C30, and when it is 9°, the grade should not higher than C60 and when it is 8°, the grade should not higher than C70[9,16].

2.3.2 The shear wall structure system and material selection

The shear walls bear both vertical and horizontal loads. Because of the large lateral stiffness of the shear wall itself in the plane, there are rigid floors support in the horizontal direction. The shear wall is generally arranged horizontally, and the floor is placed on the wall. The space between the shear walls is usually 3-8m; if it is 3m, most shear walls only need the reinforcement due to the small axial force and bending moment of the residential buildings below 15 floors. The shear wall structure houses are generally divided into individual spaces by walls; the layout and use of buildings is with constraint to some certain extent so that this kind of structure is mostly suitable for residential buildings such as the small-spaced houses, apartments and hotels etc. Generally, the concrete grade should not be lower than C30; during the anti-seismic design period, the grade should not be higher than C30; and when seismic resistance is required, the ratio between the measured tensile strength and the measured yield strength of reinforcement should not be less than 1.25 and the ratio between the measured yield strength and the standard yield strength of reinforcement shall not be greater than 1.30[9].

2.3.3 The frame - shear wall system and material selection

The vertical load of the frame-shear wall system is borne by the frame, and the horizontal load including the wind load and seismic load is borne by the shear wall. About 70%~90% of the horizontal load is borne by shear walls. The frame - shear wall structure is endowed with the advantages of frame structure and the shear wall structure which makes the layout of architectural plane flexible. Therefore, the frame-shear wall system is widely adopted in multi-floor factories, high-rise office buildings and hotels. In high-rise buildings, the frame-shear wall system used on 8-15 floors can bring great economic benefits and have the functions of structural bearing capacity and lateral stiffness. Generally, the concrete grade should not be lower than C30; when seismic resistance is required, the ratio between the measured tensile strength and the measured yield strength of reinforcement should not be less than 1.25 and the ratio between the measured yield strength and the standard yield strength of reinforcement shall not be greater than 1.30[9,16].

2.3.4 The tube structural system and material selection

The tube structural system can be divided into inner tube, outer tube, tube-in-tube and multi- tube types. The structure mainly composed of tube types can be classified as the tube structure. The multi-tube high-rise building (with more than 40 floors) is comprised of several connected frame tubes to bear the vertical load and horizontal load. The tube should choose the regular geometry, such as circle, regular polygon, square and rectangle and so on. The increase of multi-tube building floors and the symmetrical decrease of the tube could reduce the size of the plane which is beneficial to relieve the wind load or seismic force gradually. Owing to the force uniqueness of tube structure, it is widely used in the super high-rise buildings to effectively reduce the investment. Generally, the concrete grade should not be lower than C20; the concrete strength grade of the basement-floor building with solid end of the structure should not be suitably less than C30. The concrete grade of the prestressed concrete structure should not be suitably less than C40, and should not be lower than C30 [9].

2.3.5 The steel-concrete composite structure system and material selection

The steel-concrete mixed structure mainly contains the steel reinforced concrete (SRC) and Concrete Filled Steel Tube Structures (CFST). SRC refers to the stiffened concrete structure system with embedded steel, which is widely used in the bottom, large span and large load of the high-rise buildings owing to its high bearing capacity, good crack resistance and anti-seismic performance, etc. CFST refers to the components formed by steel tube filled with concrete, which greatly improves the bearing capacity of components compared with reinforced concrete ones, in the meantime, this kind of component is endowed with small section size, good plasticity and toughness and improves the seismic performance so that it is no need for support and formwork during construction, and besides, the fire resistance of the component is better than pure steel structure. The 460m-high Shanghai World Financial Center has witnessed the development of China's high-rise buildings by adopted the shape steel concrete, frame tube and reinforced concrete inner tube system at the bottom. The concrete grade of the steel-reinforced concrete beams and columns should not be lower than C30. The section steel and steel tube should select Q345-grade and Q235-grade steel as well as Q390, and Q420 grade steel or other structural steel frame that conforms to the requirements. The section steel should choose Grade Q235 and Q345 steel [17, 18].

3. Conclusion

The architecture industrialization provides the technical support for high-rise and super-high-rise buildings which ensures the springing up of the skyscrapers driven by the continuous development of economy. It is an embodiment of modern people's pursuit for the appearance, comfort requirement and securitization of buildings and the harmony and unity with the natural environment etc. The paper systematically discusses the factors that influence the structure and material selection of high-rise and super high-rise buildings which provides the referential value for subsequent buildings' structure design.

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