Innovative Prestressed Support System applied to the Excavation

Zhang Qiang
GuangDong construction vocational technology institute, Guangzhou, Guangdong, 510440, China
Corresponding author’s e-mail: 654746715@qq.com

Abstract: A new kind of work method, Innovative Prestressed Support System, or IPS is based on the prestressed beams from the belly of the fish, a gusset, column, bar, beam, triangular contacts and other standard components combination, which is constituted by prestressing effective support system and three-dimensional plane prestressed support structure. IPS engineering methods to improve the rigidity and stability of the entire excavation system can precisely control lateral displacement control pit deformation. This paper introduces the principle and process Lenticular Beam Prestressed instrumental combination support system, combined with the actual project case study on a subway line network operation and management command center excavation detailed description of the specific operating points and difficulty of the construction method, bit similar projects for reference.

1. Principle and process

1.1. Principle
Innovative Prestressed Support System mainly adopts prestressing the steel strands, angle braces and oppbraces on the fish belly beam chords. Under the prestress, the combination of angle braces, opposite braces and triangular link points are mutually connected forms a support system to effectively control the deformation of the foundation pit slope.

The fish belly beam after prestressed treatment can control the deformation through the combination of special joints and diagonal braces and angle braces after prestressed treatment. The applied prestress will make the envelope structure produce the advanced displacement to the outside of the foundation pit, which leads to the passive earth pressure produced by the soil outside the pit. During the excavation process, the passive earth pressure is gradually converted into the active earth pressure, so as to offset part of the displacement and effectively control the displacement of the foundation pit.

After the fish belly beam is assembled, the fish web beam will be deformed into the foundation pit by the earth pressure and water pressure outside the foundation pit, the steel strand will be prestressed by the jack, and the tensioned steel strand will produce the reaction force to the supporting web member of the fish belly beam, and transmit it to the steel waist beam, so that the steel waist beam will have a large reverse bending moment. With the excavation of the foundation pit, the bending moment generated by the prestress will be gradually offset by the external bending moment transmitted by the retaining pile. When the foundation pit is excavated to the bottom, the bending moment and deformation of the steel waist beam can be controlled within the safe range, and the force diagram of the fish belly beam is shown in Figure 1.
1.2. Process flow
Innovative Prestressed Support System is composed of prefabricated parts such as fish belly beam, angle brace and profile steel opposite brace. The system is composed of various types of standard parts, auxiliary parts, etc. by bolt connection. The composition form is shown in Table 1, which has the characteristics of convenient installation and quick disassembly.

| Composition form | Description                                                                 |
|------------------|-----------------------------------------------------------------------------|
| opposite brace + fish belly beam + opposite brace | Each support force can be a single-layer section steel stress system, |
| opposite brace + fish belly beam + angle brace     | It can also be a double-layer section steel stress system                  |
| angle brace + fish belly beam + angle brace         |                                                                             |

IPS is a prefabricated component, which is assembled on site. The construction process is shown in Figure 2.
2. Calculation of the main components of IPS

2.1. Calculation of waist beam
The waist beam in IPS is a two-way bending member. The main loads are structural self-weight, water and earth pressure in the horizontal direction, and the horizontal load of the steel strand. Considering the most unfavorable load combination, the calculation formula is as follows:

\[
\sigma_{bcx} = \frac{M_{\text{max},tr}}{W_x} \tag{1}
\]

\[
\sigma_c = \frac{N_{\text{max}}}{A} \leq f \tag{2}
\]

\[
\frac{N_{\text{max}}}{A} + \frac{M_{\text{max},tr}}{\gamma_x W_x} + \frac{M_{\text{max},y}}{\gamma_y W_y} \leq f \tag{3}
\]

\[
\frac{N_{\text{max}}}{\varphi_x A} + \frac{\beta_M M_{\text{max},tr}}{W_x (1 - \varphi_x)} + \frac{\beta M_{\text{max},y}}{W_y} \leq f \tag{4}
\]

In the above formula: \(\sigma_{bcx}\) is the bending normal stress; \(\sigma_c\) is the compression normal stress; \(A\) is the section cross section area, and \(\gamma_x\), \(\gamma_y\) is the x-axis and y-axis respectively Section plastic coefficient; \(\varphi_x\) is the stability factor of the axial compression member; \(\beta_{mx}\), \(\beta_{ty}\) is the equivalent bending moment coefficient, \(N_{Ey}\) is the component parameters.

2.2. Calculation of steel strand
The steel strand is made of high-strength material, and its basic calculation parameters are: standard value of ultimate strength \(f'_{ptk} = 1860\text{N/mm}^2\), sectional area of steel strand \(A=140\text{mm}^2\), and design value of tensile strength of one steel strand is 184.8kN. The pre-stressed tension adopts jack, and the determination of Jack tension is based on the external water and soil side pressure, the distance between supporting webs, the angle between steel strand and waist beam and other parameters. The required quantity of steel strand shall be calculated according to the tensile force of each strand and its tensile design value, and the safety factor of 1.1 ~ 1.2 shall also be considered.

2.3. Calculation of support web
The supporting web of IPS is a compression bending member. The web directly bears the self weight load of the structure. The horizontal concentrated load generated by horizontal tension of steel strand, the reaction force generated by the stress on the waist beam, and the vertical projection force of the diagonal tie rod can be calculated according to the eccentric compression design.

3. Engineering example application

3.1. Project Overview
The construction site of the project is divided into three blocks: South, North and East. The North block consists of podium building and two super high-rise towers. The podium building consists of shops (5
floors) and COCC (6 floors). The two towers are subway command center building (45 floors) and business office building (28 floors). The South plot is a business office building (27 floors) with podium (6 floors). The East plot is a public transportation construction site with an underground floor. The whole project is equipped with 3 basements, The buried depth of the basement is 15.6m, part of which is 10.4m and 7.2m. Pile foundation is proposed to be used for high-rise tower, and pile foundation or shallow foundation is proposed to be used for podium and basement. The road on the north side is the urban main road with a width of 60m, and the red line of the road is about 15-18m from the basement. The road on the east side is a planned road with a width of 70m, and the red line of the road is about 50m from the basement. The supporting structure of the foundation pit is designed as temporary structure, and the effective service life is the completion of the main works.

The South plot (area B) adopts the foundation pit support design scheme, which adopts IPS technology, there are two internal supports, and each support is a double-ply composite structure (connecting the upper and lower two floors through a secondary beam)) Forced together.

3.2. Support system design
The maximum span of buttress is 74.8m, and the span of the intermediate steel column is 12.3m. The maximum span of fish web beam is 35m. 10.9 grade high-strength bolt and nut (M24 * 80mm) are used to install the bracket and support beam on the section steel column between the members. after the prestress is applied to the opposite brace, angle brace and fish web beam, all the connecting bolts are tightened with special tools.

The specific method adopted by the support system is opposite brace (∗×3) + 35m span fish belly beam (∗×12) + 29m span fish belly beam (∗×2) + 18m span angle brace (∗×1) + 22m span angle brace (∗×1). The specific layout of the support system is shown in Figure 3 to figure 4.

![Fig.3 The column plan](image1)
![Fig.4 The support system floorplan](image2)

3.3. Key points of construction technology

3.3.1. Column construction
The setting out of sample pile construction shall be carried out in strict accordance with the standards. After the setting out is completed, cast-in-place piles shall be poured, and the positioning points shall be placed after the site is leveled. After the insertion is completed, the verticality of pile body shall be tested, and the deviation of verticality shall meet the design requirements. The pile construction of the column adopts the rotary excavation cast-in-place pile inserting section steel.
3.3.2. Corbel construction
Before the bracket welding, the concrete protective layer at the connection of cast-in-place pile shall be completely removed to expose 2 or 3 main reinforcements to facilitate the welding of bracket. For the steel bracket after welding, it is necessary to check the firmness and reliability of the triangle connection part. It is required that the welding is firm and stable enough.

3.3.3. Bracket and support beam installation
There are strict requirements for verticality in the installation of bracket parts. After the installation of the bracket, the bracket component shall be closely linked with the column pile.

3.3.4. Corner brace installation
In the connection process of partial angle brace, if there is more space when the component is placed, the steel plate with considerable thickness must be used to pad and weld firmly, so as to prevent the displacement of the supporting structure after the stress.

3.3.5. Lenticular Beam installation
During prestressed tensioning, the tension line of the jack and the axis of the prestressed reinforcement shall be consistent. The difference between the actual value of the elongation value and the theoretical value must meet the design requirements. The difference between the two values is required to be controlled within ±5% in the project.

3.3.6. Bracing installation
Two or four-point lifting should be used when the supporting brace is in place. The lifting point should be controlled at 0.2L from the end point.

3.4. Foundation pit deformation monitoring
After the completion of the prestressed fish belly beam tool type combined internal support system, the whole process of foundation pit excavation is monitored by a third-party organization, and the monitoring results are shown in Table 2.

| Monitoring project                                      | Location                      | Measured value | Design alarm value |
|--------------------------------------------------------|-------------------------------|----------------|-------------------|
| Maximum accumulated lateral displacement of retaining  | Southwest of foundation      | 12.53mm        | 24mm              |
| structure of foundation pit                             | pit                           |                |                   |
| Maximum accumulated horizontal displacement of the top   | Northeast side of foundation  | 9.56mm         | 24mm              |
| of retaining structure                                  | pit                           |                |                   |
| Maximum accumulated vertical displacement of the top of | The third support on the      | 4.70mm         | 24mm              |
| retaining structure                                     | west side of foundation pit   |                |                   |
| Cumulative maximum axial force of steel bracing         | Inner bracing of the first    | 1730.85kN      | 3200kN            |
|                                                        | floor on the north side of    |                |                   |
|                                                        | the foundation pit            |                |                   |
| Maximum accumulated deformation of horizontal           | Northwest of the third pit    | 15.79mm        | 24mm              |
| displacement monitoring data of steel brace            | of the foundation pit          |                |                   |
| Maximum accumulated deformation of vertical displacement| Purlin on the west side of    | 13.66mm        | 24mm              |
| monitoring of fish web beam                             | the third span of             |                |                   |
|                                                        | foundation pit                |                |                   |
It can be seen from the above table that the horizontal displacement, settlement, and cumulative axial deformation of the support beam and the supporting brace are relatively small, no abnormality is found in the monitoring process, and the maximum value of all displacement and deformation does not exceed the alarm value, which is in a safe and controllable state during the monitoring period.

4. Conclusion
The IPS prestressed fish belly beam tool-type combined internal support system can effectively control the displacement and deformation of the foundation pit. The whole support system does not need to be poured and maintained. It is completely an assembly construction process, thus reducing the construction difficulty, speeding up the progress, and ensuring the quality. The components of the whole support system can be reused multiple times without causing waste of materials. It is superior to the traditional reinforced concrete support system in terms of safety, quality and progress, and has a broad application prospect, providing necessary technical reference for similar projects. At the same time, it should also be noted that because the IPS construction method is still a new construction method and lacks relevant specifications and technical standards, the realization of fine and standardized construction is the future development direction of IPS construction method.

Acknowledgments
This article was financially supported by the Guangdong Natural Science Foundation (Grant NO.2014A030310272).

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