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## **CORE DESIGN STRATEGIES FOR PORTAL STEEL FRAMES: A STRUCTURAL ANALYSIS**

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**Abstract:** The practical implementation of portal steel frames has witnessed notable advancements through the strategic incorporation of inclined beams. This innovative addition serves a dual purpose, enhancing overall structural stability while curbing the consumption of foundational materials. The result is an effective cost-control strategy, ensuring economic feasibility during the construction process. Additionally, the introduction of lightweight steel structures within portal steel frames contributes to a substantial reduction in the overall structural weight. This not only promotes the structural system's seismic performance but also underscores its suitability for a wide range of applications, particularly in the construction of single-storey houses and industrial plants. The utilization of portal steel frames equipped with lightweight steel structures offers a cost-effective approach to single-storey house construction. This synergy between structural elements enables a practical and efficient construction process. Consequently, portal steel frames have become an integral component in the construction of industrial plants, facilitating enhanced efficiency and cost-effectiveness. However, for these structural systems to fulfill their full potential, a systematic analysis is indispensable to address the myriad challenges inherent in the design process. A continual commitment to enhancing design quality remains the cornerstone of broadening the scope of their application.

**Keywords:** Portal Steel Frames, Inclined Beams, Lightweight Steel Structures, Cost Control, Design Quality Enhancement

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### 1. Introduction

In the practical application process of the portal steel frame, the use of inclined beam to achieve the purpose of overall stability, reduce the amount of basic materials, and achieve the purpose of cost control. Light steel structure weight of the whole is light, seismic performance is relatively good. In the construction process of single-storey house, the construction cost of portal steel frame can be effectively controlled through the application of light steel structure. Therefore, this structure will be used in the construction process of many industrial plants. In order to expand the scope of application, it is necessary to make targeted analysis of many problems existing in the design process, and constantly improve the design quality.

### 2. Load value problem

Most of the portal steel frame light steel structure is used in the construction of industrial plants, industrial warehouses and other buildings. At the beginning of the planning and design of these factories and warehouses, the space size and plane size have been relatively fixed, and the functional zoning is also designed in advance. Therefore, in the process of structural design, it is necessary to focus on the load value problem, which is also one of the important factors affecting the construction cost. The industrial plant and warehouse designed by door steel frame light steel structure are mainly based on the stress advantage of door steel structure. In the practical application process, this kind of structure generally has a large span. If the load value has problems, it will have an impact on the overall stability of the building. For example, a 2008 snowstorm accident in southern China led to the collapse of many industrial plants. In the process of analyzing the causes of the collapse of the plant, it can be found that many portal steel frame light steel structure plant collapsed, which is greatly related to the error of snow load value<sup>[1]</sup>. This has also sounded the alarm for people, in the process of the portal steel frame light steel structure design, to improve the importance of the value of the wind load and snow load. China's terrain conditions are complex. In the southwest of China, the crustal movement is frequent and often affected by earthquakes. In the process of the design of portal steel steel structure, the attention of seismic action should also be improved. The latest version of the "Technical Code for Steel Structure of light door steel frame" requires that in the process of roof snow load numerical calculation, the accounting must be conducted in accordance with the following formula.  $S_k = \mu_r S_0$

In formula:  $S_k$ ---Standard value of snow load ( $\text{kN} / \text{m}^2$ )  $\mu_r$ ---Roof snow cover distribution coefficient

$S_0$ ---Basic snow pressure ( $\text{kN} / \text{m}^2$ )

In the Code, the basic snow pressure is also clearly stipulated, requiring the basic snow pressure to be adopted according to the snow pressure of the 100-year return period<sup>[2]</sup>. In addition, in the process of accounting for the snow load coefficient, the distribution coefficient of the roof snow cover should also be considered, and the load-bearing components should be designed according to the distribution of different snow load conditions.

### 3. Support system design issues

The biggest advantage of the portal steel frame light steel structure is that it has a unique stress structure, which can not only effectively deal with the load in the plane, but also can effectively solve the load outside the plane through the application of the support system. Therefore, in the process of practical application, the application range of portal steel frame light steel structure is relatively wide. However, the application of portal steel light

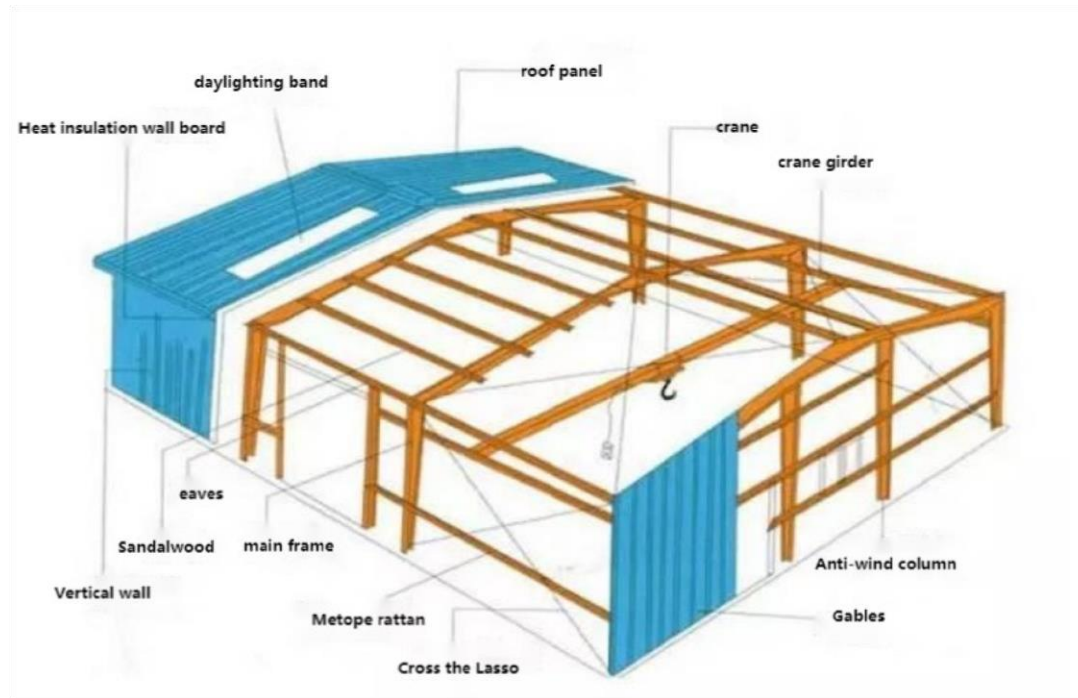
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steel structure for industrial plant and industrial warehouse design, will inevitably involve the door design and equipment distribution, these problems will affect the portal steel light steel structure support system, lead to horizontal support and column support respectively in two different rooms. This will have an impact on the stability of the overall structure, once suffering from the load outside the plane, it is easy to lead to the collapse of the building problem. Therefore, in the design process, we should focus on the support system, the position of the inter-column support can be adjusted, and the steel cross support can also be increased to improve the overall force capacity. If the cross castings cannot be applied in the planning and design process of industrial plants and warehouses due to the rigid conditions, then the portal frame support can be designed, which can also increase the longitudinal stiffness of the overall structure, which is one of the main strategies to solve the design problem of the light steel structure support system of the portal steel frame. In the process of practical application, we should combine different solution strategies and applications to ensure the stability of the main structure. If conditions permit, the support spacing should try to keep between 30 meters and 45 meters.

### **4. Roof purlin design problem**

In the process of portal steel frame light steel structure design, roof purlin design is one of the main design contents. Roof purlin is an important structure to support the roof panels and wall panels, and can also offset a part of the longitudinal load force. Purlin is also an important part of the longitudinal support system in the whole structure. In the process of analyzing the type of purlin, it can be found that some roofs with large load force are mainly the use of hot pressed steel and H steel purlin construction design, and the light roof of pressed steel plate is mainly the application of cold-bent thin-wall steel type purlin construction design. In most factories and warehouses, cold-bent thin-wall steel is usually used to reduce costs. However, the overall bending resistance of this type of purlin is poor, and there are safety risks in the actual use process. Therefore, in the use of cold-formed thin-wall steel foundation, usually will add a pull or pole. According to the Technical Code for Steel Structure of Door Steel frame Light Buildings, the width ratio of purlin margin is less than or equal to 13, the ratio of the rim width to flange width is greater than or equal to 0.25, and less than or equal to 0.326, which also makes the economic benefits of the whole project seriously affected<sup>[3]</sup>. Therefore, in the current portal steel frame light steel structure design process, most of them will use cold-bent thin-wall steel as the roof purlin. In addition, in the process of roof purlin design to add purlin. The purpose of setting purlin support is to prevent the torsion of the end section of purlin and enhance the stability of the overall structure. Moreover, in the process of connecting the purlin with the purlin support, the connection bolts should be greater than or equal to two, so as to ensure the stability of the connection. In the construction process of industrial plant, warehouse and other single-storey industrial buildings, if the portal steel frame light steel structure is used, then, it is necessary to combine the construction cost, structural stability and other design parameters, the roof purlin planning, can also be shown in the following figure, increase the roof purlin, wall purlin, skylight frame purlin and so on.

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*Figure 1: Construction technology of light steel structure roof purlin of portal steel frame*

### 5. Design problem of portal steel frame beam and column

In the design process of portal steel frame light steel structure, the problem of portal steel frame beam and column is also one of the most important design problems. In the design process, the unreasonable design of the beam and column structure will lead to the overall decrease of the bearing force, and the stability of the structure will also be greatly affected. Therefore, in the design process, we should improve the degree of attention to the portal steel frame beams and columns. China has the largest wind power station in Jiuquan. Although wind can be converted into electricity, it contributes to the adjustment of energy structure. However, in the construction process of the industrial plant in this area, it will also be affected by the large wind force, resulting in the problem of large wind load, which puts forward higher requirements for the design ability of the portal steel frame and light steel structure. In the area with large sealing load like Jiuquan, Gansu province, the design method of swing column is usually used to ensure the overall stability of the portal steel frame and light steel structure. In this way, in the actual use process of the building in the later period, even if the large wind force is borne, the middle column only needs to bear the axial force, and does not need to bear the bending moment, and the overall stability will be relatively strong. The design in this way will cause the increase of the length of the side column, which is not conducive to the overall cost control. In the design process of the portal steel frame beam and column, the connection point between the inclined beam and the column is also one of the contents that need to be paid close attention to. Only by ensuring the rigid connection, can the stability of the overall structure be guaranteed. Therefore, at the connection point will usually use the end plate vertical, flat and oblique three ways to connect. Take the vertical side of the short board as an example, the value of the release of the short board is relatively high, but it will have a great impact on the bolt, leading to the destruction of the bolt first.

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### **6. Column-foot design problem**

Most of the industrial plants and industrial warehouses constructed by the portal steel frame and light steel structure are located in relatively open areas. The overall terrain conditions of such areas are poor, and the buildings are greatly affected by the wind force in the actual use process. Therefore, in the design process, we must focus on the wind load. In the design process of most portal steel frames, shear bonds will be set on the bottom plate of the portal steel column, so that it can effectively resist the shear force sent from the bottom of the column, and ensure the relative stability between the column bottom plate and the top surface of the foundation bolt. In the practical application process of the industrial plant with the portal steel frame and light steel structure, if there is a slip between the column base plate and the top surface of the foundation bolt, the relative position between the beams and columns will change, which will have a serious impact on the overall supporting force of the structure. The main advantage of the portal steel frame is the unique stress structure, which will have a serious impact on the force of the portal steel frame, and is also one of the main factors causing the collapse of the light steel structure buildings of the portal steel frame. Therefore, in the design process of the light steel structure of the portal steel frame, the concrete pouring construction of the secondary grouting layer is usually added for the portal steel frame column foot, and clearly marked in the construction drawings. In the process of design disclosure, the construction personnel should also be emphasized. It is required that in the construction process of the portal steel frame footnote, the secondary grouting must be filled out. There are also strict requirements for grouting materials, we must use special grouting materials or micro-expansion concrete, only in this way, to ensure the filling and irrigation compaction. In addition, in the process of concrete matching, the water-cement ratio should also be strictly required to ensure that the concrete used for secondary grouting will not appear dry shrinkage.

### **7. Seismic design problem**

China is located in the Eurasian plate. In recent years, the frequent movement of the Eurasian plate is, leading to the frequent occurrence of different levels of earthquake disasters within China's territory, resulting in building collapse, casualties and other accidents. As shown in Table 1 below, the frequency of earthquakes above magnitude 5 in China has been high in the past five years. If the building does not consider the earthquake factors in the design, even if a slight earthquake occurs, it will also lead to the building collapse, damage and other problems, which will pose a huge threat to the safety of the building. As the light steel structure is the most commonly used structure in the construction process of industrial workshop and warehouse of the door steel frame, we should also focus on the seismic problem in the design. Only in this way, can we ensure that under the influence of the earthquake, the overall structural stability of the industrial plant can be effectively guaranteed, and will not cause property losses and casualties. Up to now, China has no clear division of the seismic grade of steel structure. However, in the design should also take the height of the building as the core, and constantly improve the seismic grade. In the design, the seismic grade of the portal steel frame light steel structure can be improved by adjusting the length of the steel frame and the width of the beams and columns.

*Table 1: Number of earthquakes of magnitude 5 in China 2016-2021*

Unit: times

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In 2016,	In 2017,	In 2018,	In 2019,	In 2020,	In 2021,
33	19	16	30	25	37

### 8. Fire protection and heat insulation design problem

In the practical application process of portal steel frame and light steel structure, most of it is applied to the construction of industrial plant and industrial warehouse. Whether industrial plant or warehouse, will involve the storage and use of a large number of basic raw materials. Especially the industrial plant, in the process of use, will involve the operation of machinery and equipment, resulting in fire hazards in the industrial plant. In addition, many basic raw materials have strict control on the temperature. If the overall temperature in the industrial plant or warehouse is too high, it will lead to the failure of raw materials. At 4 PM on July 28, 2021, a fire occurred in the factory building of Maoqian Bag Parts Co., LTD., Xishan Village, Baigou Town, Baigou City, Baoding City, Hebei Province, killing six people. The fire accidents in these industrial plants remind people to focus on fire insulation in the design of portal steel frame and light steel structure. For example, in the design, it may be possible to require the use of concrete to bury the part of the steel column below the ground, to improve the fire insulation capacity of the steel column.

### 9. Basic design problem

Door steel frame light steel structure is a kind of main structure designed with light steel as the main material, the overall weight is light, the vertical load of the foundation is relatively small, which also leads to the problem of too large foundation eccentric, which is easy to cause the tilt and collapse of industrial plants and warehouses. Therefore, in the structural design, to strengthen the basic design. Improve the stability of foundation by increasing the aggravation of foundation, increasing deep burial and adopting pile foundation. However, different methods have limitations and application scope in the practical application process. Therefore, in the process of applying these methods to solve the basic design problems, it is necessary to choose and apply the actual situation of the construction site of the portal steel frame and light steel structure.

### 10. Overall deformation problem

The overall span of the portal steel frame and light steel structure is large, most of them are single-storey buildings, and the overall load force of the roof is large. In the northern region of China, the application of portal steel steel structure for the design of industrial plant and warehouse will involve the problem of snow load coefficient. If after the winter snow, the snow can not be evenly distributed in different positions of the roof, then, in the computer snow load, it should be calculated according to the uneven distribution coefficient, otherwise it will lead to the overall deformation or collapse of the portal steel frame light steel structure. Because the section of all components in the portal steel frame light steel structure is relatively small, it is also easy to cause the overall deformation problem. To solve this problem, the spacing can be appropriately shortened between them, or the cross-section area of the roof purlin can be adjusted, so as to improve the overall stability of the portal steel frame light steel structure. Door rigid frame light steel structure as a large overall span structure, once the overall deformation, it will lead to a serious threat to the safety of the building. Therefore, in the design, we should combine the actual situation and focus on solving the potential deformation hidden danger.

### 11. Temperature impact problem



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Door steel frame light steel structure is a kind of structure based on steel material construction, steel as a material material, will physically change due to the influence of temperature. Especially in the low temperature environment, steel, it is easy to become cold and brittle, it is easy to fracture and other safety problems. Therefore, in the process of using the portal steel frame and light steel structure of industrial plant and industrial warehouse design, the surrounding climate conditions and temperature conditions should be fully considered. The winter climate in northern China is cold, and the overall temperature is low. When conducting construction in such areas, we should choose to resist low temperature suppression steel as far as possible, which can effectively improve the low temperature resistance of the light steel structure of the portal rigid frame and ensure the safety of the building. In the south of China, the annual average temperature is higher, the overall climate is relatively humid, and the steel is easy to oxidation, which will have an impact on the service life of the portal steel frame light steel structure. Therefore, in the construction of this kind of area, the steel to prevent oxidation treatment, but also to increase the antirust coating, so that you can resist the impact of high temperature and humidity on the door steel frame light steel structure.

### **12. Maintenance system design issues**

Most of the industrial plants and warehouses built with portal steel frame and light steel structure are applied in the outdoor environment. Therefore, we need to increase the maintenance system to resist the wind and rain in the natural environment. Only in this way, can we ensure that industrial plants and warehouses will not appear water leakage, moisture return and other problems. It can not only improve the use value of portal steel structure, but also meet the functional needs of industrial plant and warehouse. Therefore, in the design, to focus on the maintenance system. Most industrial plants and warehouses have the requirements for ventilation, lighting and temperature control, and the application of maintenance systems is designed to meet these requirements. For example, the facade structure of long gas buildings can be used to increase the ventilation in industrial plants and warehouses. In addition, in the process of designing the maintenance system, it is also necessary to strengthen the ability to adapt to the main structure, so as to ensure the overall coordination and consistency.

### **13. Conclusion**

In short, although portal steel light steel structure is the most commonly used in single building structure form, but common in the design process of load value, support system design problems, roof purlin design, portal steel beam column design, seismic design, fire insulation design, overall deformation, temperature, maintenance system design, foundation design, and portal column design problems, this is all need to focus on in the design process, otherwise it will affect the overall construction quality. In the design process, we should be adopted to improve the design quality of portal steel frame light steel structure.

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