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Safety control of hydraulic self-climbing formwork in south tower construction of Taizhou Bridge

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Abstract

Hydraulic self-climbing formwork has the advantages of self-climbing, easy operation, less operating personnel, and good appearance quality, with relatively mature construction techniques and technology, and so has been widely used in many large and medium projects. Its operating platform and climbing system are as a whole, and the overall pressure-driven device can achieve even climbing, and therefore can markedly improve its safety performance. However, hydraulic self-climbing formwork with a complex and bulky structure is still the focus of construction safety control. There is a great safety risk in the process of operation and use, such as its installation and dismantling, adjustment of position, which is prone to lead to template collapse, fall from high places, and strike against objects, etc. Taizhou Bridge introduced hydraulic self-climbing formwork system during the construction of South-Tower, and achieved good results through a series of effective security control measures. This paper, South Tower of Taizhou Bridge as background, analyzed the major risk factors in the construction of hydraulic self-climbing formwork, and proposed corresponding control measures, which can play a good reference for similar projects.

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1. Introduction

Hydraulic self-climbing formwork can climb as a whole characterized with stable motion, high safety-performance and fast speed, and so can decrease the labor intensity effectively. Hydraulic self-climbing formwork adopts the standardized wood system with the advantages of high stiffness and light weight, and can be easy to install, calibrate and dismantle. In addition, the concrete built by hydraulic self-climbing formwork has a more smooth surface and alignment. Nowadays, hydraulic self-climbing formwork has been widely used in the construction of large bridge engineering, such as Runyang Bridge, Sutong Bridge, and so on[1-3].

Taizhou Bridge lies among Taizhou city, Zhenjiang city and Changzhou city along the Yangtze River, with 62 kilometers long approximately. Its total investment is about 9.37 billion RMB, and the construction period is five and a half years. The main bridge adopts the suspended cable structure with three towers and two spans, and is mainly consisted by five parts, namely: North Anchor, North Tower, Middle Tower, South Tower, and South Anchor[4-6]. And South Tower with 180m height, is consisted of two bilateral symmetry limbs and two parallel beams which is made of reinforced concrete structure, as shown in Fig.1.

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In order to speed up the construction progress and improve the concrete appearance quality, South Tower adopted 2 advanced DOKA hydraulic self-climbing formworks for pouring construction. The pouring construction consists of 39 construction section with 4.5 m in height for each, and the pouring speed is the 30 m$^3$/h. In this paper, the major hazardous factors in the construction of hydraulic self-climbing formwork were analyzed, and corresponding safety control measures were proposed.

2. Brief introduction of hydraulic self-climbing formwork

2.1. Characteristics and advantages

Besides the traditional characteristics of slide template and large template, Hydraulic self-climbing formwork has the new advantages of faster construction, simple operation, and etc. The main advantages are highlighted in the following aspects: (a) The concrete poured by Hydraulic self-climbing formwork, has a high quality of smooth surface and corner seams; (b) Hydraulic self-climbing formwork with the operation platform and climbing system into one system has traits of whole compact mechanism and easy operation; (c) The overall equipment can climb freely, conveniently driven by the hydraulic climbing device[7].

2.2. Formwork structures

The new Hydraulic self-climbing formwork consists of large scale formwork system, climbing system and steel structure work platform, as shown in Fig. 2. The large scale formwork system is linked with the whole system by using the steel structure; the formwork set 6 operation platforms; each platform is connected by a fixed staircase. The platform set some fire prevention board devices and the hydraulic oil cylinder assembles the safe equipment which can prevent oil pipeline rupture[8].

2.3. Process flow

The process flow of hydraulic self-climbing formwork is as shown in Fig. 3.
3. Hazardous factors identification

Hydraulic self-climbing formwork has the operating platform and climbing system as a whole, and the overall pressure-driven device can achieve even climbing. As a result hydraulic self-climbing formwork has markedly improved its safety performance. However, hydraulic self-climbing formwork with a complex and bulky structure is still the focus of construction safety control. There is still a great safety risk in the process of operation and use, such as its installation and dismantling, adjustment of position, which is prone to lead to template collapse, fall from height, and strike by objects, etc, especially in the construction of South tower with the elevation of +180m.

3.1. Template collapse

As typical large-scale construction equipment, the collapse accidents of Hydraulic climb formwork occasionally happened due to improper use and operation, such as working procedure of installing, climbing, and removing of the formwork[9].

3.2. Falling from height

The construction of south tower belongs to height operations. And the narrowly height operation space will cause the danger of falling if workers don’t wear the seat belt or use it incorrectly. The falling accident’s consequences would be catastrophic[10].
3.3. Strike by objects

Tools and some small working machines will easily fall when the operating personnel working in a limited operation space, especially during the process of vertical crossing operation, cranes lifting, and ground prefabrication. And these will cause a severe consequence if those tools and machines hit on workers who walk on ground.

4. Safety control of hydraulic self-climbing formwork

4.1. Safety control during the process of preparation

The safety control during the preparation of the hydraulic self-climbing formwork would be focused on the followings.
- Safety schemes programming and technological explanations.
  A targeted, operable safety special scheme should be programmed before construction. In the safety special scheme, the hazardous factors have to be identified, and corresponding safety protection design and management measures should be put forward.
  Before construction, all the relevant managers and workers should participate in the safety education in order to improve their safety awareness and skills, and technological explanations should also be organized to make managers and workers be familiar with the hazardous factors and emergency response measures.
- Preparation of hoisting and installation.
  Hydraulic self-climbing formwork needs a high hoisting precision because the narrow hoisting space in the construction of South Tower. During the hoisting, crashing the existing frame and concrete pillar are forbidden, and the bolt should be tightened timely. Hydraulic self-climbing formwork is divided into four independent frames in four directions. Each frame body should be assembled on the ground in advance and connected firmly. The climb cone should not be attached by the oil things and anchors must be pre-buried correctly.
- Safety acceptance before operation.
  It is important to accomplish the safety acceptance of hydraulic climb formwork before using it. Equipment manufacturers, supervision engineers, owner's representative, and some related experts when necessary, should be invited to inspect the safety function of the formwork system. The inspection should be done according to the original design documents, and the key check points include: component connection point, hydraulic self-climbing devices, and so on. And the welded parts of important components should be conducted by weld flaw detection.

4.2. Safety control during the process of self-climbing

Self-climbing process should strictly comply with the operation procedures. Before self-climbing, it is necessary to clear the all scattered objects and only the workers could stay on the work-platform. During self-climbing, it is necessary to pay special attention to monitor the sliding guide, climbing speed and dynamical system. After reaching a new pendant point, hydraulic climb formwork could come into use only by safety acceptance.
- Self-climbing of sliding guide.
  Before self-climbing of sliding guide, the operation personnel, construction person in charge, and safety officer and other relevant personnel administrator need to be at present. In addition, it is necessary to ensure the concrete strength are over 20MP and all the components and control systems are in good condition.
- Self-climbing of climbing-frame.
  Before self-climbing of climbing-frame, it is important to remove the unnecessary loads, such as reinforced head, oxygen and acetylene empty bottles, and so on. The safety inspection emphasis includes: ① the connection between the long side and short of climbing-frame has been removed; ② the length of main cable suspension is adequate from tower cranes to climbing-frame; ③ all hydraulic components and control systems are in good condition.
- Safety check at the end of self-climbing.
  At the end of self-climbing, the safety inspection emphasis includes: ① The load-bearing pins and safety pins are inserted in place; ② all platform wheels and feet touch the concrete surface tightly; ③ the anchor bolts are tighten, and the corners of the connection parts are solid; ④ the protection facilities for each platform are put in place.

4.3. Safety control during the process of operation

The safety control during the operation of the hydraulic self-climbing formwork is focused on the followings.
- Operating platform protection.
The operating platform must ensure passage unobstructed, and protective rails and safety nets in place. Operating platform protective railing which consisted by two horizontal rails and vertical rails should be installed strictly according to specifications: the height of bottom horizontal rail is 0.5 ~0.6m, the height of top horizontal rail is 1.0 ~1.2m meters high, and the distance between the vertical rails is no more than 2m. In addition, bridging and bracing has also been set in the construction of South Tower.

It is also very important to select the type of the safety net. If using the ordinary dense-mesh net, high-altitude wind will affect the stability of hydraulic self-climbing formwork; if using larger-mesh safety vertical net, it will increase the risk of altitude litter; In addition, the construction has a large number of welding slags, welding flowers which can easily ignite the ordinary safety net. Based on the comprehensive consideration of the above factors, a new kind of new fire-retardant and dense-mesh safety net is adopted in the construction of South Tower.

- Operating load control.
  All the construction loads of hydraulic self-climbing are supported by ten anchor points in four directions. By calculating, the maximum load capacity of work template is 31.5kN/m2, 1.5kN/m2 for the climb device platform, and 1.0kN/m2 for the elevator entrance platform. So it is necessary to reduce additional loads as far as possible, and all the loads are forbidden to pile together.
- High altitude operation management.
  South Tower has the height of 180m and so its construction faces great risk of high altitude operation. All the construction operation must be strictly in accordance with “Construction safety technical specifications for high altitude operation” (JGJ 80–91). Workers in high altitude operation must wear labor protective equipments properly, and begin to work after manager’s consent. The number of workers must be in strict control and the worker should be divided into two classes as far as possible. Special operations personnel need to comply with the operating procedures of special operations, for example, the cranemen must execute the rules of “no lifting for ten occasions”, and welders need to respect the electric welding operating procedures.

5. Conclusions

After six months of construction, the hydraulic climbing formwork of South Tower has accomplished all 38 climbing-operation successfully and guaranteed safety operation with no accidents. The safety control measures of hydraulic climbing formwork in Taizhou Bridge have obtained good effect, and so could be available for similar projects.

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