Proceedings of the 2023 International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/9/20230010

The design and construction of the green building--the Shanghai Tower as an example

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Abstract. With an increasingly strong concept from the public in protecting the ecological environment, green buildings account for more percentages in the buildings built in recent years. However, there are still many problems to be solved in the design and construction of green buildings. Therefore, this paper combines the construction and design process of the Shanghai Tower, a famous green high-rise building, and analyses many aspects, such as foundation, structural design, material selection, circulatory system, technology application, and other areas, to draw some options that can be effectively used and practiced in green buildings. For example, the selection of alternative materials and the promotion and application of energy-saving design aspects, the use of geothermal energy and rainwater resources near the building and the effectiveness that BIM can play provide inspiration for the future development of green building design and construction, as well as an important embodiment of the concept of green and sustainable development.

Keywords: green building, BIM, materials, structure.

1. Introduction

Green building is a type of building which has the capability to be harmless to the environment, make full use of environmental natural resources, and does not damage the basic ecological balance of the environment, and not only provide people with healthy, suitable and efficient space for use, but also live in harmony with nature. Evaluation of the building cannot leave the purpose of use, so green buildings can have higher requirements for environmental protection and energy conservation on the basis of meeting people's use requirements. Now with the increasing concern for the environment, the concept of environmental protection has gradually penetrated into people's daily requirements. Then the construction of green buildings has gradually occupied the main requirements of people building houses. Under the background of peak carbon dioxide emissions and carbon neutrality, green water and green mountains weigh more than golds and silvers. With the natural growth of population, the demand for green buildings also increases correspondingly. Seeking a balance between social economy and natural environment leads to a better protection in ecology.

The Shanghai Tower is a very complex and huge project. One of the two clear requirements at the beginning of the design is green and environmental protection, advocating the establishment of ecological buildings. Therefore, energy conservation and environmental protection should also be the key to the Shanghai Tower, the representative work of the harmonious coexistence of architecture and nature in modern society, and the combination of humanity, nature and life. The Shanghai Tower has

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also won the certification of Leadership in Energy and Environmental Design in the United States and the green three-star certification in China. This paper mainly analyses and studies the considerations and practical applications of the Shanghai Tower in the construction of green buildings, hoping to provide some experience in the construction and design of green buildings.

2. Key technologies of green building

2.1. Basic information of the Shanghai Tower

The Shanghai Tower, located at No. 501, Yincheng Middle Road, Lujiazui Financial and Trade Zone, is a skyscraper as a conspicuous landmark among buildings in Shanghai. In China, no other building is taller than the Shanghai Tower, and it also ranks third in the world. Construction began on November 29, 2008, and the overall construction of the building was completed on March 12, 2016.

In terms of use, the Shanghai Tower is mainly used for office, hotel, business, sightseeing and other public facilities; the main building has one hundred and twenty-seven floors above the ground, with the height of six hundred and thirty-two meters, and the basement has five floors; the podium has seven floors in total, including five floors above the ground and two floors underground, with a building height of thirty-eight meters; the total construction area is about five hundred and seventy-eight thousand square meters, of which the total aboveground area is about four hundred and ten thousand square meters, the total underground area is about one hundred and sixty-eight thousand square meters, and the floor area is thirty thousand and three hundred and sixty-eight square meters.

The Shanghai Tower has obtained the national three-star green building design identification certificate. It adopts high and new technologies, such as double-layer internal, external glass curtain wall structure system and intelligent modular integral steel platform formwork technology system. The design standard is high, the external facade is rotating, and the angle is 120 °. Based on the vertical urban high-rise building design, it is equipped with atrium and sky garden to realize three-dimensional greening [1].

2.2. Building information modeling

The full name of BIM is building information modeling. The Shanghai Tower uses BIM technology for guidance and design, focusing on design schemes, construction processes, post-maintenance and other aspects. It is mainly to use computers to carry out accurate spatial model modeling and establish a more intuitive model based on communication with relevant staff. This also means that if there are problems in the construction process, the BIM platform can exchange information and drawings in a timely and convenient manner, so as to quickly solve the problem [2]. At the same time, the BIM system can help the construction workers quickly find the working space, greatly improve the success rate of construction, significantly reduce the rework rate and reduce the construction cost. For instance, Shenyang Yuanda Aluminium Group, the external curtain wall contractor of the Shanghai Tower, not only used BIM technology to produce more than 20,000 glass curtain wall plates from the factory, but also achieved rapid installation with only 16 workers after arriving at the site of Shanghai Tower for installation [3].

2.3. Use of green energy

The Shanghai Tower has a water resource collection system that can collect rainwater accumulated on the surface and roof, so as to achieve the utilization of water resources for irrigation of green plants inside the Shanghai Tower, floor cleaning and other purposes. In addition to water resources, it also uses geothermal energy. Using the principle of underground constant temperature, water with lower ground temperature is circulated through underground pipes in winter, so that the water temperature can rise; In summer, the temperature is higher, and the water temperature is reduced by water circulation through pipes to reduce the energy consumption in heating and cooling water [4]. The Shanghai Tower also adopts the trigeminy of cooling, heating and power supply, which means with natural gas as the main fuel, the gas-fired power generation equipment will start to operate, and the electricity generated will

DOI: 10.54254/2755-2721/9/20230010

supply the power demand of users, while the heat generated during power generation will also be used to provide heat and cooling to users through waste heat recovery and utilization equipment [5]. In addition to the Shanghai Tower, the ice storage system is also a solution to the energy problem. Specifically, the system is used to reduce the operation cost of the system and realize the average power consumption in each period. The energy centre in the lower region is equipped with an ice storage system. The working mode is mainly to use multiple water-cooled centrifugal refrigerators to make ice, which is concentrated in the period of power generation at night. The refrigerant used is glycol solution. In the daytime, the ice melting and absorption chiller can cool the lower part of the building, while the plate heat exchanger is used to separate the glycol solution circuit from the chilled water circuit. The plate heat exchanger cools the air handling unit and other air conditioning terminal equipment by using ice melting [6].

2.4. Green glass curtain wall

The Shanghai Tower itself uses a large number of glass curtain walls, while the traditional glass curtain walls are often accompanied by high energy consumption. The visible light transmittance and thermal insulation performance of the glass itself will be the main factors affecting energy consumption. A large number of glass curtain walls often lead to feeling very hot in summer and very cold in winter, which directly leads to the excessive use of air conditioners and also brings high energy consumption. Therefore, double glass curtain wall is adopted in the Shanghai Tower, which adopts glass self-shading and horizontal-fixed-shading. The self-shading method of glass is to use the shading ability of glass itself to select glass with low shading coefficient to have better shading performance. At the same time, in the selection of materials for the inner and outer glass curtain walls, laminated glass, a certain percentage of colored glazed glass is used as the glass material of the outer curtain wall, and the low-radiation insulating glass is used as the glass material of the inner curtain wall, so that there is an area between the two glass layers that can buffer the temperature [4]. According to the annual solar angle analysis, 25%, 50% and 75% colored glazed glass is used for the southeast, south, west, southwest and northwest of the curtain wall of Shanghai Tower [7]. The specific measure of horizontal fixed sunshade is to set 0.1m horizontal sunshade outside the curtain wall of the Shanghai Tower to improve the sunshade effect [1].

2.5. Structure

2.5.1. Foundation structure. The Shanghai Tower is firmly supported by nine hundred and fifty-five piles of the main building. In terms of controlling the verticality of the pile foundation, a complete set of construction technology has been studied through design innovation, which has improved the vertical hole forming accuracy by more than fifty percent compared with the previous technology. The bored pile technology adopts bentonite slurry wall protection, mud desliming technology, shallow soft soil positive circulation construction technology, and deep sand hard layer reverse circulation construction technology. Through research, it is found that the bored concrete pile can fully meet the needs. In the aspect of foundation pit, the supporting technology combining the forward and reverse construction methods of divisional construction is adopted. It is difficult to ensure the roundness of a self-supporting circular support structure during construction. In the podium area, without controlling the construction period, using support instead of floor slab can successfully save the project cost [8].

2.5.2. Spiral rising structure. For the spiral rising structure of the Shanghai Tower, the irregular torsion angle of the facade gradually increases with the rise of the number of floors, as 120 ° is the best angle to reduce the load of wind in such high altitude. This spiral torsion state can reduce the wind load to a certain extent. Through the application of aerodynamic modeling wind resistance technology, compared with buildings of the same height, the overall wind load of the tower is reduced by twenty-five percent. Compared with traditional structures such as square section, the design wind load is only sixty percent of the square section structure. Material is also saved in this way [9].

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2.5.3. Structure to save steel consumption. The Shanghai Tower is also well-considered in terms of steel structure and consumption, and the structural design and selection also lay the foundation for the reduction of steel consumption. The steel consumption of the Shanghai Tower is mainly concentrated on giant columns, which is also because the structural height of Shanghai center has high requirements for the bending resistance of the whole building. The increase in steel consumption means the increase of strength. In order to reduce the amount of steel used in this area, several main floors are used as reinforcement layers to improve the steel content. The remaining floors do not need to use such a large steel content as the reinforcement layer, and the amount of steel saved by this can also be about twelve thousand tons [10]. Considering that the floor live load factor itself cannot be fully distributed on all floors, a certain reduction factor can be set according to the relevant specifications, which is also the basis for saving the amount of steel. At the same time, the section optimization and layout of the relevant components, combined with high-strength materials on this basis, finally achieve the effect [9].

2.6. Material

2.6.1. High-concrete material. In the process of cast-in-place mass concrete cushion, it is very easy to cause volume change due to the release of hydration heat, which will lead to early concrete cracking. In order to solve this problem, the use of low-heat cement is inevitable. Therefore, through relevant tests, a kind of ordinary portland cement can meet the requirements of producing low-heat concrete for engineering. Some admixtures are used to replace some cement to reduce the hydration heat of cement in the actual project and improve the fluidity. Then fly ash and slag powder are suitable admixtures. After testing, the hydration heat release rate of these two materials decreased, the peak time was later than that of pure cement, and it was easier to control cracks. Although these admixtures can reduce the water-cement ratio, they will increase the fluidity of concrete. The effect of polycarboxylic acid admixture is amazing.

In the aspect of coarse aggregate, the silt content is limited to less than one percent, while in the aspect of fine aggregate, the sand rate uses the medium-grade sand from the Yangtze River basin, and the silt content is less than two percent. In conclusion, changing the selection of materials and designing a reasonable mix ratio is the premise of continuous pouring success, and also an important part of the overall pouring of the foundation slab of the Shanghai Tower [11].

2.6.2. Ground granulated blast furnace slag. The Shanghai Tower has adopted a large number of environmentally friendly new building materials -GGBFS, which is independently developed by Shanghai Baosteel Group. This is a major breakthrough in the application of this new environment-friendly building material in the field of super high-rise buildings [12]. GGBFS can equally replace the amount of cement used in various concrete and cement products. As a new type of admixture for high-performance concrete, it has the advantage of improving various properties of concrete, which is embodied in that it can improve the strength of cement concrete to a great extent. Ultra-high strength cement concrete can also be prepared. The alkali-aggregate reaction resistance and durability of cement concrete can also be greatly improved. The bleeding amount of cement concrete can be reduced a lot, and the workability can also be improved. At the same time, the compactness and impermeability of cement concrete can be improved, and the hydration heat of cement concrete can be reduced. It will have great advantages in configuring mass concrete, and reduce the hydration heat of cement concrete. Meanwhile, it is suitable for configuring mass concrete.

2.6.3. Summary of material savings. The Shanghai Tower has used a large number of localized materials in building materials, accounting for ninety-four percent according to relevant statistics. In the use and distribution of concrete, concrete of grade C60 and above is used in the foundation, column and core wall, while the composite floor uses concrete of grade C35. C50 and above high-strength concrete is used in the vertical load-bearing structure, accounting for 72.1% of the total amount of concrete in the vertical load-bearing structure. The proportion of recyclable materials such as steel and glass curtain

DOI: 10.54254/2755-2721/9/20230010

wall used is up to near twenty-nine percent, the use proportion of high-strength steel bars reaches about seventy-eight percent and the proportion of recycled materials is about thirty-nine percent [7].

3. Conclusion

The construction of the Shanghai Tower was a huge challenge, not only in terms of height, but also in terms of building a green high-rise. Countless hours of work went into the design and construction to make this skyscraper as green as possible, and it is a model for green residential design and planning. In the aspect of foundation, the substitute materials used to prevent the early cracking of concrete and the replacement of cement with appropriate additives, the cement production is one of the industries with the most serious carbon pollution. During the firing process of cement, more greenhouse gases and a small part of harmful gases are emitted into the atmosphere, and in the process of cement quarrying, irreversible damage will also be caused to the mountain's ecological environment. In terms of material selection, local materials would be great selections, and new materials should be used to replace those environment-unfriendly materials used in the construction process, which can reduce environmental pollution. In addition to materials, design can also save energy consumption to a large extent and make buildings green and environmentally friendly. When building glass curtain walls, self-shading and horizontal fixed shading can effectively alleviate the problem of high energy consumption. There are also systems designed to recycle water resources and heat energy, change the structural section, improve the bearing capacity and save materials. The application of BIM technology makes many ideas that only exist in the design into reality. The visualization of the layout makes people more accurate in the use of space, and more comfortable in the use of personnel and equipment. The use of these technologies is not only the completion of a green building, but also the great progress people have made in green environmental protection. In the construction of green buildings in the future, the materials that can replace high energy consumption have not been widely used at present, which will greatly increase the construction cost. In addition, there are related limitations in structural design because of difficulties in being universal and further improving. With people's attention to the concept of green environmental protection and sustainable development, energy conservation of green buildings and environmental protection will become more important.

References

[1] Huang Zixian. Research on the Design of Contemporary Super High rise Green Buildings -- Taking Shanghai Tower as an Example [J]. Urban Housing, 2021,28 (04): 216-217

[2] Zhu Wenbo. Inheritance and Innovation of BIM Technology in Shanghai Tower [J]. Architectural Technology, 2020,4 (04): 71-72

[3] Chen Jiliang, Ding Jiemin, Ren Lizhi, etc. Application of BIM Technology in Shanghai Tower [J]. Architectural Practice, 2018,1 (11): 110-112

[4] Shao Fanxi Application of green building technology under the goal of "double carbon" - taking Shanghai Tower as an example [J]. Urban Building Space, 2022,29 (08): 88-90

[5] Gu Jianping. Super High Green Building of Shanghai Tower [J]. Architectural Technology Development, 2015,42 (02): 19-21

[6] Fan Hongwu, Han Jihong, Wang Zhenhua. Design of Building Energy Efficiency Scheme for Shanghai Tower [J]. Green Building, 2011,3 (03): 27-30

[7] Fang Zhou, Fan Hongwu, Han Jihong. Technical Features of Super High Green Building in Shanghai Tower [J]. Construction Science and Technology, 2013, No.246 (14): 28-31. DOI: 10.16116/j.cnki.jskj.2013.14.016

[8] Gong Jian, Fang Tingchen, Zuo Junqing. A Review of Key Technologies Development of Super High-Rise Building Construction in China[J]. Advances in Civil Engineering,2022,2022.

[9] Ding Jiemin, Chao Si, Wu Honglei, etc. Key technologies for green structure design of Shanghai Tower [J]. Journal of Architectural Structure, 2017,38 (03): 134-140. DOI: 10.14006/jzjgxb.2017.03.015

DOI: 10.54254/2755-2721/9/20230010

[10] Ding Jiemin, Chao Si, Wu Honglei, etc. Application and research of composite structural components in Shanghai Tower [J]. Architectural Structure, 2011, 41 (12): 61-67. DOI: 10.19701/j.jzjg.2011.12009

[11] Structural Concrete; New Structural Concrete Data Have Been Reported by J. Gong and Co-Authors (Monolithic pouring of the foundation slab of the 632-m high Shanghai Tower)[J]. Technology & Business Journal,2017.

[12] Wang Lei, Ni Weiran Baosteel slag powder has successfully entered the "Shanghai Tower" [N] China Metallurgical News, 2010-01-12 (B03)