

Long-span Steel Structure System and Application Case Summary

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Abstract. This paper introduces the origin and development of long-span steel structure system, focuses on the characteristics and composition of grid structure system, reticulated shell structure system, pipe truss structure system, chord supported structure system, and cable structure, and analyzes and studies the typical cases of five basic structure systems of long-span steel structure, such as three center round coal shed, Tianjin Binhai station, Shenyang Olympic Sports Center, etc. The purpose is to provide beginners with introductory knowledge and reference cases and to provide references for structural personnel to choose the appropriate structural system.

Keywords: Long-span Structural System; Steel Structure; Application Cases.

1. Introduction

With the rapid development of the social economy and the increasing improvement of people's living standards, the demand for long-span buildings (such as large-scale stadiums, cinemas, exhibition halls, shopping malls, and other public buildings) is increasing with each passing day. The long-span steel structure system buildings are developing day by day, the structural forms are becoming increasingly diversified and complex, the structural span is getting larger and larger, the steel grade is getting higher and higher, and the steel plate thickness is getting thicker and thicker. At the same time, because the steel structure material has high strength, light weight, strong toughness and plasticity, good seismic performance, easy to manufacture in the factory, site assembly, coupled with good sealing performance and other excellent characteristics, it has become a very common building material. At present, the main long-span structural systems are divided into five categories, including truss structure, arch structure, steel structure, suspension structure, and thin shell structure. The purpose of this paper is to summarize the characteristics of the structural system and provide a reference for the structural personnel to choose the appropriate structural system.

2. The origin and development of long-span steel structure building

The long-span steel structure has a long history. As early as 14 BC, the famous ancient Roman Pantheon (see Figure 1) was built, with a diameter of 43.5m, which was the first attempt at long-span architecture. It is the earliest and longest-span spatial arch structure in architectural history, which can be called the miracle of that era. After that, in 1851, the Crystal Palace (see Figure 2), the exhibition hall of the first international exposition in Hyde Park, London, was built. The central hall of the Crystal Palace was supported by a hollow cast iron column with a cylindrical vault. This is the first house built entirely of iron and glass, which has greatly promoted the development and progress of long-span buildings. In 1863, designed by German Schwedle, (J.W), the first steel dome with a diameter of 30m was built in Berlin for the top cover of the gas tank. Its form is that several circular arches converge into a top ring to form a radiation system, and then several intermediate horizontal rings and diagonal bars in the same direction are added to form the Schwedler Dome, which is praised by later generations. In 1925, Schoff Glass Factory in Jena, Germany adopted a rotationally symmetrical spherical shell roof with a diameter of 40m and a thickness of 60mm. It was the first real thin shell with a thickness-span ratio of 1/666.6. In China, since the national liberation in 1949, steel structures have been used in large-span heavy industrial plants, large-scale public buildings, and high-rise structures. In recent twenty years, long-span steel structures have developed rapidly.



Figure 1. Pantheon in ancient Rome



Figure 2. Crystal Palace

2.1 Main structural system of long-span steel structure building

Since then, to meet the needs of social and economic development, the number of long-span steel structures is increasing day by day. Therefore, people standardized and defined the long-span steel structure. Concrete with a transverse span of 60 meters and a span of more than 30 meters and frame structures with a span of more than 18 meters are long-span steel structures.

With the continuous exploration of the building structure, the long-span steel structure has gradually formed a system, which can be divided into grid structure systems, reticulated shell structure systems, truss structure systems, chord-supported structure systems, and cable structure systems.

2.2 Grid structure system

The grid structure is a kind of spatial truss structure, in which the stressed members are connected by nodes according to certain rules. Generally, the joints are designed to be hinged, the members mainly bear the axial force, and the cross-section size of the members is relatively small. These spatial intersecting members support each other, which organically combines the stressed members with the supporting system. Due to the regular structure combination, a large number of rods and nodes have the same shape and size, which is convenient for factory production and site installation. The grid structure system can be classified according to its structure, mainly including single-layer grids, double-layer grids, and three-layer grids. A flat grid is a very common form of grid structure system. A flat grid has no horizontal thrust or tension, and it is generally simply supported on the support, which greatly simplifies the side beams, facilitates the layout of the lower load-bearing structure, has a simple structure, and saves materials. The typical building is a lump of the three-center round coal shed.

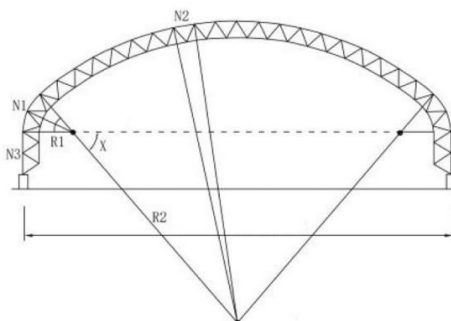


Figure 3. Grid structure diagram

In the three-center round coal shed, the stress of the building structure is reasonable, which reduces the amount of steel used to a certain extent. The construction is convenient, and the reasonable shape and grid division can make the number of members less. Jining Mining Group Logistics Co., Ltd. was built in one year, and the 900,000-ton coal storage shed with a total investment of 180 million yuan was built in Liangshan County. It is one of the large-span steel coal storage sheds in China. The

steel coal storage shed covers an area of 203.96 mu, with a total length of 660 meters, a total width of 206 meters, and a center height of 52.8 meters.



Figure 4. Three-core round coal shed

2.3 Reticulated shell structure system

A lattice shell is a kind of spatial truss structure similar to a flat grid. It is a spatial framework that is based on members, forms a grid according to certain rules, and is arranged according to the shell structure. It has both the properties of a truss and shell. Its characteristic of force transmission is mainly point-by-point force transmission through tension, pressure, or shear in two directions in the shell. This structure is a kind of space structure that attracts much attention at home and abroad and has broad development prospects. The reticulated shell structure also includes single-layer reticulated shell structure, prestressed reticulated shell structure, plate-cone reticulated shell structure, ribbed ring cable-supported reticulated shell structure, and single-layer forked cylindrical reticulated shell structure, etc. The single-layer reticulated shell structure is the most common structure in the reticulated shell structure system. For example, Binhai Station in Tianjin Binhai New Area is a typical single-layer reticulated shell structure. It is the world's first single-layer long-span reticulated shell dome steel structure project, with a length of 143.9 meters from north to south, east-west width of 80.9 meters, and the highest point of 25.8 meters above the ground. The dome, weighing 4,200 tons, is equivalent to half the weight of the Eiffel Tower. Its main members are connected by 36 positive spiral and 36 negative spiral curved steel box girders, but there is no support in the middle. All of them are supported by steel structures and pushed by 36 bases around them. Its shape is very characteristic and beautiful. The total construction area of Binhai Station is about 276,000 square meters. The station building is about 874 meters long from north to south and 63 meters wide from east to west. The construction area is about 86,168 square meters. The highest point is 25.8 meters above the ground, and the deepest stratum is 65 meters. The steel dome is 143 meters long, 80 meters wide, and 24 meters high, with a total weight of about 4,600 tons. There are 36 steel box girders with positive and negative spiral variable cross-section curves on the main pole respectively. The platform is 450 meters long and 11 meters wide.

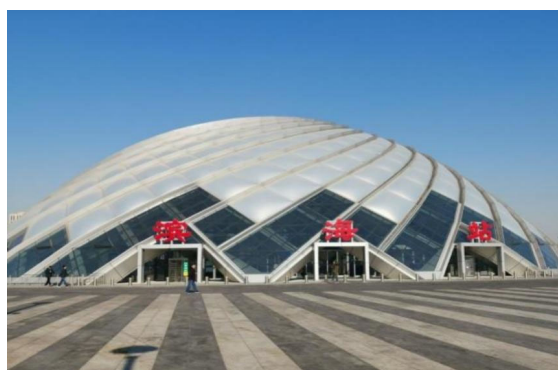


Figure 5. Binhai Station

2.4 Pipe truss structure system

Tube truss refers to a lattice structure composed of round bars connected at the ends. Its cross-section is generally triangular and evenly distributed, with greater rigidity and bending and torsion bearing capacity, simple structure, and easy construction. Truss makes the truss structure economical in materials and light in self-weight. It is easy to form various shapes to adapt to different uses, such as simply supported trusses, arches, frames, and towers, etc. It has excellent overall performance, beautiful shape, clear stress of each member, and is especially suitable for long-span spatial structures. In 2007, Shenyang Olympic Sports Center (see Figure 6) was completed as a sub-stadium for the football match of the 2008 Beijing Olympic Games. The main arch of the steel structure project of Shenyang Olympic Sports Center, which can accommodate 60,000 spectators, is 360 meters long and is the largest pipe truss structure in China. The main structure of the Shenyang Olympic Stadium tent is a long-span arch truss combined with a single-layer (tube) reticulated shell structure. According to the functions of structural components, the main structure is divided into three parts: main arch, ring arch, and north-south connecting truss. At the same time, in Dazhou Stadium, Sichuan Province, China, the space truss structure of circular steel tubes connected at the joints is adopted, and the dome is a covered membrane structure. The main arch span of the circular steel tube space truss is 240m, and the maximum span of the secondary arch perpendicular to the main arch is 34m. The main arch section is a rhombic space truss, the secondary arch is a triangular space truss, and the secondary arch and the main arch are connected through each other.



Figure 6. Shenyang Olympic Sports Center

2.5 Chord-supported structure system

Chord structure clearly defines the components and characteristics of the structure: "Chord" refers to the cable at the lower part of the structure like a bowstring; "Branch" refers to the compression bar which plays a supporting role in the middle of the structure; "Structure" refers to the concrete structural form of the upper part of the chord-supported structure. Based on introducing the concept of structure, the chord-supported structure is divided into the plane chord-supported structure, decomposable space chord-supported structure, and non-decomposable space chord-supported structure. Put forward chord-supported grid structure, chord-supported concrete floor, chord-supported tube shell, and chord-supported arch shell structure;

Three naming and classification schemes are given based on the results of related studies. It is suggested that this kind of structure system should be called a chord-supported structure system, and this kind of structure should be classified according to the principle of clear structure concept and complete system. String structure system mainly includes beam string, truss string, suspend dome, etc. Beam string structure was put forward by Professor M.Saitoh of Japanese University in modern times, which is a new hybrid roof system different from the traditional structure. Beam string structure is a kind of hybrid structure system formed by the upper chord of rigid members, flexible cables, and struts in the middle. Its structural composition is a new self-balancing system, a long-span prestressed

spatial structure system, and a relatively successful creation in the development of a hybrid structure system.

The beam string has a simple structural system, very clear force points, various structural forms, and gives full play to the advantages of both rigid and flexible materials, and is simple and convenient to manufacture, transport and construct, so it has good application prospects. For example, Guangzhou International Convention and Exhibition Center (see Figure 7) adopted the beam string structure.

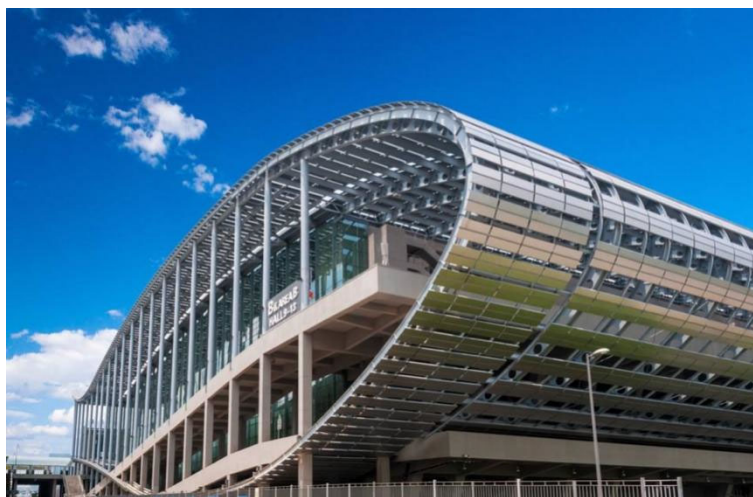


Figure 7. Guangzhou International Convention and Exhibition Center

String truss is a method of building construction, and the roof member adopts a string truss structure. The truss string structure is adopted in the preparation, training, and training venues of the 2022 Beijing Winter Olympics, including the Avenue Speed Skating Hall, the Ice Hockey Curling Hall, and the athletes' apartment in the media center. A typical suspend-dome structure system is composed of an upper single-layer reticulated shell, a lower vertical strut, radial tie rods or cables, and hoop cables, in which the upper end of each hoop strut is hinged with each link point corresponding to the single-layer reticulated shell, the lower end of each strut is connected with the next link point of the single-layer reticulated shell by radial cables, and the lower ends of struts in the same ring are connected by hoop cables, so that the whole structure forms a complete system and the force transmission path of the structure is relatively clear. For example, Lanzhou Olympic Sports Center Complex (see Figure 8).



Figure 8. Lanzhou Olympic Sports Center

The Tulip Complex of Lanzhou Olympic Sports Center, which has the largest span suspen-dome in northwest China, is a Class A large gymnasium with a building area of about 40,000 square meters, and a building height of 36 meters and four floors above ground. The plane projection is oval, with

an east-west long axis of 173 meters and a south-north short axis of 132 meters. The suspen-dome of Lanzhou Olympic Sports Center Complex adopts the ribbed ring-joint combined single-layer reticulated shell with more architectural aesthetic expression for the first time, and is the first one in the world to hang a large-tonnage bucket screen with a rise-span ratio of less than 1/2.

2.6 Cable structure

Cable structure refers to the prestressed structural system formed by cables as the main load-bearing components. Cable structures cover a wide range, such as cable-stayed bridges and suspension bridges. At present, housing construction refers to structures such as suspension cables and cable-stayed. Membrane structure also called tensioned membrane structure, is the most representative and promising architectural form in the 21st century. There are many typical buildings with cable structures, such as Beijing Workers Gymnasium (see Figure 10), Hangzhou Gymnasium, Anhui Gymnasium, Shijiazhuang International Exhibition Center, etc. The roof of Beijing Workers' Gymnasium is a radial suspension cable structure with a span of 94 meters. There are 12,000 fixed seats and 1,000 temporary seats. In addition to the central hall, there are also special venues such as the badminton hall.

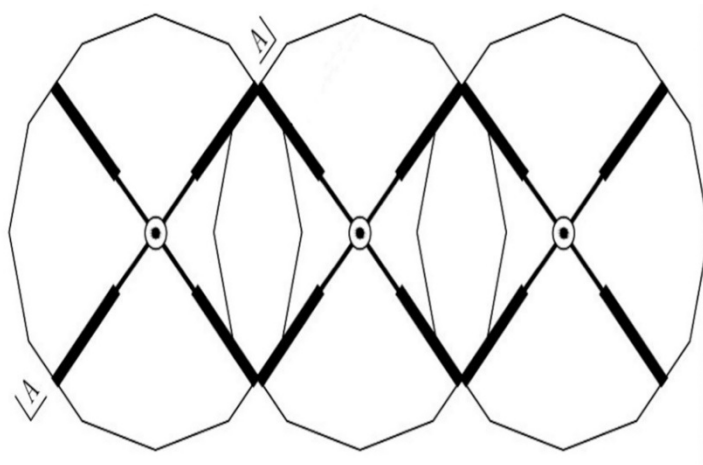


Figure 9. Cable structure diagram



Figure 10. Beijing Workers Gymnasium

3. Conclusion

This paper introduces the large-span steel structure system from a whole perspective. Based on the historical background of large-span steel structure, it explains the definition of large-span steel structure system and respectively states the spatial grid structure system, reticulated shell structure

system, tube truss structure system, rotating structure system, and cable structure, and carries out analysis and researching to different solutions. Through the above information, it can be known that the large-span steel structure system places an irreplaceable role in the process of social development and progress. But in the current situation of resource shortage, pushing the industrialization, greening, and informatization transformation of global construction appears significantly important.

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