

Application of Prefabricated Prestressed Fish Belly Beam Steel Support in Deep Foundation Pit Engineering

Jiashun Pan, Xukun Qi, Qichen Li and Xueyuan Guo

School of Civil Engineering and Architecture, North China University of Science and Technology, Tangshan 063210, Hebei, China

Abstract: With the rapid development of urban construction, the scale and complexity of deep foundation pit engineering continue to increase, which puts forward higher requirements for foundation pit support technology. As a new type of deep foundation pit support technology, prefabricated prestressed fish belly beam steel support has been widely used and researched in recent years because of its advantages of large span, large space, green environmental protection and recyclability. Through the comprehensive analysis of a number of related literatures, this paper expounds the research status of the structural composition, working principle, application examples, technical superiority, and mechanical deformation characteristics of the prefabricated prestressed fish belly beam steel support, and points out the shortcomings of the current research, and looks forward to the future research direction, aiming to provide a reference for the further application and development of this technology in deep foundation pit engineering.

Keywords: Prefabricated type, prestressed fish belly beam steel support, deep foundation pit engineering, applied research.

1. Introduction

In the process of urban underground space development and utilization, the importance of deep foundation pit engineering is becoming increasingly prominent. Traditional foundation pit support methods, such as reinforced concrete support and steel pipe support, have many limitations in practical application, such as long construction period, difficult demolition, and large environmental impact. The prefabricated prestressed fish belly beam steel support technology came into being, which integrates the advantages of steel structure and prestressing technology, and provides a more efficient and environmentally friendly solution for deep foundation pit support. Many scholars have carried out extensive research on this technology, covering its working performance, application effect, mechanical properties and other aspects, and have achieved a series of valuable results. This paper systematically reviews and summarizes these studies, which is helpful to gain an in-depth understanding of the development status and future trend of this technology, and to promote its further application in deep foundation pit engineering.

2. The Structure and Working Principle of The Prefabricated Prestressed Fish Belly Beam Steel Support

2.1. Structural Composition

The prefabricated prestressed fish belly beam steel support system is usually composed of fish belly beam, butt brace, gusset, enclosing purlin, steel strand, column and other components[1,2]. The fish belly beam is the key component of the system, which generally uses high-strength and low-relaxation steel strand as the upper chord structure, H-shaped steel as the stressed beam, and H-shaped steel beams of different lengths. This structural design enables the fish belly beam to give full play to the performance of the material when stressed, and improve the bearing capacity of the support

system. For example, in the Binhai International Cruise Home Port project[3]. The internal support adopts a prefabricated prestressed tension beam steel structure, which is composed of lattice truss pair bracing and tension string beam system. Among them, the chord of the tension string beam adopts a specific specification of I-beam, and a stable structural system is formed by setting up the steel web member and the bracket, which provides reliable support for the foundation pit.

2.2. How it works

The support system works on the basis of the principle of prestressing. In the construction process, by applying prestress to the lower chord steel strand of the fish belly beam, the fish belly beam produces an outward force[4,5]. This force can mobilize the passive earth pressure on the outside of the enclosure structure, and before the excavation of the foundation pit, the enclosure structure produces a certain deformation to the outside of the pit, so as to balance the active earth pressure generated by the subsequent excavation of part of the foundation. With the excavation of foundation pit earthwork, the active earth pressure gradually increases, and the passive earth pressure gradually decreases, and the deformation of the foundation pit can be adjusted by adding prestress at this time to ensure the stability of the foundation pit. Take the foundation pit support project of Xuzhou Ruyi Plaza as an example[5]. Through the tensioning steel strand on the spot, the force relative to the earth pressure outside the foundation pit is generated inside the fish belly beam member, which effectively reduces the bending moment of the earth pressure on the enclosing purlin, and then reduces the horizontal displacement of the foundation pit and ensures the safety of the surrounding environment of the foundation pit.

3. Application Examples in Deep Foundation Pit Engineering

3.1. Application under different geological conditions

3.1.1. Soft soil areas

Foundation pit engineering in soft soil areas faces many

challenges such as low shear strength, high compressibility and high water content. A commercial plaza project in Shaoxing City[1].The soft soil of the site has a large distribution thickness, and the soil properties of the foundation are poor. The foundation pit adopts the SMW construction method pile and two prefabricated prestressed fish belly beam steel structure support scheme. In the construction process, due to the characteristics of soft soil, the foundation pit has a large deformation, and the failure of some steel support nodes leads to the instability of the support system. This indicates that the influence of soft soil on the support system needs to be fully considered when applying the support technology in the soft soil area, and the stiffness and stability design of the support system should be strengthened.

And in a super-large deep foundation pit project in Shanghai[3].There are undesirable geological conditions such as dark banks on the site. The project adopts occlusive pile and prefabricated prestressed fish belly beam steel support system, through the reasonable design of the parameters of the enclosure structure and the support system, as well as strict control of the construction quality, the deformation of the foundation pit is effectively controlled, and the safety of the project is ensured. This shows that according to different soft soil geological conditions, after reasonable design and construction, the prefabricated prestressed fish belly beam steel support technology can play a good role in the deep foundation pit engineering in the soft soil area.

3.1.2. Other geological conditions

In other geological conditions, such as sandy soil formations, rock formations, etc., there are also application examples of prefabricated prestressed fish belly beam steel support technology. Although there are few specific cases in the relevant literature, it can be speculated that in the sandy soil layer, due to the large permeability of sandy soil, the influence of groundwater on the support system needs to be considered, and precipitation measures may be required to ensure the stability of the support. In the rock formation, although the bearing capacity of the soil is relatively high, in the process of excavation and support, it is necessary to pay attention to the protection and treatment of the rock to avoid the impact on the surrounding environment due to blasting and other construction methods. The application of these special geological conditions also requires more engineering practice and research to accumulate experience and improve the application of this technology.

3.2. Application in complex surrounding environment

3.2.1. Close proximity to buildings and pipelines

A foundation pit project in Wuxi[6].The surrounding environment is complex, the north side of the foundation pit is the first phase of the resettlement housing community of Chuncheng Home, the east side is the Jiangnan gas station, and the south side has a thermal pipeline. The project uses $\Phi 800@1000$ cast-in-place piles and $\Phi 850@1200$ triaxial cement-soil mixing piles as the vertical enclosure system, and a prestressed fish-belly steel support as the horizontal support system. Through the comparison of theoretical calculation and practical monitoring, it is found that the support system can effectively control the deformation of the foundation pit and ensure the safety of the surrounding buildings and pipelines. This shows that in the complex surrounding environment close to buildings and pipelines, the

prefabricated prestressed fish belly beam steel support technology can meet the requirements of foundation pit deformation control through reasonable design and construction, and ensure the normal use of the surrounding existing facilities.

3.2.2. Near special environments such as subways

Shaanxi International Sports Window Project[7].The foundation pit is close to Metro Line 6 and Line 8, and the pipelines along the line are intricate. The project adopts the prefabricated prestressed fish belly beam steel support system and various forms of combined support system, and combines the regional geographical factors and surrounding monitoring data to improve the original design of dismantling and replacing the support idea. Through these measures, the construction safety and the normal operation of the surrounding subway are effectively guaranteed. This shows that in the special environment with extremely high requirements for deformation control such as near the subway, the steel support technology of prefabricated prestressed fish belly beam needs to be combined with other support forms, and with the help of advanced monitoring means and reasonable construction schemes, the deformation of the foundation pit can be strictly controlled to ensure the safety of the surrounding special environment.

4. The Analysis of Technical Superiority

4.1. Informatization

The prefabricated prestressed fish belly beam steel support technology is equipped with an advanced foundation pit engineering safety intelligent monitoring, early warning and control system[1-8]. By arranging various sensors in the support system, the system can collect data such as support axial force, foundation pit displacement, and settlement of surrounding buildings in real time, and quickly process and analyze these data. Once the monitoring data is abnormal, the system will send out an early warning signal in time to provide decision-making basis for the construction personnel, so as to take timely measures to adjust the construction progress or strengthen the support system to ensure the safety of the foundation pit and the surrounding environment. In the actual project, through the information monitoring system, the deformation of the foundation pit can be grasped in real time, and the potential safety hazards can be found in advance to avoid accidents.

4.2. High security redundancy

This technology forms a better superstatically determined structure by adding many additional components to increase the stability of the system and improve the super-static redundancy, such as column brackets, beams, scissor braces, and U-shaped fixtures between longitudinal and horizontal components[1-8]. This structural form greatly improves the integrity of the support system, and can effectively enhance the ability of the system to resist occasional impact loads. Different from the brittle failure mode of the traditional support system, the failure mode of the support in the tool-type combination of the prestressed fish belly beam is ductile failure, and there will be obvious deformation premonition before the failure, which improves the safety of the foundation pit support structure and provides more response time for the construction personnel.

4.3. Energy saving, emission reduction, green environmental protection

The prefabricated prestressed fish belly beam steel support system is assembled at the engineering site using low-alloy materials and standardized components[1,2,8]. After the construction of the underground structure is completed, all steel components can be recovered and recycled, which greatly reduces the generation of construction waste and reduces the pollution to the environment. Compared with the traditional reinforced concrete support, it avoids the pouring and demolition of a large amount of concrete, reduces the consumption of cement, sand and other building materials, and is in line with the concept of sustainable development. In the context of increasingly stringent environmental protection requirements, the advantages of energy saving, emission reduction and green environmental protection of this technology are particularly prominent.

4.4. Good economic benefits and good construction convenience

This technology has significant advantages in terms of economic efficiency and ease of construction[1,2,8]. In terms of economic benefits, it greatly reduces the construction period and cost of installation and dismantling of supporting structures. Because the steel components are prefabricated in the factory, the on-site assembly speed is fast, which can shorten the construction period and reduce the rental cost and labor cost of construction equipment. At the same time, its recyclable nature also reduces material costs. In terms of construction convenience, the prefabricated prestressed fish belly beam steel support system provides an open construction space, which is convenient for excavation, soil transportation and underground structure construction, improves the construction efficiency, and reduces the difficulty and duration of earthwork excavation and main structure construction.

5. Research on Deformation Characteristics Under Force

5.1. Analytical solution and reasonable prestress value

Xu Qiyuan simplified the structure of the fish belly beam into a superstatically determined tension string beam structure, and derived the analytical solution of the stress deformation of the fish belly beam structure based on reasonable assumptions[9]. By analyzing the effects of the span, sagittal height, upper and lower chord stiffness and prestress on the deflection of the upper chord beam, the reasonable prestress value was determined. It is found that the reasonable prestress value is proportional to the square of the span, inversely proportional to the vector height, and equivalent to the canonical value. When the prestress does not exceed the reasonable prestress value, the analytical solution is in good agreement with the finite element results, which can be used as a reference for engineering design. However, when the prestress continues to increase, the deviation between the two is very large. The research results provide a theoretical basis for the determination of the prestress value in engineering design, which is helpful to optimize the design of the fish belly beam structure and improve its mechanical performance.

5.2. Factors influencing stiffness

Bi and Xu Qiyuan simplified the web of the fish belly beam, regarded the fish belly beam as a structural beam fixed at both ends, used the displacement method and MATLAB program to solve the load deformation of the fish belly beam, and introduced the concept of "equal generation flexural stiffness" to deduce the calculation formula of the fish belly beam[9,10]. The results show that the stiffness of the fish belly beam is affected by the fish belly curve model, the number of steel strands, the end angle and the span. The selection of quadratic parabola or arc curve has little influence on the stiffness of the fish belly beam, and considering that the arc curve is more concise, it is recommended to use the arc curve model in engineering design. The greater the number of steel strands, the greater the stiffness of the fish belly beam; The angle of the end has little effect on the stiffness of the fish belly beam, but the larger the angle, the greater the stiffness. The span has a great influence on the stiffness of the fish belly beam, and the larger the span, the smaller the stiffness. These conclusions provide guidance for adjusting the stiffness of the fish belly beam according to the specific needs in practical engineering.

6. Deficiencies and Prospects of Current Research

6.1. Deficiencies

Although some progress has been made in the research and application of prefabricated prestressed fish belly beam steel support technology, there are still some deficiencies. At present, the research on the applicability of this technology in complex engineering needs to be strengthened, especially in deep and large foundation pit engineering, and the application experience is relatively small [11]. There is a lack of systematic research and practical experience in complex geological conditions, such as deep soft soils, karst areas, etc., as well as the application of extremely complex surrounding environments, such as close proximity to historical buildings and important municipal facilities. The design and construction deformation control standards need to be further improved, and the current standards may not be able to meet the actual needs of the project in some special cases. The dynamic feedback system based on monitoring data is not mature enough, and it is difficult to realize real-time optimization and precise control of the support system. In addition, there is insufficient research on the long-term performance of the support system, such as the prestress loss during long-term use and the influence of material aging on structural properties, which makes it difficult to accurately evaluate its reliability in the long-term use process.

6.2. Future Research Directions

Future research should focus on strengthening the applied research under complex engineering conditions. By carrying out more field tests and numerical simulations, the applicability of the technology in deep and large foundation pits, complex geology and surrounding environments is deeply studied, and rich engineering cases and data are accumulated to provide a more reliable basis for design and construction. Further improve the design and construction deformation control standards, combined with practical engineering experience and advanced monitoring technology, formulate a more scientific, reasonable and comprehensive

standard system to ensure that the deformation of foundation pits can be effectively controlled in various complex situations. Strengthen the research on the interaction mechanism of fish belly beam-enclosure pile-soil, establish a more accurate calculation model, consider the nonlinear characteristics of soil, pile-soil interaction and the collaborative work between the support system and the soil, and improve the accuracy of design calculation. Combined with intelligent technology, the monitoring and early warning system is further optimized. Using big data, artificial intelligence and other technologies, real-time analysis and prediction of monitoring data can be realized, potential potential safety hazards can be found in time, and the parameters of the support system can be automatically adjusted to achieve real-time and accurate control of foundation pit engineering. Strengthen the monitoring and research of the long-term performance of the support system, establish long-term monitoring stations, track and analyze the impact of prestress loss, material durability and other factors on the structural performance, and formulate corresponding maintenance and reinforcement measures to ensure the safety and reliability of the support system in the long-term use process.

7. Conclusions

As a new type of deep foundation pit support technology, prefabricated prestressed fish belly beam steel support has shown many advantages in research and application in recent years. Its structure composition is reasonable, the working principle is clear, which can effectively control the deformation of the foundation pit and ensure the safety of the surrounding environment. The application examples in different geological conditions and complex surrounding environments show that the technology has good adaptability through reasonable design and construction. At the same time, its superiority in informatization, safety redundancy, energy saving, emission reduction and economic benefits makes it meet the development needs of modern construction engineering. The study of its mechanical deformation characteristics also provides important theoretical support for engineering design. However, there are still deficiencies in the applicability of complex engineering, design and construction standards and long-term performance studies. In the future, it is necessary to strengthen relevant research and continuously improve this technology to promote its wider application in deep foundation pit engineering and provide

more reliable technical support for the development and utilization of urban underground space. In the future research and practice, it is necessary to closely combine the actual engineering needs, continuously explore and innovate, solve the existing problems, and make the prefabricated prestressed fish belly beam steel support technology play a greater role in the field of deep foundation pit engineering.

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