A Discussion on the Type Selection of the 200 m Span Closed Coal Shed in the Thermal Power Plant

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Abstract: This thesis discusses the type selection of the concrete implementation of the 200 m span closed coal shed in the thermal power plant. We analyze the characteristics and development situations of five schemes for selection, and focus on introducing and recommending the closed coal shed which uses the PVDF membrane material as its outer space cover. Then we choose the steel grid of three-centered circulars and the membrane framework as its structure selection, and strives to make it highly coordinated with the surrounding buildings and environment. Such renovation is to turn it into an industrial construction in the new era with both aesthetics and practicality, and to promote the rapid development of the membrane material structure as a new product of new technology. At the same time, the paper provides guidance and reference for the type selection of the supramaximal span structure of 200 m and above.

1. Closed Coal Shed

Article 31 of ‘Law of the People’s Republic of China on the Prevention and Control of Atmospheric Pollution’ stipulates: When coal, gangue, coal cinder, coal ashes, sandstone lime soil or other material is stored in densely inhabited areas, fire and dust prevention measures shall be taken in order to prevent atmospheric pollution. [1] After the thermal power plant has gradually completed the environmental protection transformation with the ultra-low emission, the project of sealing the coal yard becomes a relatively large environmental protection project in thermal power plants. The closed coal shed covers a large area, the construction cost is high, and the investment income is low, which has a great influence on the overall landscape of thermal power plants. In recent years, whenever a new power plant is built, it is a basic requirement to build the supporting closed coal yard, and the renovation projects of the closed coal sheds of the built power plants are also vigorously promoted and implemented. Therefore, we should actively carry out renovation plan on the coal storage yards of the thermal power plants. The renovation plan is in line with the long-term development interests of enterprise and the industrial standards. What’s more, it meets the requirements of laws and regulations and complies with the requirements of increasing corporate social responsibility.

This thesis introduces the coal yard’s phase-III closure project of the 2 × 680 MW unit in a power plant in Shandong. The Shenfu-Dongsheng coal was used as the type coal in this design, and four strip-shaped coal storage yards were built. The total coal storage capacity was 190,000 tons, which met the coal consumption of 15 days under the maximum continuous output operating condition of the unit. The coal storage capacity just reached the requirements of ‘Code for Design of Fossil Fired Power Plant’ (GB 50660 - 2011): The coal storage capacity should not be less than the 15-day coal consumption of the corresponding unit in a thermal power plant with a transport distance greater than 100 km [2]. The economic benefits of thermal power plants are closely related to coal prices, and the coal storage will be adversely affected by winter transportation. As a result, it is necessary to do a good job of coal storage...
in advance for winter, so as to meet the requirements of sustainable and stable operation of thermal power plants and to ensure the public’s livelihood demands for heating. Most of the coal yard areas of the built power plants are in relatively urgent usage and do not have the conditions for the expansion of the coal yards. Therefore, it is necessary to build the large-span closed coal sheds to ensure that the coal storage meets the operation requirements of the unit.

2. Engineering Overview
This paper introduces the coal yard’s phase-III closure project of the 2 × 680 MW unit of the ultra-supercritical coal-fired condensed generator set in a power plant in Shandong, located on the coast of the economic and technological development zone. Two bucket wheel stoker-reclaimers of the DQ2500/2500 · 35 type were set up in the coal yard, and there are four strip-shaped coal yards. The effective length is 210.7 m, the stack height is 12 m, and the width of the coal yard is 47.5, 73.8 (of the intermediate two yards) and 47.5 m, respectively. The total coal storage capacity of the original design is 190,000 tons [3]. The peak ground acceleration of the location of the factory is 0.10 g, the basic seismic intensity is 7 degrees, the basic wind pressure is 0.65 kN / m² in 50 years and 0.75 kN / m² in 100 years, and the basic snow pressure if 0.50 kN / m² in 50 years and 0.60 kN / m² in 100 years [4].

3. A Discussion of Type Selection for the Design
According to the on-site capital collection and reconnaissance, the proposed closed coal yard was designed according to the following dimensions: the span is 200 m, the length is 216 m, and the closed projection area is 43,200 m². The following five designs for selection are proposed for analysis and comparison.

3.1 Type 1 for Selection: The Double-Span ‘Seagull-Shaped’ Steel Grid of Three-Centered Circulars Plus the Membrane Framework
In the double-span ‘seagull-shaped’ steel grid of three-centered steel circulars plus membrane framework, the seagull-shaped cylindrical grid of three-centered circulars is used as the internal supporting frame of the building, and the membrane material is used for external closure. The requirements of building dry coal sheds for coal-fired power plants were first proposed by some small and medium-sized power plants in the late 1960s. Until the early 1970s, dry coal sheds were quickly used in most provinces south of the Yangtze River. This trend rapidly became a leading concept and was included as a design standard in ‘Design Specification’ [5]. The span of the dry coal sheds constructed in early period was generally small, for it was set according to the limited area within the coal yard. After decades of development, at present, the grid design and the construction technology, more used in the engineering within a span of 120 m, have been very mature and reliable, and have accumulated rich experience of engineering technology and operation management. In all the already built closed coal sheds, purlins plus color steel plates are used while membranes were used as the material of the exterior-protected construction. The weight of the membrane material is lighter than that of the profiled steel sheets of aluminum-coated zinc, and the load of membrane frameworks is smaller than that of the conventional purlins plus the color steel plates. By using the membrane framework, the load of the external closure of the steel grids of the three-centered circulars is reduced, which can not only reduce the amount of steel used in the structure and the size of the foundation piles, but also reduce the total cost of the engineering of the closed coal shed. The membrane structure is the building or structure composed of membrane materials and other components, and it is divided into the tension membrane structure and the inflatable membrane structure [6].

In this paper, the tension membrane structure is adopted. The design of the membrane structure is implemented according to the relevant requirements of ‘Technical Specifications for the Membrane Structure’, and the acceptance check of the membrane is implemented in reference to the relevant provisions of ‘Acceptance Regulations for Construction Quality of Membrane Structure Engineering’ T / CECS 664-2020. Due to the elimination of purlins, for the closure of the coal yard of the same scale, the steel consumption per square meter in the scheme of membrane framework is about 5 kg less than
that of the grid structure scheme, and the steel consumption per unit area of horizontal projection of the former scheme is about 52 kg / m². The structural section of scheme one is shown in Figure 1.

![Fig. 1 Scheme 1 Structural Section](image1)

Features of the double-span ‘seagull-shaped’ steel grid of the three-centered steel circulars plus the membrane framework: 1. It uses the double-span design, its grid structure has high supporting strength and its structure is stable. 2. In its external structures, the membrane framework is used instead of the conventional purlins plus color steel plates in closure, ensuring the light weight and the easy maintenance. The density of membrane material is only about one-fifth of that of the color steel plate. The use of the structure of membrane framework can save the purlin weight and steel consumption of the steel grids, and the cost of membrane material itself is also low, and thus the use of membrane material can reduce the cost of enclosure. 3. The closed coal shed is symmetrically arranged along the axis of the middle column on both sides of the structure, forming a ‘seagull-shaped’ mode. It has an aesthetic outlook in coordination with the blue sea, especially in the place hundreds of meters away from the sea. 4. The service life of the membrane framework is better than that of the color steel plate, and the former is excellent in corrosion resistance. The overall advantage of it is reflected in the saving of investment costs. 5. The row of supporting structure in the middle of the coal yard has some influence on the shovel and unloading operation. At the same time, it is necessary to set up protection devices to avoid the corrosion of the coal heap on the main stress structure. 6. Effective discharge of rain, snow and water should be considered and drainage channels should be set up in the ditches. For areas with large snow load, it is also necessary to consider setting up a heating snow elimination device, or consider the human device, so as to facilitate the later dust and snow cleaning operation. It is suitable for southern areas with less or no snow load in winter. 7. Due to the fact that the structure of membrane framework in sealing the coal yards has been applied not for a long time, most of the data are provided by the manufacturers, and they still need to be checked in long periods of practices.

3.2 Type 2 for Selection: The Double-Span ‘Arc-Shaped’ Steel Grid of Three-Centered Circulars Plus the Membrane Framework

In the double-span ‘arc-shaped’ steel grid of the three-centered circulars plus the membrane framework, the arc-shaped cylindrical grid of the three-centered circulars is used as the internal supporting frame of the building, and the membrane material is used for external closure. On the basis of design 1 for selection, the height of the middle supporting structure and the overall shape of the grid are adjusted.
After the closure is completed, the overall appearance of the coal shed is an arc structure, which can reduce the snow load on the roof, improve the safety of the structure, and reduce the snow cleaning during the operation and maintenance period, especially suitable for areas with large snow load in winter. The steel consumption per unit area of horizontal projection of this scheme is slightly higher than that of scheme one, about 60 kg / m². The structural grid section of scheme two is shown in Figure 2.

### 3.3 Type 3 for Selection: The Prestressed Large Span Steel Trusses

The main structure of the coal shed of the prestressed large span steel trusses is the prestressed truss cable structure, and the longitudinal pipe truss and the longitudinal horizontal strutting pieces are arranged between the main trusses to ensure the longitudinal force transmission and the safety and stability. In the roofing enclosure structure, it generally adopts scheme of ‘purlins plus color steel plates’. On the whole, the steel consumption of prestressed truss structures is less than that of grid structures and portal steel frames under the same span. With the development of steel structure technology and the exploration of calculation software, a variety of structures of dry coal sheds have been emerging.

At present, the prestressed structure of pipe trusses formed by the organic combination of prestressed technology and ordinary steel trusses has been able to realize the closure of the coal shed with a span of more than 200 m [7]. For example, the span of the closed coal shed of Fangjiazhuang Power Plant is 229 m, which is the largest span among similar buildings. Under this scheme, the steel consumption per unit area of the horizontal projection is about 69.08 kg / m². The structural section of scheme three is shown in Figure 3.

![Fig. 3 Scheme 3 Structural Section](image)

The prestressed large span steel truss can span a large space. By setting the horizontal string cables, it can reduce the thrust of the arch feet and resist the wind load. The foundation column distance can be made about 15 m. Compared with the traditional grid foundation, it can save nearly half of the foundation engineering quantity, and its advantage is more obvious in regions of poor geological conditions. The prestressed large span steel truss sets prestressed cables in the upper clearance area of the arch, balances the horizontal thrust of the partial arch structures, and forms the arch truss structure of cables, which are dominated by arch force and have the characteristics of the string truss structure. Thus, the vertical stiffness of the horizontal section of the roof is strengthened, and the steel consumption is saved. [8] The number of prestressed pipe truss members is small and the structure is simple. All the
The basic welding work of installing the general steel trusses is completed on the ground, and the installation is completed in differently hoisted sections with high construction safety. Since the joint welding work is basically constructed on the ground, it is also convenient for the owners and supervisors to monitor the construction quality. At the same time, the prestressed pipe truss has good sealing and convenient maintenance in the later stage. In this scheme, there is no system of vertical columns in the middle part of the coal yard, so the coal piling is not affected and the reserves can be large in amounts. With the high safety performance, there will not be excessive snow load on the roof. The middle area will not affect the operation of stacker reclaimers, shovel trucks and other equipment. However, the steel consumption per unit area is large, the construction cost is high, and it needs on-site processing, while the processing is difficult and the construction period is long.

3.4 Type 4 for Selection: The Two Independent Grid Structures
This scheme adopts the closed coal shed of two independently arranged steel grid structures of the three-centered circulars plus the single-layer profiled steel sheets of aluminum-coated zinc. It is necessary to reserve an 8-meter-wide channel in the middle. The span of two closed coal sheds is around 96m, and the total projected area is 41,472 m². In this scheme, the steel consumption per unit area of horizontal projection is 45.70 kg/m². The structural section of scheme four is shown in Fig. 4.

The grid structure has the advantages of wide adaptability, mature technology, convenient processing, easy installation, practicability and economic efficiency, and aesthetic values for the buildings. The grid structure has large horizontal thrust, small column spacing (usually 6-8 m or even smaller), large foundation engineering quantity and costs, and high requirements for foundation site, though. Especially in the environment of poor geological conditions or serious restrictions of surrounding buildings in reconstruction projects, the adverse effects of the large reaction force of the grid foundation on structural safety and economy is more obvious. The grid nodes are connected by bolt balls with a large number of nodes. The connecting points of bolt rods are prone to the electrochemical reaction with the corrosive medium. The coal shed corrosion in the past was mainly the internal corrosion of the ball node, which was not easy to be found, repaired or maintained. Some improvement measures have been taken in the current design. The total coal storage capacity of this scheme is only 170,000 tons, which is about 10% less than that of other schemes for type selection. To meet the coal storage capacity of 15 days, it is necessary to increase the length or span of the closure.

3.5 Type 5 for Selection: The Coal Shed of the Air Membrane
The air membrane is a new type of building with high technology in the new era. This coal shed adopts an independent inflatable membrane structure with a span of 200 m, a length of 216 m and a projected area of 43,200 m². The fully enclosed inflatable membrane structure is a new kind of closed structure emerging in recent years. The membrane structure adopts the special membrane material of high strength and flame retardancy as the closed structure to be welded and assembled into a closed shell, the lower edge of the membrane structure is anchored with the concrete coal retaining wall to form a closed space, and the air is injected with the blower and the pressure difference between the indoor and the outdoor is maintained, so that the membrane surface is pulled to ensure stiffness, while maintaining the shape and resisting external load as a peculiar structural form [9].

There are many examples of the construction and operation of air-membrane buildings abroad, and the construction examples of air-membrane buildings in China are gradually increasing. With the increase of construction and operation experience of air-membrane buildings, the span of the air-membrane closure is also increasing. The closed coal shed of Wanggu Power Plant is the air-membrane building of the largest span in Asia, with a span reaching 180 m and a length of 198 m. As to air-membrane building with a span above 180 m, there still lacks relevant design data and construction experience.

The fully enclosed coal shed of air membrane has large space and flexible shapes, with the characteristics of free pollution, small workload for maintenance and long life. This flexible membrane material has light weight, low cost, and its overall cost is much lower than that of the grid structure and
the prestressed structure of pipe trusses. Its construction period is short and can be constructed in winter. It has good light transmittance with reusable ability and strong corrosion resistance. Continuous gas supply is needed during the operation of the air-membrane coal shed, and a certain amount of electric energy is to be consumed. Compared with the coal storage shed of the steel structure used in the industry, the coal storage shed of air membrane greatly reduces the use of steels and cements, and the cost of concrete foundation alone can be reduced by 60%, while saving nearly 30% of the overall project funds. It is estimated that the operation and maintenance cost of the coal storage shed in Shenba Coal Preparation Plant is about CNY 900,000 a year, and the coal storage shed of the steel structure of the same level is around CNY 1.5 million [10].

The following design schemes are aimed at the closed coal shed of a supramaximal span over 200 m. The double-span ‘seagull-shaped’ steel grid of three-centered circulars plus the membrane framework can be used to seal the coal shed. The membrane framework is used to replace the conventional purlins plus the color steel plates for external sealing, and the load of the membrane framework is less than that of the conventional purlins plus the color steel plates. The use of the membrane framework can reduce the load of the external sealing of the steel grid of the three-centered circulars, which can reduce the amount of steels used in the structure and the size of the foundation piles, and reduce the total cost of the project of the closed coal shed. The double-span ‘arc-shaped’ steel grid of the three-centered circulars plus the membrane framework can be used to seal the coal shed.

On the basis of using membrane framework, the shape is changed from ‘the seagull-shaped’ to ‘the arc-shaped’, which well solves the problem of easily accumulated snow in the middle of the coal shed in the ‘seagull-shaped’ scheme. When the coal shed is sealed by the prestressed large span steel truss, the coal storage in the middle is not affected, but the steel consumption per unit area of horizontal projection is relatively large, and the project cost is relatively high. When the two independent grid structures are used to seal the coal shed, the intermediate channel occupies the original coal accumulation area, which results in a reduction of coal storage by around 10%. The coal shed of the air membrane is a new type of coal shed in engineering application in recent years. It has certain advantages over other closed coal sheds in terms of environmental protection and costs. Therefore, it can be used as a choice in the design of coal sheds in thermal power plants in the future. Its adaptability to the environment in terms of wind pressure and snow pressure needs to be further tested and improved in actual operation [11]. Photos of each scheme after implementation are shown in Fig. 5.

![a. Double-Span ‘Seagull-Shaped’ Coal Shed b. Double-Span ‘Arc-Shaped’ Coal Shed](image-url)
This project is located in the coastal area of Shandong Province. The closed coal shed adopts the structural scheme of the steel grid of the three-centered circulars plus the membrane framework. It uses the PVDF membrane material as the external supporting structure, and the reasonable technical measures are adopted to create the supramaximal space to meet the functional requirements. Based on its huge structural system of the steel grid of the three-centered circulars plus the membrane framework, it will be the most prominent monomer in the factory after completion. The new closed coal shed focuses on the concept of green environmental protection and low-carbon development. The façade of the closed coal shed is processed with modern techniques into a simple and spacious form. Therefore, the design of this project adopts the structural scheme for selection of the coal shed of the double-span ‘seagull-shaped’ steel grid of the three-centered circulars plus the membrane framework, and fully considers the snow load of the two-span middle ditch in winter. For the coal shed with large snow load in the region, it should also consider the installation of de-icing devices to avoid the adverse impacts of excessive snow on the coal shed. After the implementation of this project, it will become a typical example of the supramaximal structure of the membrane framework. The grid model of this scheme is shown in Figure 6, and the partitions of the membrane structure is shown in Figure 7.
4. Conclusion
With the continuous development and progress of scientific technology and material properties, there will be more and more structures with a span over 200 m, and the technology of selection for schemes of structures with a supramaximal span will be constantly updated. The recommended scheme for selection of the structure of the steel grid of the three-centered circulars plus the membrane framework is the innovative product proposed by continuous exploration on the basis of existing technology and experience. It is the combination of the grid structure and the membrane structure for the first time to give play to the advantages of their respective systems and realize the overall benefits of the project of the closed coal shed. This selection uses the PVDF membrane as the external supporting structure, adopts the reasonable technical measures, creates the large-span space, meets the functional requirements, and reflects the industrial characteristics. The adopted closed coal shed of the structure of the steel grid of the three-centered circulars plus the membrane framework is an industrial building in the new era with both aesthetics and practicality. While highlighting the main body, it pays more attention to the detailed design. Through the discussion on the selection for scheme of the 200 m-span closed coal shed, it provides guidance and reference for the selection of large-span structures of 200 m and above, and focuses on the introduction and recommendation of the membrane framework structure as a new product and of the new technology.

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