Reliability Analysis of Deflection Control of Prestressed Concrete Crane Beam

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Abstract. The report is intended to establish the reliability analysis method of prestressed concrete crane beam and analyze its influence factors. Previous studies have shown that due to lack of an appropriate probability model to accurately reflect the random variables of the vertical crane load and determination of variable effect by the maximum value of the combination of random variables, the deflection control level is unknown. Therefore, to make up for the deficiency, the design method of deflection control of prestressed concrete crane beam was analyzed using the probability model of crane vertical load and the stochastic process combination method. Then, the reliability indexes of prestressed concrete crane beams required not to crack and prestressed concrete crane beams allowed to crack are calculated under different control years, and the factors affecting the deflection control are analyzed. The results revealed that it is appropriate for reliability control of prestressed concrete crane beam required not to crack, but a little conservative for reliability control of prestressed concrete crane beam allowed to crack in the national standard GB 50153-2008[1], which can be adjusted. From these results, it is recommended that reliability control level can be adjusted appropriately according to the importance of influencing factors.

1. Introduction
Prestressed concrete crane beams are widely used in industrial buildings at present. Long-term and intermittent load action of the crane during its service period will cause deflection deformation of the prestressed concrete crane beam, which will lead to problems such as crane running track clamping and so on. Therefore, high reliability level is required for deflection control of the prestressed concrete crane beam. In the past reliability analysis of deflection control of concrete crane beam at home and abroad, the reliability model reflecting crane load has not been established and the combination of stochastic processes has not been considered, so the combination of stochastic variables expressed in maximum value is often used. Firstly, the reliability analysis model of deflection control is established in dimensionless form based on the deflection checking calculation method of prestressed concrete crane beam from the national standard GB 50010-2010[2]. Then, the corresponding statistical parameters of the stochastic process combination method in the reliability analysis of the applicability of the concrete crane beam are defined. Finally, the reliability index of deflection control under
different combination methods is calculated and compared with that of common bending members. Meanwhile, the influencing factors are quantitatively analyzed.

2. Overview of deflection control method and probability analysis model for prestressed concrete crane beam

In the deflection control of the prestressed concrete crane beam, the design value $S$ of the action combination effect should satisfy:

$$S \ll C$$  \hspace{1cm} (1)$$

Where: $C$ is the deflection limit specified in the specification.

Prestressed concrete crane beam is subjected to both constant and crane loads as composite stress members. The deflection calculation only considers the deadweight of crane beam, rail, etc. and the vertical load of the crane, so considered bearing permanent action $G$ and one variable action $Q$, i.e.:

$$M_k = M_{Gk} + M_{Qk}$$  \hspace{1cm} (2)$$

$$M_q = M_{Gk} + \psi_q M_{Qk}$$  \hspace{1cm} (3)$$

Where, $M_{Gk}$ and $M_{Qk}$ are the bending moment produced by the standard values of $G$ and $Q$ respectively, $\psi_q$ is the quasi-permanent value coefficient of $Q$.

Based on the stochastic process combination method of action, the performance functions of the prestressed concrete crane beams required not to crack and the prestressed concrete crane beams allowed to crack are respectively [3]:

$$Z = \frac{C}{l_0} - \frac{(\theta - 1)(k_2 M_G + k_2 M_{Q,T}) + (k_2 M_G + k_2 M_{Q,T})}{E_C/E_S}$$  \hspace{1cm} (4)$$

$$Z = \frac{C}{l_0} - \frac{(\theta - 1)(k_2 M_G + k_2 M_{Q,T}) + (k_2 M_G + k_2 M_{Q,T})}{E_C/E_S} \times \left\{ \min(k_{cr}, 1) + [1 - \min(k_{cr}, 1)] \left[ 1 + \frac{0.21 E_C}{E_S} \left( 1 + 0.45 \sigma_f \right) - 0.7 \right] \right\}$$  \hspace{1cm} (5)$$

Where: $\eta$ is uncertainty factor of calculation model for deflection; $f_t$ is tensile strength of concrete; $E_C$ is elastic modulus of concrete; $M_G$, $M_{Q,T}$, $M_{Q,T}$ are bending moments produced by $G$, $Q_{q,T}$, $Q_T$; $\sigma_{pc}$ is Pre-compressive stress of concrete produced by pre-loading. The above variables are considered as random variables, ignoring the variability of geometric parameters, elastic modulus of reinforcement, reinforcement ratio, and other variables.

There is little statistical data on prestress component at present. The coefficient of variation of tension control stress of prestressing reinforcement in document [4] is 0.0365; the coefficient of variation of the total loss of prestressing estimated in document [5] is 0.107, which is 0.15 here. The ratio of the total loss of prestress to tension control stress is 25-30% [4], which is taken as 30%. After calculation, $\sigma_{pc}$ is 0.08, and its mean coefficient is 1.0. According to the literature [6], it is considered that it follows the normal distribution. For prestressed concrete flexural members $\theta = 2.0$. Relevant parameters are taken from the literature [7].

3. Reliability analysis results

3.1. Reliability analysis results under different combination methods

Based on the random process combination method and the random variable combination method, the reliability index of the action effect ratio prestressed concrete crane beam required not to cracks and prestressed concrete crane beam allowed to cracks are calculated respectively. The reliable index of deflection control of prestressed concrete crane beam required not to cracks varies from 0.2 to 1.1 and of prestressed concrete crane beam allowed to cracks varies from -0.2 to 4.4. According to Figure 1 (a)
and Figure 1 (b), the deviation of the reliability index calculated by the current random variable combination method is between 0 and 0.2.

![Figure 1. Comparisons of Reliability Indicators under Random Process Combination Method and Random Variable Combination Method](image)

Where: L = light crane beam, M = mediate crane beam, H = heavy crane beam, $\beta$ = reliability indexes. The transverse coordinates represent different crane working systems. The following figures have the same symbolic meaning.

3.2. Comparison of Reliability Index with Normal Bending Beam

The limit values of deflection control reliability indexes of prestressed concrete flexural member required not to cracks is shown in Table 1, which reliability indexes range from -0.1 to 1.0. The reliability index range of light crane beam from -0.2 to 0.3, mediate crane beam from -0.1 to 4.2 and heavy crane beam from -0.2 to 4.4. It is shown here that the reliability level of deflection control of light crane beam is lower than that of ordinary bending beam, while the reliability level of medium and heavy crane beam is similar to that of ordinary bending beam, and reliability level of the prestressed concrete crane beam allowed to cracks is higher than that of the deflection control of concrete flexural members.

![Table 1. Reliability index of member deflection control](image)

Where: no crack=prestressed concrete crane beams required not to crack, crack= prestressed concrete crane beams allowed to crack, upper= upper limit value, lower= lower limit value, $\Delta$ = Difference.

4. Analysis of Influencing Factors of prestressed concrete crane beam

In this section, the control variable method is used to calculate the reliability index under each variable to analyze the influencing factors. The value of each variable is from the literature [3].

4.1. Influence factors of prestressed concrete crane beam required not to cracks
For the analysis of prestressed concrete crane beam required not to cracks, the relative values of variable action effect $\rho_{Q_k}$, the ratio of crane width to crane beam span $\eta$, and the ratio of crane wheel distance to crane width $\epsilon$ are shown in Figure 2. The results show that under different working systems, the larger $\rho_{Q_k}$, the higher the reliability level of deflection control; the larger $\eta$, the lower the reliability level of deflection control; the larger $\epsilon$, the higher the reliability level of deflection control. In different crane working systems, the reliability level of medium and heavy crane beam is significantly higher than the light crane beam. Among them, $\rho_{Q_k}$ has a significant influence on the reliability level of deflection control of prestressed concrete crane beam required not to cracks, while $\eta$ and $\epsilon$ is a little significant.

4.2. Influencing factors of prestressed concrete crane beam allowed to cracks

For the analysis of prestressed concrete crane beam allowed to cracks, the relative values of variable action effect $\rho_{Q_k}$, the reinforcement ratio of longitudinal tensioned reinforcement $\rho$, Relative value of cracking bending moment $\kappa_{cr}$, the ratio of crane width to crane beam span $\eta$, the ratio of crane wheel distance to crane width $\epsilon$, the relative elastic modulus of concrete $E_c/E_S$, the relative sectional area of tensioned flange $\gamma_f$, and the prestress concurrence value $\rho_{pc}$ are shown in the figure. The results show that under different working systems, $\rho_{Q_k}$, $E_c/E_S$, $\gamma_f$, and $\rho_{pc}$ are proportional to the level of deflection control; $\rho$ and $\eta$ is inversely proportional to the level of deflection control; The influence of $\kappa_{cr}$ on the reliability level of crane beam deflection control is non monotonic. According to the calculation results, when $\kappa_{cr}$ is between 0.437 and 1.639, the reliability index changes caused by it. When the value of $\kappa_{cr}$ is greater than 1, it has no effect on the reliability level of deflection control; When $\rho_{pc}$ takes the lower limit value, $\rho_{pc}$ has no effect on the reliability level of deflection control; when $\rho_{pc}$ takes the upper limit value, it only affects the reliability level of the crane beam with light, medium and the lifting capacity of 5t for heavy cranes; For $\rho_{Q_k}$, and $\kappa_{cr}$, the reliability level from high to low is heavy grade system, intermediate system and light grade system. For other factors, the reliability level of medium and heavy grade crane beam is significantly higher than that of light grade crane beam.
5. conclusion

1) The reliability level of deflection control of light-weight pre-stressed concrete crane beam requiring no cracks is lower than that of the concrete flexural member, while the range of reliability index of medium and heavy-grade crane beam is significantly larger than that of the ordinary concrete flexural member.

2) The reliability level of the pre-stressed concrete crane beam with allowable cracks is higher than that of the deflection control of the concrete flexural member.

3) The main influencing factors for the prestressed concrete crane beam allowed to cracks are as follows: the relative values of variable action effect $\rho_{Qk}$, the ratio of crane width to crane beam span $\eta$, and the ratio of crane wheel distance to crane width $\varepsilon$. And the influence of $\rho_{Qk}$ is higher than of $\eta$ and $\varepsilon$.

4) The main influencing factors for the prestressed concrete crane beam allowed to cracks are as follows: the relative values of variable action effect $\rho_{Qk}$, the reinforcement ratio of longitudinal tensioned reinforcement $\rho$, and the relative value of cracking bending moment $\kappa_{cr}$.

5) The influencing factors for prestressed concrete crane beams allowed to cracks are as follows: the ratio of crane width to crane beam span $\eta$, the ratio of crane wheel distance to crane width $\varepsilon$, the relative elastic modulus of concrete $E_c/E_s$, the relative sectional area of tensioned flange $\gamma_f$, and the prestress concurrence value $\rho_{pc}$.

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