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Research on Construction Technology of Comprehensive Support and Hanger for Finished Mechanical and Electrical Pipelines Based on BIM

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Abstract. With the development of the construction industry, modern buildings have gradually put forward higher requirements in terms of safety, beauty, ease of operation and maintenance, and renovation and upgrading. The construction of comprehensive supports and hangers is simple, and is generally completed before pipeline construction. It can avoid the complicated process of installing supports and hangers during the construction process. The pipeline layout is clear and concise, which not only effectively utilizes space and improves work efficiency, but also has advantages in reducing steel consumption and reducing construction costs. With the development of technology, supports and hangers have evolved from the original single variety to the current diversification, from the original single constant force supports and hangers to the later elastic supports and hangers and restrictive supports and hangers. Comprehensive support and hanger technology is to coordinate the planning of pipelines, bridge supports and hangers for building water supply and drainage, ventilation and air-conditioning, fire protection, and electrical specialties and integrate several specialties into one system, so as to meet the needs of various specialties for supports and hangers under the premise of ensuring the construction requirements of each specialty, and realize the reasonable allocation of installation space and resource sharing.

Keywords. Electromechanical pipeline, comprehensive support and hanger, mechanical analysis, construction technology

1. Introduction

At present, the design and construction processes and methods in the industry, the bracket design content is usually not included in the scope of work of the design institute, and the design and construction drawings are all designed based on a single discipline to achieve system functions. The construction party can only perform single-professional single-pipe installation and construction based on this drawing, and cannot use a comprehensive bracket system. The quality of comprehensive support and hanger calculation review software on the market varies. Mature large-scale finite element calculation software has high requirements for professional skills, complex modeling

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process, and low work efficiency; some BIM software plug-ins have calculation review functions, which can be used for modeling and force analysis. The finished bracket involves a wide range of specifications and models of materials and accessories, and the assembly method is complex. The quality of construction and installation is uneven, and there is no convenient and intuitive method to detect the installation quality.

This paper focuses on the current development characteristics of finished support and hanger brackets in my country, the current status of installation technology, the research status of related projects at home and abroad, and the problems that are prone to occur in current electromechanical engineering. Based on the collection of literature related to bracket selection and verification, this paper takes engineering as an example to study the convenient method of bracket point arrangement, summarizes the bracket selection specifications with reference to relevant bracket verification software, and studies the management method of controlling the construction of finished brackets based on mechanical analysis.

2. Comprehensive Support and Hanger BIM In-Depth Layout Analysis

2.1. Principles of Comprehensive Layout of Pipeline BIM

Pressurized pipes give way to unpressurized pipes, small pipes give way to large pipes, and round pipes give way to rectangular pipes. The collision points are arranged in layers to ensure the functional use of the space and the reasonable and beautiful layout of the pipelines [1]. After the equipment and pipeline parameters are determined, the detailed design is completed before construction. The BIM software is used to overlay the professional drawings to find the collision points of the pipelines and equipment. The colliding pipelines and equipment are adjusted to avoid pipelines passing through public areas such as driveway entrances and exits or being laid in rows against walls. The elevation and direction of the pipelines and equipment are consistent, and the layout is reasonable and maintenance is convenient.

Main pipelines should be arranged in public areas as far as possible and should not be arranged indoors. No pipelines should be arranged at the downwind and side wind outlets. Pipelines should be avoided by making use of beam recesses as far as possible, and reserved insulation space for air ducts and water pipes [2] [3]. Pipelines should be arranged horizontally first. When horizontal arrangement is difficult, they should be arranged in the same vertical direction with the bridge frame on top and the water pipes on the bottom. Comprehensive coordination should be made to utilize the available space to ensure that there is as much operating space as possible for construction and maintenance. A certain distance should be left between the high-voltage bridge frame and the low-voltage wire duct to avoid mutual interference. They should be arranged on both sides of the corridor as far as possible. To avoid electromagnetic field effects, the distance between the two should not be less than 300mm. If the bridge frame needs to be bent to avoid, the low-voltage bridge frame should avoid the high-voltage one [4]. When the width of the air duct and drainage pipe is not less than 1200mm, sprinklers should be arranged 150mm below the pipe to meet fire protection requirements.

2.2. Pipeline BIM Comprehensive Layout

Use BIM to perform 3D modeling and check the construction space conditions of supports, pipes, and bridges. There may be situations where the supports collide with pipelines, the supports block the branch pipelines, or the support space is not suitable for pipeline construction. Fine-tune each one in the 3D model to determine the final point position [5].

The setting interval of multi-system integrated bracket is 2m. One set of bracket can be used to install air ducts, water pipes, bridge frames and other pipelines. The integrated bracket can also be used to install multiple pipelines of single profession separately. All integrated brackets are rooted by connecting the channel steel base with rear-expanded bottom anchor bolts, and the channel steel base is equipped with channel steel column connection method.

Independent air ducts, bridges, water supply and drainage, fire protection pipes, or multiple bridge combinations with smaller loads, bridge and air duct combinations and other pipelines can be installed with single-system finished product brackets. Single-system finished product brackets are divided into flexible brackets (the vertical poles are screw rods) and rigid brackets (the vertical poles are C-shaped steel). The comprehensive bracket spacing is set according to table 1.

Table 1. Comprehensive support layout table.

Serial number	Pipeline system name		Bracket arrangement spacing /m	Bracket Type
1	Air duct	Width≤ 500 mm	2	Flexibility
		Width ＞ 500mm	2	Rigid and flexible alternating arrangement
2	Bridge	Width ≤ 200 mm	2	Flexibility
		Width ＞ 200 mm	2	Rigid and flexible alternating arrangement
3	water pipe	Diameter ≤ DN65 mm	3	Flexibility
		Diameter ＞ DN65mm	3	Rigid and flexible alternating arrangement

2.3. BIM Deepening Results Display

BIM model of the comprehensive layout of basement pipes, see figure 1 and figure 2.

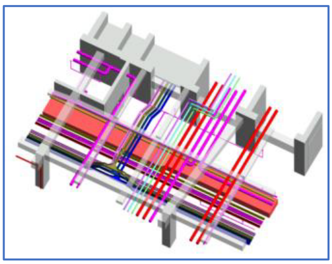

Figure 1. Basement pipe complex BIM model 1.

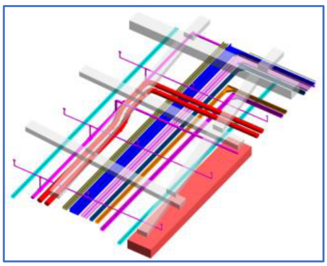

Figure 2. Basement pipe complex BIM model 2.

3. Comprehensive Support and Hanger Selection Theory

The selection calculation is based on the ultimate limit state design method based on probability theory [6]. The combination of variable load effect control is calculated using the following formula:

$$S_d = \sum_{j=1}^{m} \gamma_{Gj} S_{G_{jk}} + \gamma_{Q_1} \gamma_{L_1} S_{Q_{1k}} + \sum_{i=2}^{n} \gamma_{Q_i} \gamma_{L_i} \psi_{ci} S_{Q_{ik}}$$

γ_{Gj}—When it is unfavorable to the structure, take 1.2; when it is favorable to the structure, take 1.0;

γ_{Q_1} or γ_{Q_i} value, generally 1.4.

Combinations controlled by permanent load effects:

$$S_d = \sum_{j=1}^{m} \gamma_{Gj} S_{G_{jk}} + \sum_{i=1}^{n} \gamma_{Q_i} \gamma_{L_i} \psi_{ci} S_{Q_{ik}}$$

γ_{Gj}—When it is unfavorable to the structure, the value is 1.35; when it is favorable to the structure, the value is 1.0;

γ_{Gj} or γ_{Q_i} value, generally 1.4.

4. Mechanical Analysis and Verification of Comprehensive Supports and Hangers

The calculation model is shown in figure 3, and its corresponding axial force distribution is shown in figure 4, shear force distribution is shown in figure 5, bending moment distribution is shown in figure 6, displacement distribution is shown in figure 7, and support reaction force distribution is shown in figure 8.

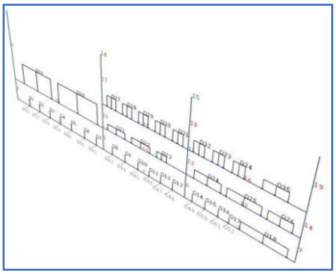

Figure 3. Calculation model diagram.

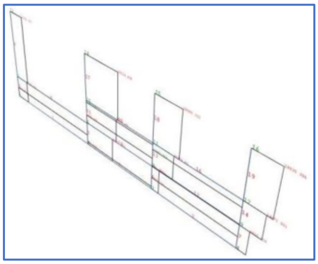

Figure 4. Axis force diagram.

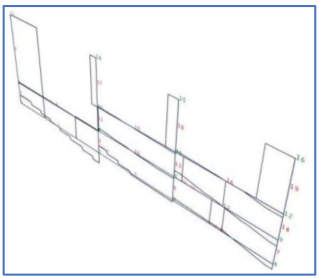

Figure 5. Shear force diagram.

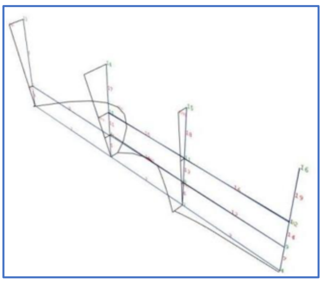

Figure 6. Bending moment diagram.

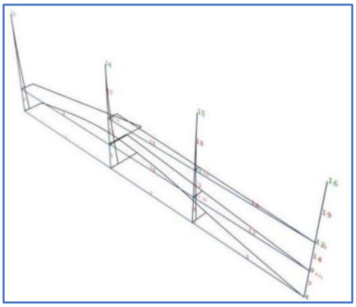

Figure 7. Displacement diagram.

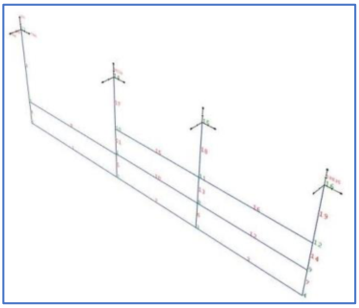

Figure 8. Reaction diagram.

4.1. Span Verification

Maximum span of integrated support calculated according to strength conditions:

$$L_{max} = 0.1 \times \sqrt{(\frac{1}{q} \times W_p \times [\sigma]^t)}$$

Calculated: $L_{max} = 8.225m$

Maximum span of integrated support calculated according to stiffness conditions:

$$L_{max} = 0.048 \times \sqrt{(\frac{1}{q} \times E_t \times [L_p]^t)}$$

Calculated: $L_{max} = 5.844m$, Conclusion: Satisfy the requirements

4.2. Cross Arm Verification

Each load effect combination is divided into basic combination and standard combination, among which the basic combination model is:

$$S_{d1} = \gamma_0 \left[\sum_{i \geq 1} (\gamma_{Gi} \times DL_{ik}) + \gamma_{Q1} \times \gamma_{L1} \times LL_{1k} + \sum_{j \geq 1} (\gamma_{Qj} \times \psi_{cj} \times \gamma_{Lj} \times LL_{jk}) \right]$$

The standard combination model is:

$$S_{d3} = \left[\sum_{i \geq 1} DL_{ik} + LL_{1k} + \sum_{j \geq 1} (\psi_{cj} \times LL_{jk}) \right]$$

Tensile /compression bending strength verification:

$$\frac{N}{A_n} \pm \frac{M_x}{\gamma_x W_{nx}} \pm \frac{M_y}{\gamma_y W_{ny}} \leq f$$

in: $\gamma_x = 1.05$, $\gamma_y = 1.2$, $\sigma = 209.96 < 215$, fulfil requirements.

Shear strength:

$$\tau = \frac{VS}{It_w} \leq f_v$$

$\tau_x = 26.83 < 125N/mm^2$, fulfil requirements.

$\tau_y = 7.34 < 125N/mm^2$, fulfil requirements.

Local pressure:

$$\sigma_c = \frac{\psi \times F}{t_w l_z} \leq f$$

in: $\psi = 1$, $\sigma_c = 4.91 < 215\mathrm{N/mm^2}$, fulfil requirements.

Comprehensive stress:

$$\sqrt{\sigma^2 + \sigma_c^2 - \sigma \times \sigma_c + 3 \times \tau^2} \leq \beta_1 f$$

in: $\beta_1 = 1.1$, $84.67 < 236.5\mathrm{N/mm^2}$, fulfil requirements.

Stability:

$$\frac{M_x}{\varphi_b W_x f} + \frac{M_y}{\gamma_y W_y f} \leq 1.0$$

in: $\gamma_y = 1.2$, $\varphi_b = 0.77$, $\sigma_w = 9.44 < 1$, fulfil requirements.

Deflection:

$f \leq L/200$. Result: $1.68 < 12.05$, fulfil requirements.

4.3. Pole Verification

Stiffness:

$$\lambda = \mu l/i \leq 400$$

in: $\mu = 1$ $\lambda = 57.06 < 400$, fulfil requirements.

Tensile /compression bending strength:

$$\frac{N}{A_n} \pm \frac{M_x}{\gamma_x W_{nx}} \pm \frac{M_y}{\gamma_y W_{ny}} \leq f$$

in: $\gamma_x = 1.2$, $\sigma = 209.16 < 215$ fulfil requirements.

Shear strength:

$$\tau = \frac{VS}{It_w} \leq f_v$$

$\tau_x = 1.57 < 125\mathrm{N/mm^2}$, fulfil requirements.

$\tau_y = 3.52 < 125\mathrm{N/mm^2}$, fulfil requirements.

4.4. Weld Strength Acceptance

According to the formula of GB 50017-2017 Steel Structure Design Standard:

$$\sigma_f = \frac{N}{h_e l_w} \leq \beta_f f_f^w$$

According to the formula of GB 50017-2017 Steel Structure Design Standard:

$$\tau_f = \frac{N}{h_e l_w} \leq f_f^w$$

According to the formula of GB 50017-2017 Steel Structure Design Standard:

$$\sqrt{\left(\frac{\sigma_f}{\beta_f}\right)^2 + \tau_f^2} \leq f_f^w$$

in: $\beta_f = 1.22$, $f_f^w = 160$.

Positive stress $\sigma = 99.631 < 195.2\mathrm{N/mm^2}$, meets the requirements.

Shear stress $\tau_f = 3.949 < 160\mathrm{N/mm^2}$meets the requirements.

Reduced stress $\sqrt{\left(\frac{\sigma_f}{\beta_f}\right)^2 + \tau_f^2} \leq f_f^w = 81.761 < 160\mathrm{N/mm^2}$meets the requirements.

Select a node

in: $\beta_f = 1.22$, $f_f^w = 160$.

Positive stress $\sigma = 46.114 < 195.2\mathrm{N/mm^2}$, meets the requirements.

Shear stress $\tau_f = 0.123 < 160\mathrm{N/mm^2}$meets the requirements.

Reduced stress $\sqrt{\left(\frac{\sigma_f}{\beta_f}\right)^2 + \tau_f^2} = 37.798 < 160\mathrm{N/mm^2}$meets the requirements.

4.5. Anchor Bolt Verification

Anchor bolt arrangement:

The anchor bolts are arranged horizontally, the anchor bolt specification is M18, and the number of anchor bolts is 8, with a spacing in the X-axis direction $L_1 = 198\mathrm{mm}$and a spacing in the Y-axis direction $L_1 = 101\mathrm{mm}$.

Acceptance of shear composite strength:

$$\left(\frac{N_{\mathrm{sd}}}{N_{\mathrm{Rd,s}}}\right)^2 + \left(\frac{V_{\mathrm{sd}}}{V_{\mathrm{Rd,s}}}\right)^2 \le 1$$

in: $N_{\mathrm{Rd,s}} = 38170.351 \ \ V_{\mathrm{Rd,s}} = 19085.175$

$Result$: $0.497 < 1.000$, fulfil requirements

5. Research on the Application of Finished Product Comprehensive Support and Hanger Technology

5.1. Installation Requirements

For supports with slope requirements, the height difference between the front and rear supports needs to be calculated. If the height difference is less than 50 mm, the support height can be adjusted by cutting the length of the support pole. When the height difference is ≥ 50 mm, the height of the middle support is calculated by interpolation [7].

If the location or elevation of the on-site structure differs from the drawings, the material cutting size shall be based on the actual size.

All C-channel steels are cut to size in the cutting area. For single-sided channel steel, the opening is cut downward. The cutting speed should be appropriately increased to avoid deformation caused by overheating of the cutting surface; the cutting position of the C-channel steel of the bracket cross arm should be set as far as possible at the 5cm scale on the back of the channel steel to retain the complete back hole of the channel steel, which is convenient for the through-through installation of the screw in the subsequent process.

After cutting the C-channel steel, a grinding wheel should be used to trim the burrs to prevent scratches on the installers and affect the appearance quality during the installation process.

There are many and densely packed pre-buried pipelines on the top of underground space. Often, a lot of damage will occur during the installation of supports and hangers, which will require the use of exposed wiring pipes for later treatment, which will affect the overall visual quality. Traditional electromechanical integrated pipeline installation usually involves installing supports and hangers first, followed by the installation of wire pipes. This takes a long time to complete and poses safety risks such as falling from heights [8]. Integrated support and hanger technology can achieve reasonable allocation of installation space and resource sharing. For specific construction processes, see figure 9.

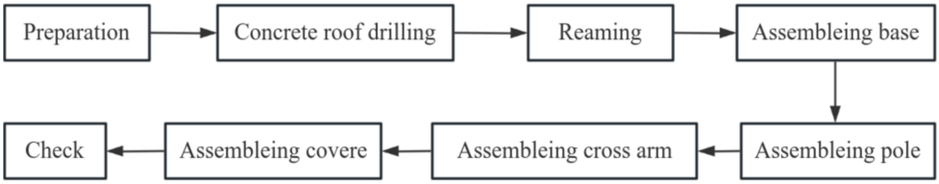

Figure 9. Comprehensive Support and Hanger Construction Process Flow Chart.

5.2. Measurement and Positioning

Carry out measurement and positioning work according to the design drawings and the actual situation on site. Mark the locations where pipes, bridges, air ducts, etc. need to turn, and leave space for the installation of suports and hangers.

5.3. Bracket Installation

Locate the bracket positions at the two ends of the same row of brackets, then use these two points to draw the line and position the other brackets according to the bracket spacing [8]. For brackets with slope requirements, it is necessary to calculate the design height difference between the first and last brackets. If the height difference is less than 50mm, the bracket height can be adjusted by cutting the length of the bracket pole; if the height difference is greater than or equal to 50mm, the height of the middle bracket needs to be calculated by interpolation.

The location or elevation of the on-site structure is different from the drawing, the material cutting size should be based on the actual size. All C-channel steels are cut to size within the cutting area. The cutting position of the bracket cross arm C-channel steel should be set at the 5 cm scale on the back of the channel steel as much as possible to retain the complete back hole of the channel steel, which is convenient for the subsequent screw installation. After the C-channel steel is cut, the burrs should be trimmed with a grinding wheel to prevent scratches on the installers and affect the appearance quality during the installation process.

5.4. Installation of Vertical Bars, Horizontal Bars, Connectors and other Accessories

After the nut is inserted into the C-channel steel mounting surface, rotate the lock 90° and loosen it so that the lock teeth are aligned and engaged with the C-channel steel crimping teeth [9].

Place the connector and pre-tighten it with the hexagonal bolts. Tighten the nuts with a wrench, and control the torque to about 50N.m.

For gantry supports with a width greater than 1.5 meters, the support crossbars should be installed at the location of the support after the support uprights are positioned and installed on site. It is not advisable to install the complete gantry support in the processing plant and then transport it to the site for installation.

5.5. Installation of Pipe Clamps and Pipe Accessories

During the initial tightening, the rubber strip needs to be pressed down to contact the pipe wall and then the pipe is adjusted. After adjustment, tighten the bolts until all rubber parts are in close contact with the pipe, and the installation is complete [10]. The screw rod is firmly screwed into the connecting screw hole on the upper part of the pipe clamp. The screw rod is screwed in for more than three threads.

6. Conclusion

This paper uses computer software to realize the automatic arrangement and point verification of comprehensive supports and hangers, which reduces a lot of manpower and time costs. By comparing the force verification results of theoretical mechanics with those of software, it is verified that BIM software has the function of bracket force verification, but the verification process ignores some comprehensive factors. In the actual application process, professionals are required to add corresponding coefficients for adjustment. Comprehensive application greatly improves the verification efficiency and simplifies the verification process.

By using BIM software to carry out in-depth layout, establish calculation models, perform span verification, and verify the strength, shear resistance, local strength, comprehensive stress, and stability of crossarms, vertical poles, and anchor bolts, the welding strength verification meets the requirements of national and relevant specifications.

The construction process involves factory prefabrication and assembly construction, which can greatly improve productivity, change the working environment, reduce safety accidents and project costs, and improve project quality.

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