Discussion on bearing capacity inspection of prefabricated concrete components

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Abstract. The main inspection projects of prefabricated components are its structural performance inspection. For prefabricated concrete components, its structural performance inspection items include strength index (capacity), stiffness index (deformation) and crack resistance index. This paper described the performance inspection of prefabricated concrete components in detail, discussed the bearing capacity inspection and some suggestions are given. All this can provide references for prefabricated yard, supervision department and quality assurance department.

1. Introduction

The structural performance inspection of prefabricated concrete components has been widely concerned in civil engineering due to which has an important relationship with the masses of people's lives and property. It is the daily work of the prefabrication factory to inspect the structural performance on schedule and in batch. For prefabricated concrete components, its structural performance inspection items including strength index (capacity), stiffness index (deformation) and crack resistance index. Compared with the intermediate quality control link, the structural performance inspection is the final judgment of component quality to a certain extent. The structural performance inspection is systematically specified in code for quality acceptance of concrete structure construction (GB 50204-2015) [1], which can be used by engineers. However, misunderstanding may be occurred due to the value of coefficient in the formula. In this paper, the structural performance inspection of prefabricated concrete components is described in detail, and the bearing capacity test is discussed in detail by examples. Some suggestions are given and all this can provide references for prefabricated yard, supervision department and quality assurance department.

2. Inspection of structural performance inspection for prefabricated concrete components

In the 1950s and 1960s, China adopted the principle of multi-coefficient limit state design for concrete structures. The C value inspection method in the former Soviet Union standard was used to evaluate the strength of structural components [2]. In 1960, China promulgated the national standard "code for construction and acceptance of prefabricated concrete" (construction code 3-60), in which the quality standards and inspection methods for prefabricated concrete components were put forward [3]. After the 1970s, China began to adopt single factor limit state design principles. Accordingly, the strength inspection coefficient is used as the index to evaluate the component strength and the inspection of component performance is systematically specified for the first time. The corresponding inspection method is called safety coefficient method [4]. In 1989, China adopted the partial factor limit states
method instead of the concept of safety coefficient. New inspection standard was established and promulgated in 1990[5], in which the inspection coefficient of bearing capacity is adopted as the index to evaluate the bearing capacity of components. To adapt to the new code for design of concrete structures (GB 50010-2002) [6] and (GB 50010-2010) [7], code for acceptance of construction quality of concrete structures (GB 50204-2002) [8] and locally revised version (GB 50204-2002(2011 version)) [9] were promulgated in 2002 and in 2011. The mainly change content is about the allowable values of some inspection coefficients which are adjusted in accordance with the new provisions on material strength and the changes of component performance calculation formulas. With the rapid development of industrialization of buildings, code for quality acceptance of concrete structure construction(GB 50204─2015) [1] was promulgated in 2015 and the present inspection coefficient method is put forward. The structural performance inspection methods adopted in China can be successively called C value inspection method, safety coefficient method and inspection coefficient method. The present inspection coefficient method is inherited and developed from the C value inspection method and safety coefficient method.

2.1. The C value inspection method
In the 1950s and 1960s, China adopted the principle of multi-coefficient limit state design for concrete structures. The C value test method is used to evaluate the strength of structural components in domestic engineering field. It is only used to verify the strength of the component, namely the bearing capacity of the component, and its inspection formula is:

\[ C = \frac{P_m \cdot m}{P_f} \geq [C] \]  

where \( P_f \) is the failure load; \( P_m \) is the computational load; \( m \) is the working condition coefficient; \([C]\) is the allowable value of inspection coefficient.

The method was derived from the Soviet Union standard, and not based on China's engineering practice.

2.2. The safety coefficient method
After the 1970s, the safety coefficient method is used to evaluate the strength of the component. This method summarizes the experience of more than 20 years of engineering practice in China. The inspection items include strength, stiffness, crack resistance and crack width. The strength inspection formula is:

\[ \beta = \frac{K_s}{K} \geq [\beta] \]  

\[ [\beta] \geq \beta = \frac{K_s}{K} \geq 0.95[\beta] \]  

\[ K_s = \frac{Q_s}{Q_k} \]  

where \( K_s \) is the measured safety coefficient; \( Q_s \) is the measured failure load; \( Q_k \) is the load for design use; \( K \) is the safety coefficient specified in the specification or design requirement; \([\beta]\) is the allowable value of the strength inspection coefficient; \( \beta \) is the inspection coefficient whose value is greater than 1. In the safety coefficient method, the inspection coefficient is related to the failure mode of components, which is determined according to the statistical data, engineering experience and the relevant foreign standards then.

2.3. The inspection coefficient method
At present, the inspection coefficient method has been widely used by engineers. According to the current inspection coefficient method, the formula for the bearing capacity inspection is respectively:
\[ \gamma_a^0 \geq \gamma_o \gamma_a \]  
\[ \gamma_a^0 \geq \gamma_o \eta \gamma_a \]  
where \( \gamma_a^0 \) is the measured inspection coefficient of bearing capacity, that is, the ratio between the measured of load and the designed of load (including dead weight); \( \gamma_o \) is the allowable value of the inspection coefficient of the bearing capacity that is related to the failure mode of components; \( \gamma_0 \) is the importance coefficient of structural components; \( \eta \) is the correction coefficient of bearing capacity inspection according to the design requirements, that is, the bearing capacity ratio between the actual reinforcement and the theoretical reinforcement.

3. Example analysis of bearing capacity inspection

There are two methods for the bearing capacity inspection of prefabricated components. That is, according to the concrete structure design specification and according to the actual design of reinforcement, concrete strength grade. So, what's the difference between the two methods? It is important to check whether the evaluation results are consistent.

3.1. Basic information of components

A prefabricated concrete circular hollow slab calculated span of 0.9m×3.6m, whose calculated span is 3.48m. The strength grade of concrete is C35 and the prefabricated bars are cold drawn low carbon steel wires Φ5. The characteristic value of permanent load and variable load are \( G_k = 3000 \text{N} / \text{m}^2 \), \( Q_k = 2000 \text{N} / \text{m}^2 \). After calculation, 11 Φ5 should be reinforced, but the prefabrication plant production with 14 Φ5. During the process of load test, when the distributed load reaches 9700N/m² (including dead weight), the hollow plate fractured at 650mm from the support and the main reinforcement was pulled out from the end support. The bearing capacity can be evaluated by the two methods.

3.2. According to the design specification

The design value of basic combination of load effect is \( S = M \gamma_o = 0.9 \times 3.000 + 1.4 \times 1.8 \times 3.482 \times 0.9 \times 2000 = 8719.5 \text{N} \cdot \text{m} \). The load value of bearing capacity inspection mark appears for the first time (including dead weight) is 9700N/m². So, the measured bearing capacity of hollow slab \( R_a^0 = 1/8 \times 3.482 \times 0.9 \times 9700 = 13215.5 \text{N} \cdot \text{m} \). And the measured inspection coefficient of bearing capacity \( \gamma_a^0 = R_a^0 / S = 13215.5 / 8719.5 = 1.516 \), and the corresponding \( \gamma_a = 1.50 \). It can be found that \( \gamma_a^0 > \gamma_a \), it can be concluded that the prefabricated circular hollow slab meets the bearing capacity requirements of the design specification.

3.3. According to the actual reinforcement and concrete

According to the actual reinforcement calculation, the actual resistance of this slab is \( R = \alpha f_m b_z x(h_0 - x/2) = 1.0 \times 19 \times 860 \times 7.237 \times (100 - 7.237 / 2) = 11397.4 \text{N} \cdot \text{m} \). So, \( \eta = R / \gamma_a = 11397.4 / (1.0 \times 8719.5) = 1.307 \). It can be found that \( \gamma_a^0 = 1.516 < \gamma_a \eta = 1.0 \times 1.307 \times 1.5 = 1.9605 \). It can be concluded that the prefabricated circular hollow slab does not meet the requirements.

3.4. Contrastive and analysis

From above calculation, it can be seen that different conclusions are gotten by different evaluation criteria even for the same component. This is because the second inspection method takes into account the impact of \( \eta \). Compared with the first method, it reflects the actual construction quality of structural
components. However, this may allow some prefabrication plants to take advantage of the opportunity and result in safety problems.

As is well-known, there is $\eta = R(f,c_0,A_0,A,...)/\gamma_0 S$. Compared Eq. (5) and Eq. (6), the smaller the $\eta$ is, the greater the possibility that the bearing capacity of the component meets the requirements. In other words, when the action effect $\gamma_0 S$ remains unchanged, the smaller the value $R(f,c_0,A_0,A,...)$ is (the less reinforcement or the smaller the section size), the easier for components to meet the requirements of bearing capacity performance, which is contrary to the concept in practical engineering. Therefore, the author suggests that a constraint condition $\eta\geq1.0$ should be added in the formula. In this way, for structural components consider the impact of actual construction quality, the allowable value of bearing capacity inspection coefficient should be increased if the construction quality is good; but if the construction quality is bad, the allowable value of bearing capacity test coefficient should not be reduced.

For example, in above example, due to construction error, the reinforcement is $10 \Phi^5$, according to the actual reinforcement calculation, the actual resistance of this slab is $R = \alpha f \cdot c_x(h_0 - x/2) = 1.0 \times 19 \times 860 \times 5.16 \times \left(100 - 5.16/2\right) = 8214N \cdot m$. So, $\eta = R/\gamma_0 S = 8214 / (1.0 \times 8719.5) = 0.94$. It can be found that $\gamma_0 = 1.516 > \eta\gamma_0 = 1.0 \times 0.94 \times 1.5 = 1.41$. It can be concluded that the prefabricated circular hollow slab meets the requirements. This is obviously not in line with the engineering experience, because this component is a less reinforced component.

4. Conclusions

Though the national standard well considered the influence of the construction quality of structural components on the evaluation standard of bearing capacity, some misunderstandings will occur due to the value of coefficient in the formula. In this paper, the structural performance inspection of prefabricated concrete components is described in detail, and the bearing capacity test is analysed by examples. The paper suggests that a constraint condition $\eta\geq1.0$ must be added in the inspection formula. This must be brought to the attention of prefabricated yard, supervision department and quality assurance department in order to avoid causing the unnecessary loss.

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