Discussion on construction checking calculation of high-rise precast shear panel during lifting

Jimin Liu1, Hui Yu2, Pingfan Xu1*

1 Department of architecture and civil engineering, Anhui University of science and technology, Huainan, Anhui, 232001, China
2 Department of engineering management, Huainan vocational technical college, Huainan, Anhui, 232001, China
*Corresponding author’s e-mail: 15545607332@163.com

Abstract. The lifting of precast elements is an important process in precast concrete structure construction, which directly concerns the quality of the building products and the subsequent use of precast elements. Based on the construction codes at home and abroad and some former researches, this paper discusses the construction load value, calculation model and checking calculation contents of shear panel during lifting. Taking the lifting of a high-rise building precast shear panel as the engineering background, combined theoretical analysis with numerical calculation, this paper determines the construction load of the precast shear panel during lifting, checks the maximum tensile stress of concrete, reinforcement stress at the tension section and bending capacity of the section, contracts the lifting design of the two-point lifting and the three-point lifting. Therefore, the conclusion that the two-point lifting is more economical under the premise of ensuring the safety of the lifting point is obtained, and the checking and verification problem of the precast shear panel during lifting is solved.

1. Introduction

Precast concrete structure is a new kind of concrete structure, which is developing rapidly in recent years. With a excellent quality, great productive efficiency, less labor quantity demand, lower noises during construction, it is advocated and developed by our government. At present, our national codes on precast concrete structure’s design, construction, fabrication and acceptance checking have been published and carried out continuously, and so on with local codes[1-6].

The construction process of precast concrete structure mainly consists of precast element fabrication, transportation and storage, installation and connection. And the precast elements’ lifting runs through every construction link, comprises demolding lifting, overturning lifting, transportation lifting and lifting on site etc. In the course of precast concrete structure construction, there occurs some problems in the following: 1) the handling and assembly of heavy precast members, sometimes up to several tons a unit, poses certain safety problems and increase the likelihood of risk both to human operatives or to the semi-completed structure itself, 2) the structure under assembly in its semi-completed state may cause difficulties in making access into the work spot, 3) defective connections may frequently result to cracks and water leakage which will create further maintenance problems.
Therefore, it is so important to discuss the checking calculation problem of precast elements and work out the special scheme of lifting ahead of time.

2. Determination of lifting load
In terms of precast buildings, the load of precast elements during construction is more controllable than the load during normal use. At the beginning of making the special construction scheme of lifting, the lifting load of the precast elements needs to be confirmed. At present, the determination of the lifting load is mainly by multiplying the element's self-weight code value by the related coefficient, that is to say, \( F = \gamma G_k \). Adsorption force is generated between the element and the mould during demolding lifting, and the release coefficient \( \gamma_1 \) should be drawn into. It has a lot to do with the surface condition of the elements and molds. During the process of lifting, dynamic loads and impact forces are also generated, and the dynamic coefficient \( \gamma_2 \) should also be considered. The coefficient \( \gamma_2 \) varies a lot, and has different values in different national codes[7-8], and in China \( \gamma_2 = 1.5 \).

Since de-moulding lifting and element lifting do not occur at the same time, \( \gamma_1 \) and \( \gamma_2 \) do not have to be multiplied. If the demoulding coefficient \( \gamma_1 \) and the dynamic coefficient \( \gamma_2 \) are the same, and the lifting point of the demoulding lifting is consistent with the lifting point of the element during lifting, the demoulding lifting condition is the most unfavorable construction condition. Then just check and verify the demoulding lifting. As a conclusion, in terms of the demoulding coefficient of the precast shear panel in this paper, take the release factor of 1.5, that is, the lifting load values \( F = 1.5 G_k \).

3. Checking the tensile, flexural and crack-resistant bearing capacity of precast elements
The precast concrete structure has higher requirements on the crack resistance of the elements than the ordinary concrete structure. And its tensile strength checking should be controlled according to the cracking resistance. The code [1] and [7] have the same stipulation, that the normal tensile stress of the concrete at the edge of the normal section of the reinforced concrete and pre-stressed concrete elements should meet the requirements.

\[
\sigma_{ct} \leq 1.0 f_{tk}
\]  

(1)

The code [1] further points out that the reinforced concrete elements which allowed to crack during construction can be relaxed at the normal tensile stress limit on the edge of the positive section, but the stress of the tensile reinforcement at the cracked section should be satisfied

\[
\sigma_s = \frac{M_p}{0.87A_p h_0} \leq 0.7 f_{yk}
\]  

(2)

For the checking calculation of the flexural capacity of reinforced concrete elements, the test formula introduced by C.F. Wang [9] can be used:

\[
K = \frac{f_y A_d d_0}{M_D} > 1.26
\]  

(3)

4. Lifting point design and engineering example
The number of lifting points is directly related to the running of lifting, as well as the safety, economy and rationality of lifting work. In determining the optimum position of lifting point of the precast element, two principles are generally observed, 1) to force the various sections of the precast element to be uniform, and the bending moment of the dangerous section is approximately equal, 2) to ensure the stability of the precast element during lifting.

This project is a high-rise residential community project in Binhu Runyuan No. 2 Segment, including 9 high-rise residential buildings, community complex buildings, pension centers, commercial buildings, basements and so on. The building’s area is about 180000 square meters. The main structure of residential buildings is composed of precast composite floors, precast staircases and precast steel sleeve shear panel mostly. Eight domestic QTZ80 tower cranes are used for lifting, and
special construction scheme for lifting should be worked out before construction. The precast shear panel size in this project is $4900 \times 2915 \times 290$ mm, and the weight is $7.923 \text{t}$.

4.1 Theoretical design calculation of two-point lifting and three-point lifting

If the design of two-point lifting or three-point lifting is used, the calculation diagram and its equivalent load, the maximum tensile stress of concrete, the stress of reinforcing bar at the tensile section, and the flexural bearing capacity of positive section are calculated, which is shown in Table 1.

| Calculation content | Two-point lifting | Three-point lifting |
|---------------------|-------------------|---------------------|
| Calculation diagram | ![Diagram](image1) | ![Diagram](image2) |
| Equivalent construction load | $q_e = 1.5 \times 25 \times 10^{-6} \times 2915 = 0.109 \text{N/mm}^2$ | $q_e = 1.5 \times 25 \times 10^{-6} \times 2915 = 0.109 \text{N/mm}^2$ |
| $M_{\text{max}}^+ = \frac{1}{2} q_e t (0.207 \times 1)^2 = 1.63 \times 10^7 \text{Nm}$ | $M_{\text{max}}^+ = \frac{1}{2} q_e t (0.207b)^2 = 8.91 \times 10^6 \text{N-mm}$ |
| Maximum tensile stress of concrete $\sigma_{\text{ct,max}} = \frac{M}{W} = \frac{M_{\text{max}}}{2b^2} = 0.04 \text{MPa} < f_{\text{tk}} = 2.39 \text{MPa}$ | $\sigma_{\text{ct,max}} = \frac{M}{W} = \frac{M_{\text{max}}}{2b^2} = 0.02 \text{MPa} < f_{\text{tk}} = 2.39 \text{MPa}$ |
| The stress of steel at the tension section checking | $\sigma_s = \frac{M_0}{0.87 A_{d_b}} = \frac{8.91 \times 10^6}{0.87 \times 2915 \times 2011} = 17.4 \text{MPa} \leq 0.7 f_{\text{yk}} = 280 \text{MPa}$ | $\sigma_s = \frac{M_0}{0.87 A_{d_b}} = \frac{8.91 \times 10^6}{0.87 \times 2915 \times 2011} = 17.4 \text{MPa} \leq 0.7 f_{\text{yk}} = 280 \text{MPa}$ |
| Flexural bearing capacity checking | $K = \frac{f_{\text{tk}} A_{d_b}}{M_0} = \frac{400 \times 201.1 \times 2915}{1.63 \times 10^7} = 14.3 > 1.26$ | $K = \frac{f_{\text{tk}} A_{d_b}}{M_0} = \frac{400 \times 201.1 \times 2915}{8.91 \times 10^6} = 26.3 > 1.26$ |

Conclusions safety safety

As can be seen from the above Table 1, the concrete elements are safe with two-point lifting and three-point lifting, and the lifting scheme is feasible.

4.2 Ansys numerical analysis of two-point lifting and three-point lifting

The Ansys software is used to establish the numerical calculation model. As the weight of the insulation board is small, it will be ignored here, that is to say, only two materials of steel and concrete are used in the model. And the lifting unit considers three units of concrete, steel and sling, establish a separate finite element model.

Solid65 units are used for concrete materials, link180 units for reinforcing bars, and link10 units for assembled shear wall slings. It is assumed that only the influence of the wall's self-weight and the dynamic coefficient is considered in the lifting. And the dynamic coefficient values 1.5, that is, the gravitational acceleration applied in the vertical direction is $14.7 \text{m/s}^2$. And the precast shear panel is only set the out-of-plane constraint. The calculation model for two-point lifting and three-point lifting is established separately, which is shown in Figure 1.
Calculate the stress of concrete and reinforcing bar in two-point lifting and three-point lifting repeatedly, which is shown in figure 2. The calculation reveals that the tensile stress of concrete at the anchor bolts is small, far less than the tensile strength of concrete at this time, and the concrete is not cracked. The stress of the reinforcing bar is also small and the tensile yield strength has not yet been reached. The shear panel is always in the elastic phase during the lifting process, and the lifting is safe.

4.3 Comparison of theoretical and numerical results
From the above calculation, it can be seen that by theoretical analysis, both two-point lifting and three-point lifting can guarantee the requirements of flexural and crack bearing capacity, and through numerical calculation, the stress distribution of concrete and reinforcing bar near the lifting point is further demonstrated. The forcing state of the lifting point is safe at this moment. The conclusion of theoretical analysis is the same as that of numerical analysis. Therefore, both two-point lifting and three-point lifting can meet the safety requirements of lifting. When considering the economics of lifting, the two-point hoisting should be preferred.

5. Conclusions
The construction checking calculation is an important content in precast concrete structure construction and an important basis for determining the construction scheme. The lifting process of precast shear panel described in this paper is based on the actual engineering, and the calculation
process is detailed. It is an attempt to check the high-rise precast elements, which can be used as a reference for similar projects.

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